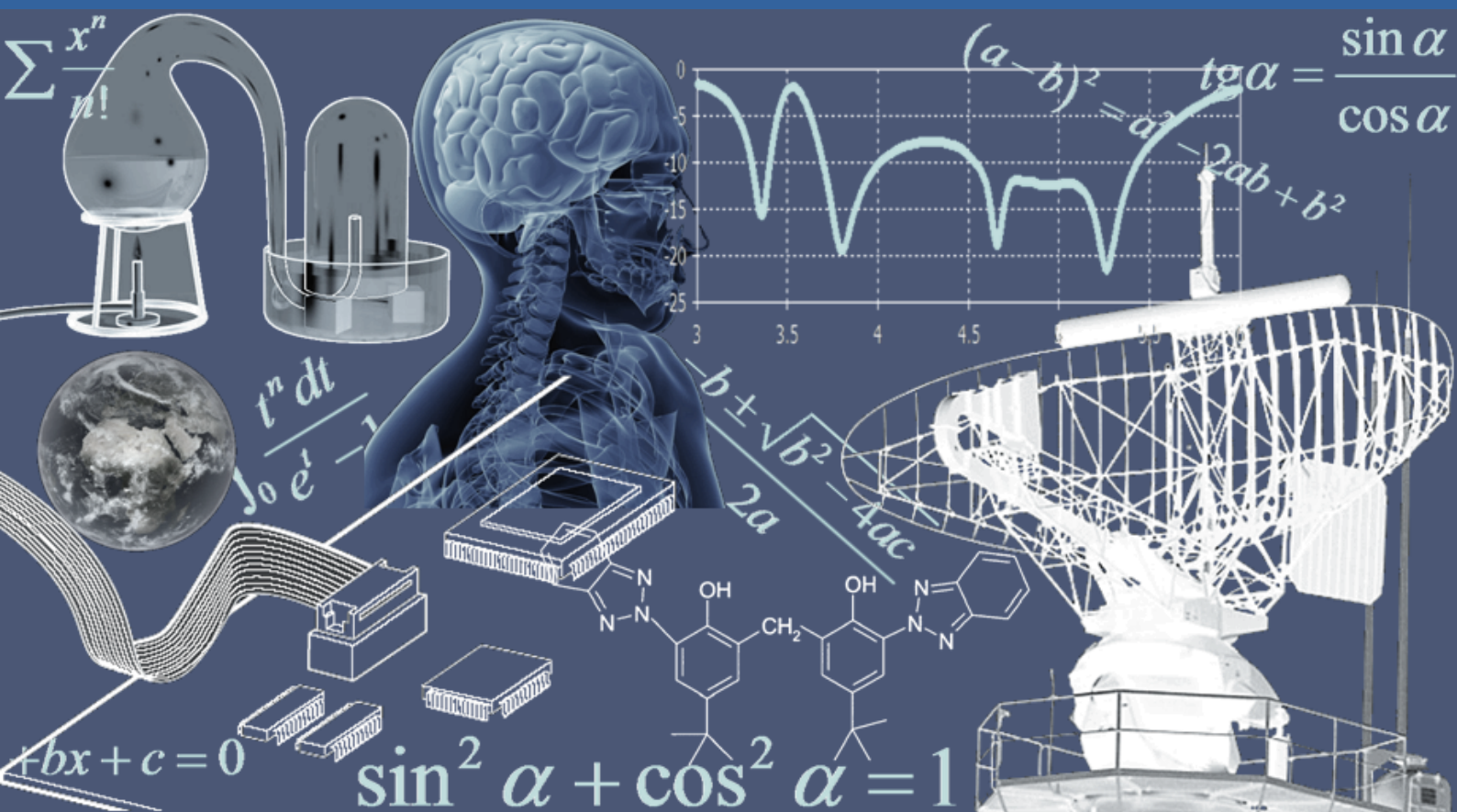


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Fundamentals of crisis-proof economics

Alexander A. Antonov

Research Centre of Information Technologies "TELAN Electronics"
P.O. Box 73, Kiev, 03142, Ukraine

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ABSTRACT: The major problem of the current market economy is absence of appropriate mathematical description of processes taking place in it, which results in misunderstanding of these processes, as well as lack of efficient means of preventing economic crises. The manuscript suggests such a mathematical description, making use of the circumstance that the 'black box' of market economy has the corresponding 'white box', which turned out to be the processes well known in radio-electronics. This approach allowed proving that the current market economy, due to the significant influence of the human factor, is described with parametric differential equations with random coefficients, the solutions of which are also random functions of time. Therefore, it is basically unpredictable and uncontrollable, which makes economic crises inevitable. In order for the economy to become crisis-proof, it has to be reformed. We suggest using the new economic tools which allow solving the problem. Here belong business-interfaces that can neutralize the internal human factor, and the new global/regional information network TV•net, which is completely free from the shortcomings of the Internet and is able to neutralize the external human factor. It is shown that after the implementation of reforms suggested in the manuscript economics will become an exact science able to successfully solve the tasks of analysis and synthesis of economic structures, the tasks of their simulation and improvement, as well as regulation of the economy in general. The new economy will become crisis-proof and rapidly developing.

KEYWORDS: Economic Crisis, Economic Reform, Crisis-Proof Economy, 'Invisible Hand', 'Goods-Money-Goods' Process, Human Factor.

1 INTRODUCTION

People, contrary to all other living beings on Earth, have one more environment – the economy. Everything we are engaged in – working, studying, doing business, paying taxes, etc. – is somehow or other connected with the economy. All our conscious activities take place in this environment. Nevertheless, we know the economy not any better than our physical environment [1].

Economics as an exact science which complies with the principles of fundamental sciences has not yet been developed. This is confirmed by the fact that the major economic phenomenon – economic crises known for centuries – still lacks a comprehensive explanation. In the opinion of Philip Kay, historian, Professor at Oxford University, the first economic crisis in world history occurred in the Roman Empire in 88 BC [2]. There are other opinions, as well. Most scientists believe the first economic crisis was the one that hit England in 1825, partially influencing the economies of the USA and France [3]. Since that time, economic crises have become inevitable concomitants of the human civilization. There are many theories of economic crises, although, certainly, only one of them can be true. In fact, none of them is actually true, since all of them failed to prevent any upcoming economic crises.

Over the past few decades, many new complicated mathematized concepts [4] have been developed in economics, and attempts of their application have been made. Here belong theories of extremal problems and specific methods of data analysis, which have become part of econometrics, as well as game theories, social choice theories, theories of general economic equilibrium, etc. Various branches of mathematics have been further employed to analyse economic

here belong the fixed point theorem, differential topology, the stability theory, functional analysis, the theory of random processes, etc. There is hardly any branch of mathematics which scientists have not tried to apply to economics.

The above may seem to testify to the prosperity of economic science. However, this is not so, because there are apparent signs of a protracted crisis of economic theory, where the most general findings are definitely negative. These are the conclusions which may be formulated approximately as follows: "The answers to your questions depend on the circumstances which you did not take into account", and "The model you used is too general or irrelevant" [4].

This is why some authors [5] started to wonder whether the natural-scientific theories should be considered as an example for developing the economic theory, or whether the economic theory should be developed based on different standards. Opinions were expressed that, apparently, a large variety of economic phenomena cannot be accounted for based on a limited number of fundamental laws. Therefore, it was suggested to substitute the principle of a unified economic theory for the principle of coexistence of competing concepts [6].

The publication brought to the attention of the reader, however, attempts to suggest a concept of a unified economic theory which complies with the criteria of the exact sciences and will allow explaining and preventing economic crises.

2 APPROPRIATE MATHEMATICAL DESCRIPTION OF ECONOMIC PROCESSES

Despite numerous economic theories developed by Adam Smith (1723 – 1790), Thomas Robert Malthus (1766 – 1834), Jean Baptiste Say (1767 – 1832), David Ricardo (1772 – 1823), Jean-Charles Leonard Sismonde de Sismondi (1773 – 1842), John Stuart Mill (1806 – 1873), Karl Heinrich Marx (1818 – 1883), Alfred Marshall (1842 – 1924), John Bates Clark (1847 – 1938), Vilfredo Pareto (1848 – 1923), Ludwig Heinrich Elder von Mises (1881 – 1973), Joseph Alois Schumpeter (1883 – 1953), John Maynard Keynes (1883 – 1946), Nikolai Dmitriewitsch Kondratieff (1892 – 1938), Friedrich August von Hayek (1899 – 1992), Simon Smith Kuznets (1901 – 1985), Wassily Wassilevich Leontief (1905 – 1999), Milton Friedman (1912 – 2006), Walt Withman Rostow (1916 – 2003), Christopher Freeman (1921 – 2010) and many other outstanding scientists [3], [7], both local and global economic crises continue, and, thus, refute all the existing theories of economic crises.

Anticipating the following (see details below), we have to note that, in terms of mathematics, the task of explaining the nature of economic crises turned out to be quite extraordinary and complicated, because processes prevailing in the current economy are described with systems of parametric differential equations with random coefficients, which are not compatible to other sciences and have no analytical solution. Therefore, crises are inevitable in this economy, and it is impossible to prevent them using the economic tools available at present.

In order to develop a controllable crisis-proof economy, new economic tools described below are necessary. In other words, the current economy has to be reformed in such a way as to allow the use of mathematical tools enabling to solve the problem.

In order to understand what these new mathematical-economic tools must be, the new appropriate mathematical description of processes prevailing in the current economy has to be found. In this respect it is noteworthy that, first of all, an important peculiarity of economic processes is the fact that they are highly multi-factor, contrary to processes studied in the exact sciences. Indeed, almost all laws revealed so far in the exact sciences (perhaps, with the exception of Kepler's third law with Newton's amendments) are low-factor, although nature, certainly, does not restrict itself to the use of only these simplest natural-scientific laws. However, multi-factor laws in the exact sciences have yet to be discovered. As for economics, it has no low-factor dependencies, with a rare exception. This is a very important circumstance which is relevant to the situation under consideration. The matter is that human rational thinking is low-factor by nature [8], because people think with visual images which are not more than three-dimensional. Therefore, people are able to perceive low-factor dependencies. As for multi-factor dependencies described with functions of more than three variables (similar to objects having more dimensions), people are unable to perceive them with their rational thinking. You can make sure of it yourselves: just try to imagine the simplest four-dimensional object – a hypercube (or tesseract). Thus, human rational thinking itself, without computer support (see below for human-computer super-intelligence), is unable to perceive multi-factor economic dependencies.

To make these multi-factor objects of economic research at least somehow understandable, they are sometimes transformed into low-factor objects with the help of mathematical statistics. However, estimates received after statistical processing of economic data are too information-depleted, and, therefore, hardly suitable for practical application. For the same reason, for instance, a doctor would never use the average temperature, as well as averaged results of other analyses, to treat the patients.

Furthermore, an extremely important circumstance which must be taken into account correctly is the fact that economic processes, as follows from the fact that they are multi-factor, belong to the so-called mass phenomena. Currently, conclusions drawn from this circumstance are so wrong that they make it impossible to develop economic theory which would comply with the criteria of the exact sciences. Mass phenomena can be found in other science, as well, e.g., in physics and radio-electronics; however, this fact does not prevent them from being the exact sciences. As for economics, acknowledgement of the circumstance that economic processes belong to mass phenomena basically resulted in complete abandonment of any attempts to understand the fundamental processes in it and to suggest their appropriate mathematical description which defines its current state of development.

With all this in view, we can state that economics remains largely unknown. In the exact sciences, the term 'the black box', introduced by William Ross Ashby (1903 – 1972), is used to denote an object of research whose operational mechanism is unknown, but the result of its operation is known. Moreover, this result is unpredictable and mathematically indefinable.

This is why any regulatory activities of governments and top-managers of the current economy turn out to be inefficient. Indeed, in order to manage the object of regulation, it is necessary to be able to extrapolate its behaviour, which is impossible without its appropriate mathematical description.

In order to solve the problem, we must be able to turn the black box into 'the white box', whose operation mechanism, according to the definition introduced by Norbert Wiener (1894 – 1964), is known, and yields the same results as the black box. In other words, the white box is the mathematical counterpart of the black box, and mathematical description of processes in the white box is therefore appropriate for processes in the black box, although, in terms of physics, the black box and the white box can be completely different. For instance, in investigation of oscillations, a pendulum may be the white box, and a radio-electronic oscillation circuit, a piano or an earthquake may be the black box.

Thus, to be able to prevent economic crises, it is first of all necessary to find an appropriate mathematical description of processes prevailing in the economy. To this end, the corresponding white box has to be found, and then, based on the well-known results of its operation, processes in the black box of the economy can be improved.

However, such a white box has not yet been found.

Furthermore, mathematical analysis of different situations using the supply and demand curves, the production-possibility curves, etc., widely used in economics, is not at all suitable to describe processes and allows defining only a state, because the intersection points of curves mathematically correspond to graphical solutions of algebraic equations without consideration of time. Certainly, the results obtained using these curves are useful. They allow, in the first approximation, giving a more or less correct estimate of a certain economic situation. However, this is definitely not enough, since they do not allow understanding the processes prevailing in the black box of the global and even of any regional economy.

Low efficiency of the mathematical apparatus used in economics was pointed to by physicists at the end of the 20th century; they even founded a new science – econophysics (econophysics = economics + physics). They reasonably assumed that phenomena observed in economics have much in common with processes in physics, and, thus, suggested to use new mathematical tools in economics [9]-[12]. These new mathematical tools of econophysics included mostly the statistical methods borrowed from statistical physics. In particular, non-traditional for economics methods developed in the theory of self-organized criticality, in fractal analysis, in the theory of phase transitions, and in the percolation theory were widely used. However, these new mathematical tools also allow defining only states.

Processes in mathematics are described with differential equations – linear, non-linear or parametric, depending on the peculiarities of their behaviour in a particular object of research. Consequently, the appropriate mathematical description of economic processes must be made using differential equations. Unfortunately, attempts to use differential equations in economics [13], [14] were not aimed at understanding the contents of the black box of the economy. This must have led to the opinion that differential equations in economics are restrictedly useful.

However, this false conclusion is determined by the improper use of mathematics. Its improper use stems from the opinion prevailing in the economy that the behaviour of this or that market participant is completely impossible to predict (this statement is both true and false, depending on the circumstances – see below). For instance, Sir Isaac Newton (1642 – 1727) wrote that simulating people's behaviour is a much more complicated task than predicting planetary motion [11]. This is why, in economics, there is a tendency to assume that it makes sense to analyse only the behaviour of a large number of market participants, i.e., to investigate mathematically only mass phenomena.

3 DIFFERENTIAL EQUATION OF THE 'GOODS-MONEY-GOODS' PROCESS

The basic economic process is certainly the 'goods-money-goods' process.

Since it is a process, it must be described with a differential equation [15], [16]. To derive it, it is certainly necessary to describe mathematically the market behaviour of the vendor and the buyer separately (for a more complicated implementation of the market – of other market participants, as well), and then – their joint behaviour. Both the buyer and the vendor may be either an individual or a corporate body. However, the goods, which are a matter of their common concern, must be the same.

Thus, given the very general, but quite possible conditions, the behaviour of the generalized buyer (hereinafter referred to as the buyer) of the goods, who is often a wage worker, is described with the formula:

$$M_B(t) = \frac{1}{T_B} \int_0^t Q_B(t) P_B(t) dt \quad (1)$$

or the inverse formula

$$Q_B(t) P_B(t) = T_B \frac{dM_B(t)}{dt} \quad (2)$$

where $M_B(t)$ is the current expenses (the amount of circulating assets) of the buyer;

$P_B(t)$ is the current market price of the goods purchased by the buyer;

$Q_B(t)$ is the current quantity of the goods purchased by the buyer;

$P_B(t)Q_B(t)$ is the current assets flow of the buyer;

T_B is the useful life of goods purchased by the buyer;

t is time.

Consequently, according to formula (1), the expenses of the buyer equal to the accrued expenditures (the amount of circulating assets) for the purchase of the necessary amount of goods taking into account the price dynamics in time.

Similarly, the behaviour of the generalized vendor (hereinafter referred to as the vendor), who is usually a manufacturer and an employer, is described with the formula

$$P_V(t) = \frac{1}{Q_V(t)T_V} \int_0^t M_V(t) dt \quad (3)$$

which is equivalent to the formula

$$P_V(t)Q_V(t) = \frac{1}{T_V} \int_0^t M_V(t) dt \quad (4)$$

or the inverse formula

$$M_V(t) = T_V \frac{d[P_V(t)Q_V(t)]}{dt} \quad (5)$$

where $P_V(t)$ is the current market price of the goods;

$Q_V(t)$ is the current quantity of the goods manufactured by the vendor;

$P_V(t)Q_V(t)$ is the circulating assets flow of the vendor;

$M_V(t)$ is the current revenue of the vendor (the amount of circulating assets) covering the manufacturing costs and generating profit;

T_V is the production time per commodity unit;

t is time.

Thus, the price of goods, according to formula (3), equals to the accrued expenses of the vendor adjusted for the planned revenue, divided by the quantity of manufactured goods.

As can be seen, in expressions (1) – (5) the values of the circulating assets and payments flow (or the amount of circulating assets) of the vendor and the buyer have not an algebraic, but a differential-integral relationship, since the price formation process is influenced by the previous transaction history of the vendor with the buyer. When making a transaction on each commodity unit, both the vendor and the buyer, in accordance with formulae (1) and (3), use their average estimates. For a transaction to be made, the vendor and the buyer must reach an agreement on payments, i.e., despite their different considerations, they must reconcile their interests and agree upon the price.

It is interesting to note the mathematical similarity of formulae (1), (2), (4), (5), describing the market behaviour of the vendor and the buyer, on the one hand, and formulae describing processes in radio-electronic components – a capacitor and an induction coil – in electric circuits. For a better comparison, the corresponding formulae are presented in the table below.

Table 1.

In economics	In radio-electronics
The amount of current (circulating) assets of the buyer $M_B(t) = \frac{1}{T_B} \int_0^t Q_B(t) P_B(t) dt$	Voltage drop at the capacitor $U_C(t) = \frac{1}{C} \int_0^t I(t) dt$
The current (circulating) assets flow of the buyer $Q_B(t) P_B(t) = T_B \frac{dM_B(t)}{dt}$	Electric current through the capacitor $I_C(t) = C \frac{dU_C(t)}{dt}$
The amount of current (circulating) assets of the vendor $M_V(t) = T_V \frac{d[Q_V(t) P_V(t)]}{dt}$	Voltage drop at the inductance coil $U_L(t) = L \frac{dI_L(t)}{dt}$
The current (circulating) assets flow of the vendor $P_V(t) Q(t) = \frac{1}{T_V} \int_0^t M_V(t) dt$	Electric current through the induction coil $I_L(t) = \frac{1}{L} \int_0^t U_L(t) dt$

Formulae relating to radio-electronic components in the table use the following notations:

$U_C(t)$ is the voltage drop at the capacitor C ;

$I_C(t)$ is the electric current through the capacitor C ;

$U_L(t)$ is the voltage drop at the inductance coil L ;

$I_L(t)$ is the electric current through the induction coil L .

At that, as shown in Fig. 1, both the economic components (the buyer and the vendor) and the radio-electronic components (the capacitor and the inductance coil) are combined in a similar way, forming similar functional links. Then, it is quite natural to expect that processes in them have a similar mathematical description.

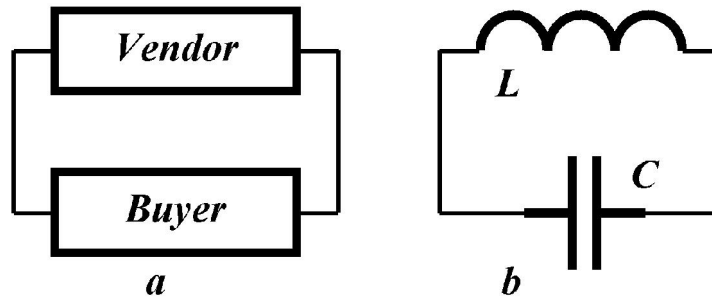
In economics the process, usually referred to as the 'goods-money-goods' process, must apparently correspond to the expression

$$M_V(t) = -M_B(t) \quad (6)$$

or

$$M_V(t) + M_B(t) = 0 \quad (7)$$

Formula (6) reflects the fact that in the isolated economic link under consideration (Fig. 1a) one of the transaction always makes the payment, and the other party accepts the payment. As a result, the total amount of circulating assets,



according to expression (7), remains unchanged (zero for the example under consideration).

Fig. 1. Simplest oscillation links in economics and radio-electronics, where a sustained oscillation process is observed

Let us suppose, for the simplest case under consideration, when there is only one vendor and only one buyer, that $Q_V(t) = Q_B(t) = Q(t)$ and $P_V(t) = P_B(t) = P(t)$, then, using formulae (1), (3), we find from (7) the expression

$$T_V \frac{d[Q(t)P(t)]}{dt} + \frac{1}{T_B} \int_0^t Q(t)P(t)dt = 0 \quad (8)$$

Substituting (1), we get **the second-degree linear differential equation describing the 'goods-money-goods' process** under consideration.

$$T_V T_B \frac{d^2 M_B(t)}{dt^2} + M_B(t) = 0 \quad (9)$$

The solution of the equation has the form

$$M_B = A \sin \omega_0 t + B \cos \omega_0 t \quad (10)$$

where A and B are the constants of integration which are found from the initial conditions $M_B(t)|_{t=0}$ and $\frac{dM_B(t)}{dt}|_{t=0}$;

$\omega_0 = \frac{1}{\sqrt{T_B T_V}}$ is the resonance frequency of the simplest economic link under investigation.

It is easy to notice that the expressions (7) and (9) are very much similar to the expressions

$$U_L(t) + U_C(t) = 0 \quad (11)$$

$$LC \frac{d^2 U_C(t)}{dt^2} + U_C(t) = 0 \quad (12)$$

which, as is known, describe processes in the electric circuit (Fig. 1b) often referred to as an electric oscillation LC-circuit. Consequently, the economic circuit given in Fig. 1a can be referred to as an economic oscillation link.

Formula (11) in the electric circuits' theory is referred to as the second Kirchhoff's law (this is certainly its simplest notation). This is why in economic circuits' theory formula (7) can also be referred to as the second Kirchhoff's law in its economic interpretation. It is also possible to demonstrate that the first Kirchhoff's law is true for the economic circuits' theory, and formulae (1) – (5) correspond to the Ohm's law (also in their economic interpretation).

Moreover, the analogy described above holds true for more complicated situations, as well (see Fig. 2). Indeed, in oscillation links presented in Fig. 2 – both the economic and the radio-electronic ones – compared to the first case, additional, the so-called dissipating elements (from Latin *dissipatio* – dissipation), are present. They are called dissipating

the reason that they dissipate the energy of oscillations, causing the latter to become damped. In the radio-electronic oscillation link (Fig. 2b) this is the resistor R . In the economic oscillation link (Fig. 2a) here belong the elements which withdraw a part of circulating assets (a bank and a tax administration in the example under consideration).

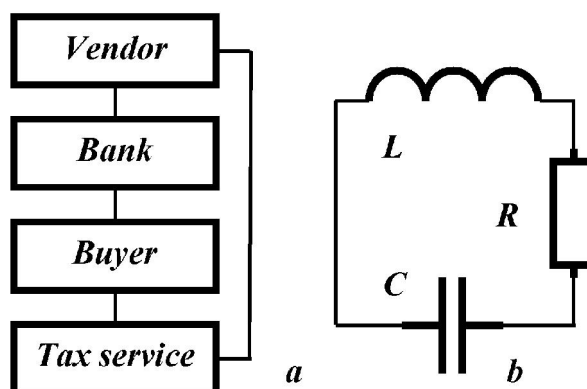


Fig. 2. Simplest oscillation links in economics and radio-electronics, where a damped oscillation process is observed

Therefore, processes in them are described with somewhat different, compared to (9) and (11), differential equations. For the radio-electronic oscillation link (Fig. 2b) this differential equation has the form

$$LC \frac{d^2 U_C(t)}{dt^2} + RC \frac{dU_C(t)}{dt} + U_C(t) = 0 \quad (13)$$

and for the economic oscillation link – the following form (for simplicity, both differential equations are given without derivation)

$$T_V T_B \frac{d^2 M_B(t)}{dt^2} + T_B (\alpha + \beta) \frac{dM_B(t)}{dt} + M_B(t) = 0 \quad (14)$$

Their solutions are damped oscillations, which are mathematically identical

$$M_B(t) = e^{-\sigma_0 t} (A \sin \omega_0 t + B \cos \omega_0 t) \quad (15)$$

$$U_C(t) = e^{-\sigma_0 t} (A \sin \omega_0 t + B \cos \omega_0 t) \quad (16)$$

where α is the relative current amount of the vendor's tax payments;

β is the relative current amount of the buyer's payments to the bank for making money transfers to the buyer;

A and B are the integration constants;

$\omega_0 = 1/\sqrt{T_B T_V}$ is the resonance frequency of oscillations in the economic oscillation link;

$\omega_0 = 1/\sqrt{LC}$ is the resonance frequency of oscillations in the radio-electronic oscillation link;

$\sigma_0 = (\alpha + \beta)/2T_V$ is the decay of oscillations in the economic oscillation link;

$\sigma_0 = R/2L$ is the decay of oscillations in the radio-electronic oscillation link.

As can be seen, the analogy between the economic and radio-electronic oscillation processes is indeed observed in the oscillation links plotted in Fig. 2. It is observed in many other situations, as well.

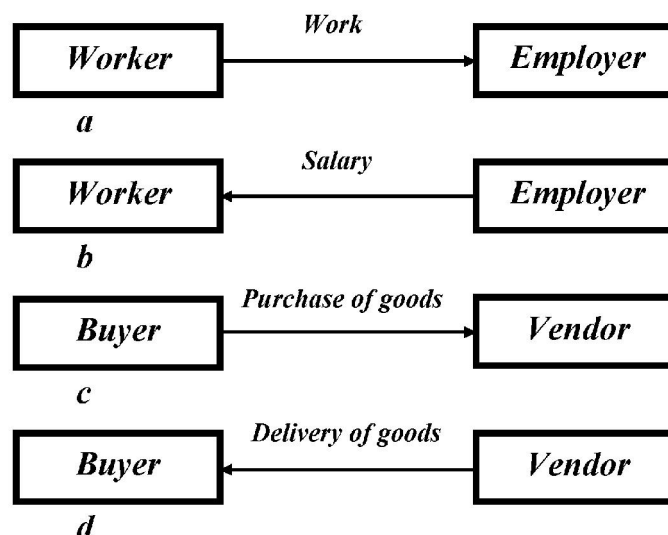


Fig. 3. The content of the oscillation process in isolated economic oscillation links plotted in Fig. 1a and 2a

Thus, **radio-electronic devices and processes are**, indeed, the aforementioned **white box with regard to the black box of economics and economic processes**. Recognition of this fact allows developing the economic theory which will completely meet the criteria of the exact sciences.

However, using this analogy requires being cautious and avoiding violating it as a result of certain incorrect actions. For example, in the electric oscillation circuit (Fig. 1b or 2b) the oscillation process in any of its phases has one and the same physical meaning determined by the motion of electrons. As for the isolated economic oscillation link (Fig. 1a or 2a), the oscillation period includes four successive processes with a different content, where business partners perform different functions. At first (Fig. 3a), the vendor is an employer and a manufacturer, and the buyer is an employee who manufactures goods at the vendor's enterprise. Then (Fig. 3b), the employer pays remuneration to the employee. After that (Fig. 3c), the employee turns into a buyer and pays the employer-vendor the cost of a purchase. Finally (Fig. 3d), the vendor delivers the purchased goods to the buyer.

Since the economic oscillation link under consideration (Fig. 1a) is assumed to be isolated for simplicity, the full oscillation period must include all the successive actions described above. For example, the condition is fulfilled if workers of an automobile plant purchase cars produced by it. If the condition above is not fulfilled, the oscillation process becomes impossible.

In more complex multi-link oscillation systems the content of the oscillation process can certainly be different; moreover, it can differ even in various links of the oscillation system.

However, even if the succession of actions described above is observed, the 'goods-money-goods' process in the economic link under consideration will not be oscillating, if all payments and deliveries are not enforced according to the sine law (e.g., made by a computer on a daily basis), which is never the case at present. Consequently, the economic links given in Figs. 1a and 2a are only potentially oscillating. In fact, the oscillation process described above has never been implemented in economics.

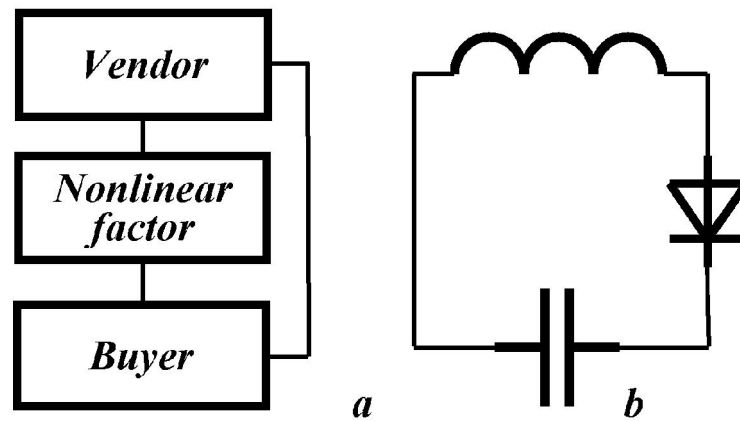


Fig. 4. Non-linear links

In this respect, it is natural to ask: what is the point of all these complications and does the economy need these oscillation processes? They turn out to be very necessary, because they provide for a more efficient use of circulating assets than currently observed. Indeed, given the current payment schedules in the form of infrequent (e.g., monthly or quarterly) payments, money works inefficiently, because the economy always experiences either surplus or shortage of it to solve its current tasks. This is why part of the money always remains idle. If sinusoidal payment schedules are used in economic oscillation systems, circulating assets will be fully used at any time and yield significantly larger returns.

Moreover, the economic oscillation systems described above will make it possible to use completely new processes which will significantly improve the efficiency of economic activity. For example, here belong processes widely used in resonant processes engineering, or processes used in wired structure systems, as well as many other processes known in radio-electronics and computer technology.

The most important point is that it is these complications that allow eventually developing the economic theory belonging to the exact sciences, which will be able to develop just as consistent and efficient systems as radio-electronics.

For better understanding of the following discussion, it is noteworthy that isolated economic and radio-electronic links may be non-linear, as well (their conditional examples are presented in Fig. 4). Processes in the non-linear economic link (Fig. 4a) and the non-linear radio-electronic link (Fig. 4b) are described with very similar non-linear differential equations:

$$T_V T_B \frac{d^2 M_B(t)}{dt^2} + T_B F[M_B(t)] \frac{dM_B(t)}{dt} + M_B(t) = 0 \quad (17)$$

$$LC \frac{d^2 U_C(t)}{dt^2} + CR[U_C(t)]C \frac{dU_C(t)}{dt} + U_C(t) = 0 \quad (18)$$

They (both the links and the differential equations) are referred to as non-linear for the reason that they include at least one non-linear element – $F[M_B(t)]$ or $R[U_C(t)]$, the value of which depends on the current value of the function under investigation – $M_B(t)$ or $U_C(t)$. In the radio-electronic link presented in Fig. 4b, the non-linear element is the diode. In the economic link given in Fig. 4a, the non-linear element is, for instance, the fact that the buyer, e.g., in a supermarket, always pays to the vendor, but the vendor never pays to the buyer. Non-linear circuits and the corresponding non-linear processes are often used both in economic and radio-electronic links which are not oscillating, and which are not the subject of the given research. This is why, in the economic link given in Fig. 4a, this circumstance is referred to as the 'non-linear factor', and not as the 'non-linear element', which is absent in the situation under consideration.

By the way, this example demonstrates very well that it is not easy to make the analogy between the economic and radio-electronic circuits.

4 “THE INVISIBLE HAND” OF ADAM SMITH

The problem of building crisis-proof sustainable economy is one of the major issues for governments of all countries and top-managers of the global economy. It is well known that both the abstract socialism as a fully regulated economy and the abstract capitalism (laissez faire) as a completely free economy, have their shortcomings and their advantages:

- socialist economy was developing very slowly, but experienced no crises;
- capitalist economy is developing much faster, but suffers from economic crises.

Thus, all countries are currently looking for their own intermediate ways of economic development, in the form of this or that variety of regulated capitalism (i.e., with elements of socialism). However, many existing economic schools [3], [7] have not reached an agreement upon this intermediate way. As a result, different countries have chosen different ways. However, an indisputable knowledge base necessary for any national leader to make a confident choice of a justified course of economic development is still lacking. This is why voters of all countries are still offered new and different economic agendas, none of which is capable of preventing economic crises for the reasons discussed above.

Therefore, a new approach towards solving the problem is suggested below. It will allow building the crisis-proof economy.

Economists often use the specific term ‘the invisible hand’ introduced by Adam Smith 1723 – 1790) [17], when they face manifestations of powerful and unclear forces driving the society in their unpredictable direction, often despite the efforts of government heads and top-managers of the economy.

For instance, in 1929 – 1930 the US gross national product suddenly dropped to 67% of the previous years. This became the national economic tragedy which is known in US history as the Great Depression.

Just think about it: both in 1929 and in 1930, the US economy had approximately the same labour force and approximately the same fixed assets. However, in 1929 huge growth of production was observed (stock quotations were exceptionally high), and in 1930 the stock market ‘collapsed’ and a 33% decline in production was recorded! Over these years, the country suffered neither a war, nor a natural disaster, nor an epidemic. Just somehow, one and the same economy was prosperous in 1929, and deteriorated in 1930. What was the reason? What drastic changes occurred in the US economy in 1930? There is still no answer. The Great Depression does not give in to any rational explanation [18].

Indeed, according to the Cobb-Douglas production function [19] $Q = AL^\alpha K^\beta$, the production volume Q depends on two slowly varying production factors: L (labour costs) and K (capital costs). Thus, the economy of any country is not supposed to experience any crises, and production volume is supposed to gradually increase year over year, following population growth (1-2% per annum) and fixed assets growth (3-4% per annum). However, in fact, something unpredictable keeps happening in economic development, and short-term sustainable growth is rather an exception than a rule.

The state of affairs means only one thing: there is the third, more powerful factor, which plays the role of a switchboard for progress or regress. This unknown third factor is, in fact, the major one defining the process of economic development. However, it is still unidentified by the economic science, despite all the efforts taken to define it.

This is why one of the major and urgent problems of theoretical economics is still to detect ‘the third factor’, to identify the mysterious ‘invisible hand’, which plays such an important part in the development of the global economy.

However, if long-term research failed to reveal the third factor among the objective circumstances influencing economic processes, it is possible to presume that it is the subjective, or, in other words, the human factor. This was the conclusion made as a result of research reported in [20]. Let us briefly review it.

As was demonstrated above, in the idealized simplest market link (Fig. 1a or 2a) the ‘goods-money-goods’ process is mathematically described with the linear differential equation (9) or (14).

Its obvious solution is an oscillation process, because the current assets must circulate between the buyer and the vendor. However, this oscillation process has nothing in common either with the Elliott waves [21], or with the seasonal fluctuations of business activity (e.g., in agriculture), or with the economic cycles of Kitchin, Juglar, Kuznets or Kondratiev [22], and it has nothing to do with economic crises.

Moreover, this oscillation process in economics is still unknown, because the conditions for its realization have never been created. They cannot be created in a random way. This is quite natural, because houses are not built in a random fashion, cars are not assembled at random, and computers are not made randomly. Constructive activities always require certain knowledge, which economics is still lacking.

This is why, the simplest links of the commodities market in Fig. 1a and 2a were said to be idealized and only potentially oscillating. Actual oscillation links always include (see Figs. 1a and 2a) not only the buyer and the vendor (as well as other market participants – third parties, banks, tax authorities, etc.), whose behaviour is described by functions (1) – (5), but ‘the invisible hand’, as well – the human factors they introduce, because actual market participants are common people with common human foibles, habits and other peculiarities. This is why, they are not always reliable, sometimes they are forgetful, often prone to emotions, illnesses, other random factors and unforeseen circumstances. As a result, for the actual links of the commodities market shown in Fig. 5a,b, the process will be described not with linear differential equation with constant coefficients (9) and (14), but with linear differential equations with variable coefficients (or, in other words, with parametric differential equations)

$$T_V T_B H_V(t) \frac{d^2 M_B(t)}{dt^2} + H_B(t) M_B(t) = 0 \quad (19)$$

$$T_V T_B H_V(t) \frac{d^2 M_B(t)}{dt^2} + (\alpha + \beta) T_B H_{B+TS}(t) \frac{dM_B(t)}{dt} + H_B(t) M_B(t) = 0 \quad (20)$$

where $H_V(t)$ is the human factor taking into account the behaviour of the vendor,

$H_{B+TS}(t)$ is the human factor taking into account the behaviour of the bank and the tax administration;

$H_B(t)$ is the human factor taking into account the behaviour of the buyer.

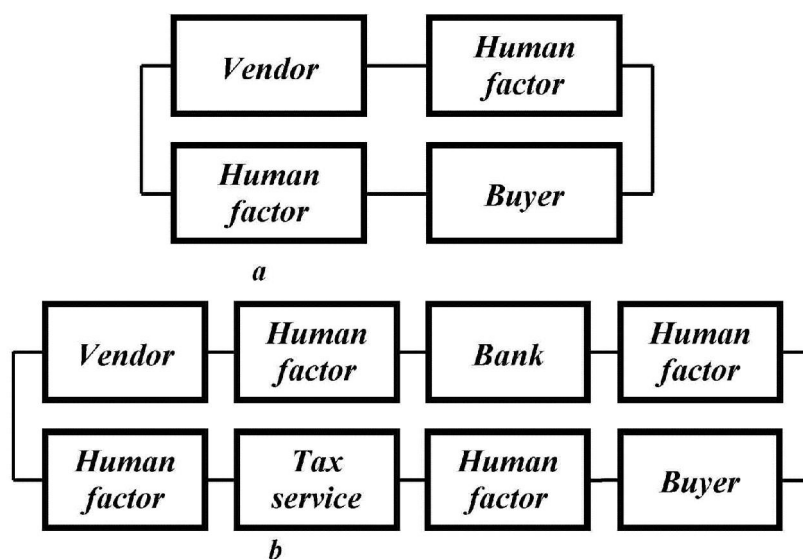


Fig. 5. Actual functional schemes of the simplest oscillation links in the economy

Since in the parametric differential equations (19) and (20) the coefficients $H_V(t)$, $H_B(t)$ and $H_{B+TS}(t)$ are different random functions of time, their solutions are also random functions of time. They cannot be found analytically.

Processes in the real capitalist economy generally comprise many similar unpredictable processes in simple economic links. Therefore, the global economy depends on the rapidly varying human factors $H_V(t)$, $H_B(t)$ and $H_{B+TS}(t)$ to a much greater extent than on the slowly varying production factors $L(t)$ and $K(t)$ mentioned above. Due to this fact, it is basically unpredictable and uncontrollable.

There is other evidence of the significant influence of the human factor on the economy. Thus, the social choice theory suggested by Arrow [23] argues that conciliation of social interests is provided for only by dictatorial regulations. Basically the same conclusion was made by Gibbard [24] after investigating other aspects of choice mechanism given the very general assumptions. In fact, this is just the statement of the conclusion made herein, worded using different terms.

Therefore, the conclusion that the Great Depression phenomena is accounted for by the human factor is quite justified.

The foregoing also fully explains the fact that the Soviet Union never suffered from economic crises. The matter is that the plan-based Soviet economy provided for the fulfilment of conditions minimizing the influence of the human factor $\lim H_V(t) \rightarrow \text{const}$, $\lim H_B(t) \rightarrow \text{const}$ and $\lim H_{B+TS}(t) \rightarrow \text{const}$, i.e., the functions $H_V(t)$, $H_B(t)$ and $H_{B+TS}(t)$ were almost constant. This is why parametric differential equations (19) and (20) in the Soviet economy were transformed into linear differential equations with constant coefficients, which made economic processes fully controllable.

5 NEW CRISIS-PROOF ECONOMIC TOOLS

Thus, **in order to avoid economic crises in the capitalist economy, the influence of the human factor in it must be minimized**, i.e., fulfilment of the conditions $\lim H_V(t) \rightarrow \text{const}$, $\lim H_B(t) \rightarrow \text{const}$ and $\lim H_{B+TS}(t) \rightarrow \text{const}$ must be provided for. However, this has to be done in a different way than in the Soviet Union.

To find out how this can be achieved, let us specify that the human factor may be internal and external.

The internal human factor is understood as a spontaneous unpredictability of behaviour of market participants due to their unreliability, illnesses, forgetfulness, imperfections of contracts or verbal arrangements regulating their activities, rumours, panic, and other similar reasons.

The external human factor is understood as the unpredictable behaviour of market participants determined by random external influence upon them by other persons and companies – competitors, public officials, criminal structures and other similar reasons.

Therefore, it is obvious that, in order to minimize the influence of the human factor in the market capitalist economy, some new economic tools [25] are necessary, because the existing economic tools have not been able to offset it. These tools must be different for the internal and the external human factors.

5.1 MINIMIZING THE INFLUENCE OF THE INTERNAL HUMAN FACTOR

Let us refer to the new economic tool aimed at minimizing the influence of the internal human factor as the business-interface [20], by analogy with a similar term used in computer engineering. Let us recall that an interface in computer engineering is understood as a hardware and software means of connecting various nodes and devices. It is clear that if, for instance, plugs and sockets of these devices are different, or even if the plugs are correct, but mismatching signals are fed to the matching pin of the plug and the socket, the computer will not operate. This is why all interfaces in computer engineering are strictly defined.

This is why we shall refer to business-interfaces as the payment (commodity-money) means of connecting market process participants, as a result of which, the vendor must supply the buyer exactly the goods ordered by the buyer, and get exactly the payment specified in the price-list. However, this is not enough. In order to avoid the destructive economic consequences caused by the human factor (remember the Great Depression), every detail of the business-interfaces must be defined; this will enable implementing oscillation processes in economic links. Thus, the corresponding contracts must contain all the details providing for:

- linearization of the economic process, which must be described with a linear differential equation with constant coefficients; to this end, all non-linear and parametric elements (or factors) must be respectively removed from the economic system;
- temporal variation of the circulating assets flow as close to the sine law as possible (it can be easily implemented using computers);
- strict and close adherence to contractual obligations by both the vendors and the buyers; breach of these obligations must inflict penalties as severe as those practiced in socialist countries for violation of labour discipline.

Thus, the primary function of the business-interfaces is to support and regulate the circulating assets flows. This is why an important part in their implementation will be played by banks, whose activity will also change the economic outlook of their clients. Moreover, certain amendments and clarifications will have to be made in the national and international legislation.

All vendors and all buyers inevitably have numerous business relationships with other vendors and buyers; for this reason, any actual economic system is multi-link and multi-related. This is why, it will be necessary to optimize the and parameters of these economic systems. In particular, an international system of operating frequencies must be

developed, tied to the natural cycles of agricultural works, forestry engineering, construction works, transportation, and other seasonal businesses. Similarly, computer engineering uses clock frequencies; television uses clock rates, etc.

Some particular examples of the business-interfaces for oscillation economic processes are discussed in [15], [16]. However, at least several hundred business-interfaces taking into account different particular cases relevant to business partners can be suggested. Therefore, it is advisable to publish a corresponding reference book, and introduce a special course of lectures teaching business-interfaces in economic schools.

Implementation of business-interfaces may bring up the question of whether their use can lead to the same grave consequences as the plan-based socialist economy due to the excessive regulation of economic activity, in particular, to the suppression of rights and freedoms. The answer is – no, it cannot, because business-interfaces will operate only for the term of a transaction, i.e., from the moment it is made to the moment it is settled, and only to the extent of the transaction, for the business partners indicated in the transaction. The latter, indeed, will have no freedom of disregarding the terms of the transaction; they will be committed to settle it. If you wish, after making a transaction, business partners will find themselves, to a certain extent, in socialism.

Similarly, nature, providing for the variety of lifestyles of various creatures, left them no choice of neglecting their duties of reproduction.

However, other people, as well as business partners beyond the extent of their transaction, will fully remain in capitalism. They will be completely free to choose what to buy or not to buy, to produce or not to produce, to hire and to fire; they will choose their occupation and place of residence, vote freely, and exercise their civil liberties and so on.

Therefore, the economy reformed as suggested above will be both capitalist and socialist: for the term of contractual obligations and to the extent of their settlement by the partners it will be socialist, and in all other respects for them and for all other people it will be capitalist. This economy will become ultimately fair and, thus, will ease social tension.

5.2 MINIMIZING THE INFLUENCE OF THE EXTERNAL HUMAN FACTOR

In order to minimize the influence of the external human factor, another economic tool is suggested, namely, the new global/regional information network TV•net [26], [27], which is free from all the shortcomings of the Internet. This information network will enable businesspeople to find business partners and make profitable transactions without having to resort to the unwanted third parties. Thus, businesspeople will have guaranteed confidentiality of their business connections, and will be able to avoid the unwanted influence of any third parties.

However, the only currently available global information network, the Internet, is hardly suitable for business purposes due to its numerous shortcomings. Indeed:

- it does not provide for guaranteed information security, i.e., protection from computer viruses, spyware, hackers, spam and other network threats;
- the www contains few if any promptly updated reliable serious information necessary for business and other intellectual activities, and, on the contrary, contains a lot of junk information;
- information retrieval time (not to be confused with information transmission time) is quite long, i.e., all search engines work not efficiently enough;
- copyright and proprietary rights (by hackers) are often infringed.

Due to the above, the Internet is often used, in fact, to resist (how else can we refer to the infringement of copyright and proprietary rights?) the fair capitalist business.

The TV•net, on the contrary, due to absence of packet-switched communication and use of one-way broadband (television or fibre-optic) communication lines:

- completely solves the problem of guaranteed information security, because it does not have the feedback communication lines used in the Internet for unauthorized access to information in the users' PCs;
- provides for zero information retrieval time, as information is broadcast to the users immediately as it is received and verified, and then stored in their personal data bases;
- provides for efficient noise reduction and protection from unauthorized access to communication lines due to noise-combating codes and cryptographic encoding;
- greatly enhances its functional capabilities due to the use of numerous new highly demanded services:

- the trading service which allows creating a global online-store;
- the exchange service which allows creating a global universal e-exchange;
- the administrative service which provides for efficient management of any institutions – ministries, banks, institutes, corporations, etc.;
- the educational service which offers mass education at the top level [28];
- the analytical service which allows implementing human-computer super-intelligence [8], [29], [30] – an alternative to the artificial intelligence whose development has faced a dead end; and so on.

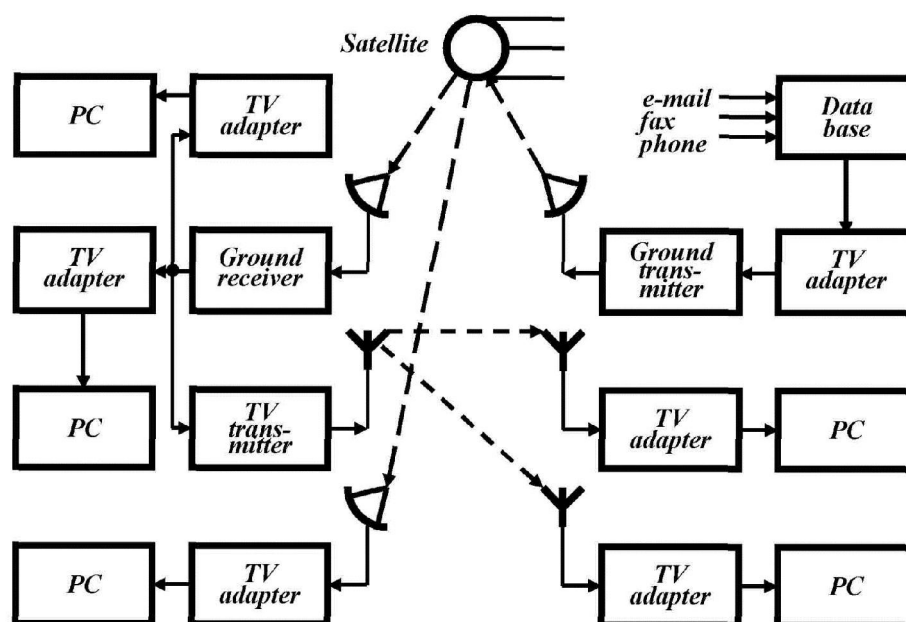


Fig. 6. An example of the simplest implementation of the TV•net information network without feedback lines

Let us briefly describe the new services offered by the TV•net information network.

The trading service of the TV•net information network is the most easy and low-cost to implement, because its deployment requires mostly organizational support. As can be seen (see Fig. 6), almost everything necessary for its implementation is already available in the market. Therefore, it can be quickly deployed in any region with a TV broadcasting network, both on-air and cable, and even away from cities, if satellite broadcasting channels are used. To deploy a small local network (e.g., for one particular city), there is no need to use satellite repeaters. For a comparatively large regional or global TV•net network, satellite repeaters are necessary. However, those used for TV broadcasting can be employed just as well.

Nowadays, the TV broadcasting network, in particular, satellite network, is so well developed and available at any place on Earth, that the main expense item for the deployment of the TV•net network is no longer required. Owners of the TV•net network do not have to launch their own satellites, because almost every satellite repeater has back-up facilities and communication lines not used to their full capacity at night. Computer information can be broadcast via the TV•net network at any time, as it will be received by the users' PCs 24 hours a day, and will be stored until it is required.

The trading service operates as follows. The users-buyers, for a certain subscription fee, connect to the TV•net information network via TV adapters, similar to modems used to connect to the Internet. The procedure is identical to subscribing to the pay-tv network. The only difference is that instead of the TV channels, the users choose the headings from the classifier. At that, the users PCs may be connected to the TV•net network either via cable TV lines, or via on-air or satellite TV, at their discretion.

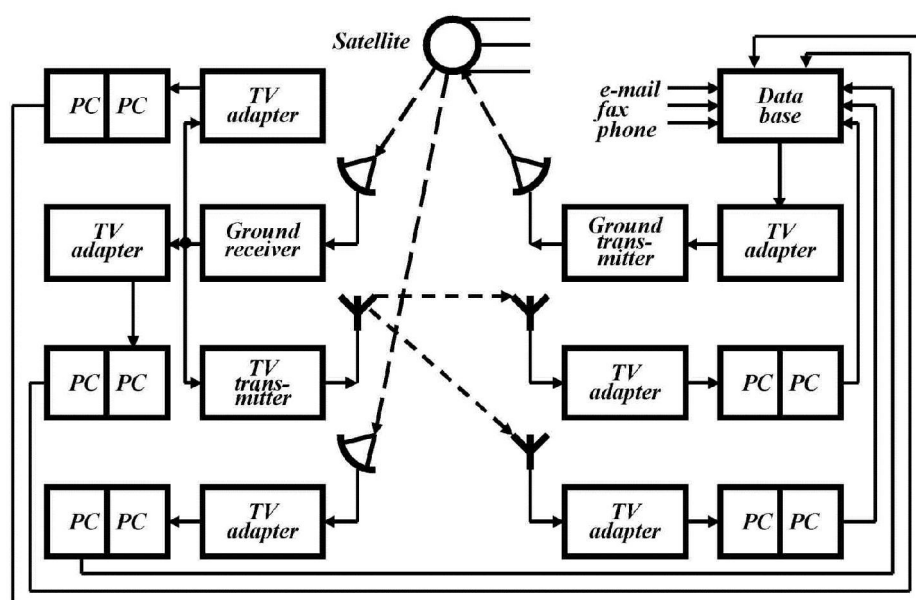


Fig. 7. An example of the simplest implementation of the TV•net information network with feedback lines

The subscribers-vendors are also connected to the TV•net for subscription fee, and regularly transmit (via any communication lines, including e-mail over the Internet) to the data base the most detailed information about the goods and services they offer. Similarly, offers of other forms of business partnership, including trade enquiries, can be submitted to the data base. In the data base, the information received is classified by the administration personnel and regularly broadcast via a TV adapter, where it is encoded and sent to a TV transmitter in the respective region (this link is not shown in Fig. 6 for simplicity). Then, via a television broadcasting network, it is transmitted to the users' PCs, and broadcast to users of other regions via satellite repeaters (Ground transmitter, Satellite, Ground receiver). The users can make their choices and purchases they need based on the corresponding criteria with the help of their PCs, either manually or using simple software.

In addition, guaranteed information security is provided for the users, since they are not connected to the Internet, and connected to the TV•net via one-way television broadcasting lines. Similarly, a TV viewer is not afraid that any information about him can be sent to the TV centre. If the users need to send any information via the Internet (e.g., order the delivery of the purchased goods), they will have to use a different PC (see Fig. 7). However, in this case, the protected PC connected to the TV•net, and the unprotected PC connected to the Internet must not have any communication between each other (except for removable disks and USB-cards).

Thus, services of the TV•net information network will be paid for by both the buyers and the vendors. Operating such a TV•net network will be quite a profitable business, may be, even more profitable, than TV advertisement.

It is easy to see that the suggested trading service, in terms of its purpose, is very similar to online-stores, and seems to be needless. However, the difference is in the amount of services offered: online-stores belong to small and medium business, and the trading service of the TV•net information network is large business and can result in the creation of a global 24/7 online-store. Therefore, as any large business, it allows generating higher profits. Consumer confidence to large business will also be higher.

The exchange service is almost identical to the trading service, with one exception: goods and services are traded not at fixed prices, but at auction prices and by the rules. Therefore, implementation of this service requires the TV•net information network to be deployed with feedback connection (Fig. 7).

Depending on the type and volume of bids, e-exchanges operating within the TV•net can certainly be both regional and global, commodity and stock, FX and others.

Naturally, the larger region the service covers, the more profit it can generate for its owners, similarly to the trading service.

The administrative service provides for guaranteed secure informational services for banks, public offices, corporations and any other large, medium and small market participants which currently are suffering from hacker attacks through the Internet, and are also vulnerable to other network threats. Therefore, the benefits of the administrative service are obvious.

A peculiarity of implementation of the TV•net information network in terms of the administrative service is tougher requirements to information security, which can be fully met due to additional use of cryptographic encoding and protected local area networks both at the input and at the output. The simplest example of implementation of such a TV•net network is given in Fig. 8.

Furthermore, in order for the top-managers of these institutions to make reasoned and highly efficient decisions, it is necessary:

- to quickly upload all available up-to-date information on any problem requiring a solution into the memory of their PCs; we shall thus refer to it as the personal memory;
- to quickly and correctly evaluate the information available in the personal memory in order to reveal the dominating trends in their respective field, which will enable them to make definitely successful decisions.

This task is addressed by another service – the analytical one.

The analytical service, thus, can help its users in revealing trends and regularities. However, within the context of conventional concepts, nothing else can be suggested to solve the problem but the interpolation and extrapolation algorithms; although, this is also quite useful.

Therefore, let us formulate the task in a different way – the analytical service, along with its other functions, is aimed at the development of the human-computer super-intelligence, as an alternative to the artificial intelligence. Since there is no conventional definition of intelligence – either human or computer – let us specify that hereinafter human intelligence is understood [8], [29], [30] as a set of intellectual sub-systems which includes the low-factor rational thinking, the multi-factor unconscious thinking and some other sub-systems. The most important one in the set is the sub-system of the multi-factor unconscious thinking. The term is used because many people at present do not even suspect it exists. This is confirmed by the fact that people still do not know why they go to sleep, because they believe that in sleep they are uselessly idle and, moreover, are more defenceless. However, nature is wiser than people and does not do anything useless. Therefore, it turns out that nature makes us go to sleep (when all human input and output senses, as well as the low-factor rational thinking governing human activities, are off) in order for us to use all our intellectual resources to process information accumulated in the wakeful state. This is why there is a proverb: “Take counsel with your pillow”, or “If you have a problem – sleep on it”. This is why, when you are sick, in the morning your temperature is lower than at night. This is why many scientific discoveries were made in sleep. And only for this reason humans have survived as a biological species.

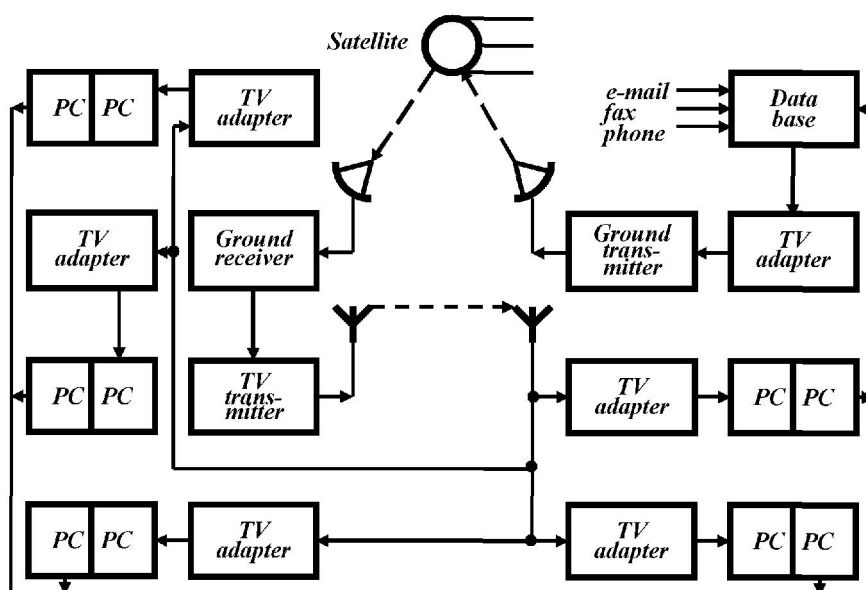


Fig. 8. An example of the simplest implementation of the TV•net information network using LANs

As for low-factor rational thinking, people need it for active day-to-day activities necessary for life support – getting food, doing work, and so on. It is referred to as low-factor for the reason that humans think with visual images (therefore people have dreams in the form of visual images and not in any other form) which are not more than three-dimensional. To make sure it is really so, try to imagine the simplest four-dimensional object – a hypercube. Processes in the real life, however, may depend on tens and hundreds, and even more factors (e.g., the economy, illnesses, weather, etc.).

Consequently, we can say that the rational low-factor thinking solves tactical tasks, and the unconscious multi-factor thinking performs strategic tasks.

Computer intelligence, usually referred to as the artificial intelligence, tries to simulate human low-factor thinking. Moreover, the artificial intelligence is often intended to meet the ambitious goal of surpassing human intelligence, i.e., to teach a computer to solve intellectual tasks without a human and instead of a human. However, this is a utopia. After 60 years of research devoted to the problem of artificial intelligence, scientists have not been able to teach a computer to tell, for instance, a dog from a cat.

Nevertheless, some scientist have developed the technological singularity concept [31], which reads that no later than 2030, following the successful solution of the artificial intelligence problem, an Internet-based computer civilization will emerge. It is not specified what this computer civilization will make of the human civilization; however, it is assumed that the process of development of the computer civilization is impossible to stop, because the countries which will try to hamper the process will be condemned to economic, military and technical underdevelopment, with all the respective consequences.

In fact, all these allegations are deceptive. Since humans possess the multi-factor thinking, and computers do not have it, humans will remain unattainably more advanced information machines than computers in the foreseeable future. The delusion about the superiority of computer intelligence seems to stem from the fact that computers are able to successfully solve complicated mathematical problems which cannot be solved by people either mentally or on paper. Many people believe that solving mathematical problems is an extremely intellectual activity. However, we should not forget that computers, contrary to humans, can solve only the tasks which are unambiguous and clear. Try to define clearly, for instance, how to tell a dog from a cat. Computers are unable to solve other, more ambiguous problems, which are prevailing in the real life. People, on the contrary, successfully solve them all the time. Therefore, computers are merely big and complicated calculators. Their intelligence is exactly at this level.

Donald Michie, Head of the Alan Turing Institute, wrote on the issue [32] that the current development of computer engineering makes it impossible even to try to approach the problem of artificial intelligence.

Many years later basically the same idea was expressed by V. M. Kuklin, Professor at Kharkov University [33]. He wrote that when solving the problem of artificial intelligence, scientists are unable to reproduce the attainments of nature even to the slightest degree.

Thus, the problem of artificial intelligence must be understood as it was formulated from the very beginning – as a research aiming at the investigation of human intelligence with the help of computer experiments. No more than that.

At present, given the phenomenal achievements of engineers and scientists in terms of computer advancement, it is time to define a new problem – the problem of human super-intelligence, which is understood herein as the development of human-computer systems able to solve multi-factor tasks. The matter is that human intelligence created by nature was not designed to use the multi-factor unconscious thinking to solve scientific and other intellectually demanding problems – centuries ago, people were busy with other things. If eventually people turned out to be able to solve intellectually demanding problems, this testifies only to the possibility of further substantial development of human intelligence, both by means of intellectual training (which is actually done by scientists) and by means of additional involvement of computer resources (which is suggested herein).

We will consider both possibilities, however, in the reverse order. We will first discuss the controllable and regular, contrary to the process of intellectual inspiration, use of the unconscious multi-factor human thinking in the wakeful state. What do scientists do when they are solving an intellectually demanding problem, i.e., when they are revealing a trend or discovering a regularity? They solve two problems in turn. First, they take all the imaginable multitude of factors and define the significant ones, which, if changed, noticeably influence the result under investigation. Then, having chosen the most significant of all the factors, they search for a mathematical relationship between them and the result under investigation. Finally, the result is taken down as a scientific law.

As can be seen, computer assistance in this research can be very helpful. Before commencing the research, a user first of all, to create in their PC a personal data base by quickly downloading from the information network all the reliable information relevant to the subject of the research. However, this is completely impossible given the current information

retrieval techniques in the WWW. On the other hand, this task can be quickly and easily performed by the TV•net information network in its realization shown in Fig. 6, except that the data base must contain the information necessary for top-managers, scientists, businesspeople, analysts of special services and other intellectual users.

Then, the corresponding software (e.g., factor analysis, or, in the simplest case, by key words) allows finding in all the ocean of information the pieces which presumably contain the significant factors. Next, these pieces of information must be studied and processed by human, in particular, multi-factor, thinking. Naturally, at this last stage of research, different software for enhancing the multi-factor intelligence can be helpful, similar to the existing software enhancing the low-factor rational intelligence.

Certainly, these tasks can be performed by supercomputers, as well. However, there are very few of them, they are very expensive and completely engaged in solving the most foreground problems. At the same time, these problems can be solved by personal computers, too, especially taking into account that important discoveries have often been unforeseen, spontaneous, and made by individual scientists. Here belong, for instance, discoveries of radioactivity, the DNA structure, the Internet, semiconductors and many other things. Let me at once answer those willing to object regarding the circumstances under which the semiconductor devices were discovered. I agree that after the World War II huge financing was allocated to the investigation of radio-electronic systems and components. In 1973 Leo Esaki, Ivar Giaever and Brian David Josephson won the Nobel Prize for discovering the tunnel diode. However, in fact, the first tunnel diode was made by physicist O.V. Losev back in 1922 [34]. It was even widely used at that time. However, no one was able to explain how it worked. Back then, even the term “semiconductor devices” did not exist.

This is why it is extremely important for the systems of human-computer super-intelligence to be accessible to all users, including talented individuals in their unplanned and ungoverned entrepreneurial, scientific and other intellectually demanding activities. Just as we need both small and large business, scientific research must also be performed not only by large groups of scientists, but by individual scientists, as well.

The educational service, in addition, is immediately relevant to the development of human super-intelligence, firstly, for the reason that creative thinking is developed in the course of education, and secondly, because creative people often have to get additional training or to be retrained.

The objectives of education can, certainly, be different – getting knowledge, mastering skills, intellectual or physical development, and so on. Therefore, taking into account that intellectual work is getting more and more demanding nowadays – even to stay rich, you must make certain intellectual efforts, otherwise you will turn poor – the major objective of education must, obviously, be the intellectual development of people.

The educational service which solves this problem operates as follows. Using the computer-television broadcasting network – the TV•net (see Fig. 6), its users, independently or via their educational institutions, receive and download to their PCs:

- textbooks and work-books supplied with a large number of hyperlinks to other sections of textbooks (other textbooks, as well) and FAQ sections;
- supplementary further reading;
- problem books with detailed solutions of typical problems and advanced problems;
- learning and developing, learn-as-you-play and other software.

As is well-known, the quality of education depends on how well individual peculiarities of students are taken into account. The point is that all people have a different body of mastered knowledge (due to individual differences in abilities, background, thinking, etc.). Thus, new knowledge is learned well only in the case it is based on the previously mastered knowledge. The art of teaching lies in the ability to take into account all these circumstances as much as possible. Naturally, the principle of learning based on the previously mastered knowledge is never fully observed in the process of collective education, because all people have different basic, well mastered, knowledge. It is poorly realized in self-education (there is no one to ask a question). At present it is best of all implemented in the process of individual education with a tutor.

However, the educational service of the TV•net allows implementing it even better, because a personal computer whose memory contains the information specified above can always help find the additional material explaining any unclear issues (basically what a tutor does). Therefore, education using the service under consideration in terms of its efficiency will be comparable to elite training on a one-to-one basis. This education will be most developing and aimed at further use of the human super-intelligence systems.

Thus, the service described above suggests new technical means aimed at the new strategy of education in order to improve the quality of education. The new strategy can be referred to as the developing learning, because, contrary to the

current teaching techniques, its objective is not merely to acquire knowledge, but to promote the skills allowing for the efficient creative application of this knowledge in further practical activity. Therefore, developing learning means of skills aimed at using the information obtained, as well as searching for the necessary information.

Developing learning will require new textbooks and workbooks. The currently available textbooks are not suitable for the purpose, because the material is often presented in an excessively dogmatic way in the form of, allegedly, absolutely true knowledge. However, developing learning requires textbooks which, first of all, teach to think. Therefore, they must not only present the knowledge, but explain the often difficult way this knowledge was obtained. Sometimes it is useful to analyse certain hypotheses rejected by science at present. It is necessary to explain that science has few absolute truths.

People who want to become super-intellectuals must not be deceived even in primary school, to say nothing about universities. They ought to know that groping for knowledge is an extremely hard work. Therefore, they must get used to not getting the ready-made knowledge, but to obtaining the knowledge themselves. In this respect, the learning process must resemble the process of a scientific research, except that at the very beginning it will take place under the supervision and with the help of teachers, then – academic advisors, and finally – independently.

People completing such a course will be prepared to the super-intellectual activity described above to the best advantage.

6 SUMMARY

Thus, it turns out that ‘the invisible hand’ of Adam Smith in economics is the human factor. It is its influence on the economy that makes processes in it be described with systems of parametric differential equations with coefficients in the form of random functions of time. For this reason, the current economy is unpredictable and cannot be efficiently managed, and economic crises in it are inevitable. In particular it is the human factor that accounts for the Great Depression phenomena in the US.

To be able to manage market economy, to make it crisis-proof, the influence of the human factor has to be minimized. To this end, new economic tools must be used. In order to minimize the influence of the external human factor, business-interfaces should be used. In order to minimize the influence of the internal human factor, it is advisable to use the new global information network TV•net, which is completely free from all the shortcomings of the Internet and offers numerous new business- and intellectually oriented services.

The economy reformed this way will be described mostly with systems of linear differential equations, i.e., it will have a mathematical description similar to the mathematical description of radio-electronic systems and processes. Therefore, this economy will become an exact science. It will be possible to use the methods borrowed from the theory of analysis and synthesis of linear electric circuits, from the simulation theory, from the automatic control theory and others. The reformed economy will allow widely using new, previously unknown oscillation processes which provide for significantly more efficient use of circulating assets.

Last, but not least – the economy reformed as discussed above will become crisis-proof and therefore rapidly developing.

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Fundamentals of crisis-proof economics

Alexander A. Antonov

Research Centre of Information Technologies "TELAN Electronics"
P.O. Box 73, Kiev, 03142, Ukraine

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ABSTRACT: The major problem of the current market economy is absence of appropriate mathematical description of processes taking place in it, which results in misunderstanding of these processes, as well as lack of efficient means of preventing economic crises. The manuscript suggests such a mathematical description, making use of the circumstance that the 'black box' of market economy has the corresponding 'white box', which turned out to be the processes well known in radio-electronics. This approach allowed proving that the current market economy, due to the significant influence of the human factor, is described with parametric differential equations with random coefficients, the solutions of which are also random functions of time. Therefore, it is basically unpredictable and uncontrollable, which makes economic crises inevitable. In order for the economy to become crisis-proof, it has to be reformed. We suggest using the new economic tools which allow solving the problem. Here belong business-interfaces that can neutralize the internal human factor, and the new global/regional information network TV•net, which is completely free from the shortcomings of the Internet and is able to neutralize the external human factor. It is shown that after the implementation of reforms suggested in the manuscript economics will become an exact science able to successfully solve the tasks of analysis and synthesis of economic structures, the tasks of their simulation and improvement, as well as regulation of the economy in general. The new economy will become crisis-proof and rapidly developing.

KEYWORDS: Economic Crisis, Economic Reform, Crisis-Proof Economy, 'Invisible Hand', 'Goods-Money-Goods' Process, Human Factor.

1 INTRODUCTION

People, contrary to all other living beings on Earth, have one more environment – the economy. Everything we are engaged in – working, studying, doing business, paying taxes, etc. – is somehow or other connected with the economy. All our conscious activities take place in this environment. Nevertheless, we know the economy not any better than our physical environment [1].

Economics as an exact science which complies with the principles of fundamental sciences has not yet been developed. This is confirmed by the fact that the major economic phenomenon – economic crises known for centuries – still lacks a comprehensive explanation. In the opinion of Philip Kay, historian, Professor at Oxford University, the first economic crisis in world history occurred in the Roman Empire in 88 BC [2]. There are other opinions, as well. Most scientists believe the first economic crisis was the one that hit England in 1825, partially influencing the economies of the USA and France [3]. Since that time, economic crises have become inevitable concomitants of the human civilization. There are many theories of economic crises, although, certainly, only one of them can be true. In fact, none of them is actually true, since all of them failed to prevent any upcoming economic crises.

Over the past few decades, many new complicated mathematized concepts [4] have been developed in economics, and attempts of their application have been made. Here belong theories of extremal problems and specific methods of data analysis, which have become part of econometrics, as well as game theories, social choice theories, theories of general economic equilibrium, etc. Various branches of mathematics have been further employed to analyse economic phenomena;

here belong the fixed point theorem, differential topology, the stability theory, functional analysis, the theory of random processes, etc. There is hardly any branch of mathematics which scientists have not tried to apply to economics.

The above may seem to testify to the prosperity of economic science. However, this is not so, because there are apparent signs of a protracted crisis of economic theory, where the most general findings are definitely negative. These are the conclusions which may be formulated approximately as follows: "The answers to your questions depend on the circumstances which you did not take into account", and "The model you used is too general or irrelevant" [4].

This is why some authors [5] started to wonder whether the natural-scientific theories should be considered as an example for developing the economic theory, or whether the economic theory should be developed based on different standards. Opinions were expressed that, apparently, a large variety of economic phenomena cannot be accounted for based on a limited number of fundamental laws. Therefore, it was suggested to substitute the principle of a unified economic theory for the principle of coexistence of competing concepts [6].

The publication brought to the attention of the reader, however, attempts to suggest a concept of a unified economic theory which complies with the criteria of the exact sciences and will allow explaining and preventing economic crises.

2 APPROPRIATE MATHEMATICAL DESCRIPTION OF ECONOMIC PROCESSES

Despite numerous economic theories developed by Adam Smith (1723 – 1790), Thomas Robert Malthus (1766 – 1834), Jean Baptiste Say (1767 – 1832), David Ricardo (1772 – 1823), Jean-Charles Leonard Sismonde de Sismondi (1773 – 1842), John Stuart Mill (1806 – 1873), Karl Heinrich Marx (1818 – 1883), Alfred Marshall (1842 – 1924), John Bates Clark (1847 – 1938), Vilfredo Pareto (1848 – 1923), Ludwig Heinrich Elder von Mises (1881 – 1973), Joseph Alois Schumpeter (1883 – 1953), John Maynard Keynes (1883 – 1946), Nikolai Dmitriewitsch Kondratieff (1892 – 1938), Friedrich August von Hayek (1899 – 1992), Simon Smith Kuznets (1901 – 1985), Wassily Wassilevich Leontief (1905 – 1999), Milton Friedman (1912 – 2006), Walt Withman Rostow (1916 – 2003), Christopher Freeman (1921 – 2010) and many other outstanding scientists [3], [7], both local and global economic crises continue, and, thus, refute all the existing theories of economic crises.

Anticipating the following (see details below), we have to note that, in terms of mathematics, the task of explaining the nature of economic crises turned out to be quite extraordinary and complicated, because processes prevailing in the current economy are described with systems of parametric differential equations with random coefficients, which are not compatible to other sciences and have no analytical solution. Therefore, crises are inevitable in this economy, and it is impossible to prevent them using the economic tools available at present.

In order to develop a controllable crisis-proof economy, new economic tools described below are necessary. In other words, the current economy has to be reformed in such a way as to allow the use of mathematical tools enabling to solve the problem.

In order to understand what these new mathematical-economic tools must be, the new appropriate mathematical description of processes prevailing in the current economy has to be found. In this respect it is noteworthy that, first of all, an important peculiarity of economic processes is the fact that they are highly multi-factor, contrary to processes studied in the exact sciences. Indeed, almost all laws revealed so far in the exact sciences (perhaps, with the exception of Kepler's third law with Newton's amendments) are low-factor, although nature, certainly, does not restrict itself to the use of only these simplest natural-scientific laws. However, multi-factor laws in the exact sciences have yet to be discovered. As for economics, it has no low-factor dependencies, with a rare exception. This is a very important circumstance which is relevant to the situation under consideration. The matter is that human rational thinking is low-factor by nature [8], because people think with visual images which are not more than three-dimensional. Therefore, people are able to perceive low-factor dependencies. As for multi-factor dependencies described with functions of more than three variables (similar to objects having more dimensions), people are unable to perceive them with their rational thinking. You can make sure of it yourselves: just try to imagine the simplest four-dimensional object – a hypercube (or tesseract). Thus, human rational thinking itself, without computer support (see below for human-computer super-intelligence), is unable to perceive multi-factor economic dependencies.

To make these multi-factor objects of economic research at least somehow understandable, they are sometimes transformed into low-factor objects with the help of mathematical statistics. However, estimates received after statistical processing of economic data are too information-depleted, and, therefore, hardly suitable for practical application. For the same reason, for instance, a doctor would never use the average temperature, as well as averaged results of other analyses, to treat the patients.

Furthermore, an extremely important circumstance which must be taken into account correctly is the fact that economic processes, as follows from the fact that they are multi-factor, belong to the so-called mass phenomena. Currently, conclusions drawn from this circumstance are so wrong that they make it impossible to develop economic theory which would comply with the criteria of the exact sciences. Mass phenomena can be found in other science, as well, e.g., in physics and radio-electronics; however, this fact does not prevent them from being the exact sciences. As for economics, acknowledgement of the circumstance that economic processes belong to mass phenomena basically resulted in complete abandonment of any attempts to understand the fundamental processes in it and to suggest their appropriate mathematical description which defines its current state of development.

With all this in view, we can state that economics remains largely unknown. In the exact sciences, the term 'the black box', introduced by William Ross Ashby (1903 – 1972), is used to denote an object of research whose operational mechanism is unknown, but the result of its operation is known. Moreover, this result is unpredictable and mathematically indefinable.

This is why any regulatory activities of governments and top-managers of the current economy turn out to be inefficient. Indeed, in order to manage the object of regulation, it is necessary to be able to extrapolate its behaviour, which is impossible without its appropriate mathematical description.

In order to solve the problem, we must be able to turn the black box into 'the white box', whose operation mechanism, according to the definition introduced by Norbert Wiener (1894 – 1964), is known, and yields the same results as the black box. In other words, the white box is the mathematical counterpart of the black box, and mathematical description of processes in the white box is therefore appropriate for processes in the black box, although, in terms of physics, the black box and the white box can be completely different. For instance, in investigation of oscillations, a pendulum may be the white box, and a radio-electronic oscillation circuit, a piano or an earthquake may be the black box.

Thus, to be able to prevent economic crises, it is first of all necessary to find an appropriate mathematical description of processes prevailing in the economy. To this end, the corresponding white box has to be found, and then, based on the well-known results of its operation, processes in the black box of the economy can be improved.

However, such a white box has not yet been found.

Furthermore, mathematical analysis of different situations using the supply and demand curves, the production-possibility curves, etc., widely used in economics, is not at all suitable to describe processes and allows defining only a state, because the intersection points of curves mathematically correspond to graphical solutions of algebraic equations without consideration of time. Certainly, the results obtained using these curves are useful. They allow, in the first approximation, giving a more or less correct estimate of a certain economic situation. However, this is definitely not enough, since they do not allow understanding the processes prevailing in the black box of the global and even of any regional economy.

Low efficiency of the mathematical apparatus used in economics was pointed to by physicists at the end of the 20th century; they even founded a new science – econophysics (econophysics = economics + physics). They reasonably assumed that phenomena observed in economics have much in common with processes in physics, and, thus, suggested to use new mathematical tools in economics [9]-[12]. These new mathematical tools of econophysics included mostly the statistical methods borrowed from statistical physics. In particular, non-traditional for economics methods developed in the theory of self-organized criticality, in fractal analysis, in the theory of phase transitions, and in the percolation theory were widely used. However, these new mathematical tools also allow defining only states.

Processes in mathematics are described with differential equations – linear, non-linear or parametric, depending on the peculiarities of their behaviour in a particular object of research. Consequently, the appropriate mathematical description of economic processes must be made using differential equations. Unfortunately, attempts to use differential equations in economics [13], [14] were not aimed at understanding the contents of the black box of the economy. This must have led to the opinion that differential equations in economics are restrictedly useful.

However, this false conclusion is determined by the improper use of mathematics. Its improper use stems from the opinion prevailing in the economy that the behaviour of this or that market participant is completely impossible to predict (this statement is both true and false, depending on the circumstances – see below). For instance, Sir Isaac Newton (1642 – 1727) wrote that simulating people's behaviour is a much more complicated task than predicting planetary motion [11]. This is why, in economics, there is a tendency to assume that it makes sense to analyse only the behaviour of a large number of market participants, i.e., to investigate mathematically only mass phenomena.

3 DIFFERENTIAL EQUATION OF THE 'GOODS-MONEY-GOODS' PROCESS

The basic economic process is certainly the 'goods-money-goods' process.

Since it is a process, it must be described with a differential equation [15], [16]. To derive it, it is certainly necessary to describe mathematically the market behaviour of the vendor and the buyer separately (for a more complicated implementation of the market – of other market participants, as well), and then – their joint behaviour. Both the buyer and the vendor may be either an individual or a corporate body. However, the goods, which are a matter of their common concern, must be the same.

Thus, given the very general, but quite possible conditions, the behaviour of the generalized buyer (hereinafter referred to as the buyer) of the goods, who is often a wage worker, is described with the formula:

$$M_B(t) = \frac{1}{T_B} \int_0^t Q_B(t) P_B(t) dt \quad (1)$$

or the inverse formula

$$Q_B(t) P_B(t) = T_B \frac{dM_B(t)}{dt} \quad (2)$$

where $M_B(t)$ is the current expenses (the amount of circulating assets) of the buyer;

$P_B(t)$ is the current market price of the goods purchased by the buyer;

$Q_B(t)$ is the current quantity of the goods purchased by the buyer;

$P_B(t)Q_B(t)$ is the current assets flow of the buyer;

T_B is the useful life of goods purchased by the buyer;

t is time.

Consequently, according to formula (1), the expenses of the buyer equal to the accrued expenditures (the amount of circulating assets) for the purchase of the necessary amount of goods taking into account the price dynamics in time.

Similarly, the behaviour of the generalized vendor (hereinafter referred to as the vendor), who is usually a manufacturer and an employer, is described with the formula

$$P_V(t) = \frac{1}{Q_V(t)T_V} \int_0^t M_V(t) dt \quad (3)$$

which is equivalent to the formula

$$P_V(t)Q_V(t) = \frac{1}{T_V} \int_0^t M_V(t) dt \quad (4)$$

or the inverse formula

$$M_V(t) = T_V \frac{d[P_V(t)Q_V(t)]}{dt} \quad (5)$$

where $P_V(t)$ is the current market price of the goods;

$Q_V(t)$ is the current quantity of the goods manufactured by the vendor;

$P_V(t)Q_V(t)$ is the circulating assets flow of the vendor;

$M_V(t)$ is the current revenue of the vendor (the amount of circulating assets) covering the manufacturing costs and generating profit;

T_V is the production time per commodity unit;

t is time.

Thus, the price of goods, according to formula (3), equals to the accrued expenses of the vendor adjusted for the planned revenue, divided by the quantity of manufactured goods.

As can be seen, in expressions (1) – (5) the values of the circulating assets and payments flow (or the amount of circulating assets) of the vendor and the buyer have not an algebraic, but a differential-integral relationship, since the price formation process is influenced by the previous transaction history of the vendor with the buyer. When making a transaction on each commodity unit, both the vendor and the buyer, in accordance with formulae (1) and (3), use their average estimates. For a transaction to be made, the vendor and the buyer must reach an agreement on payments, i.e., despite their different considerations, they must reconcile their interests and agree upon the price.

It is interesting to note the mathematical similarity of formulae (1), (2), (4), (5), describing the market behaviour of the vendor and the buyer, on the one hand, and formulae describing processes in radio-electronic components – a capacitor and an induction coil – in electric circuits. For a better comparison, the corresponding formulae are presented in the table below.

Table 1.

In economics	In radio-electronics
The amount of current (circulating) assets of the buyer $M_B(t) = \frac{1}{T_B} \int_0^t Q_B(t) P_B(t) dt$	Voltage drop at the capacitor $U_C(t) = \frac{1}{C} \int_0^t I(t) dt$
The current (circulating) assets flow of the buyer $Q_B(t) P_B(t) = T_B \frac{dM_B(t)}{dt}$	Electric current through the capacitor $I_C(t) = C \frac{dU_C(t)}{dt}$
The amount of current (circulating) assets of the vendor $M_V(t) = T_V \frac{d[Q_V(t) P_V(t)]}{dt}$	Voltage drop at the inductance coil $U_L(t) = L \frac{dI_L(t)}{dt}$
The current (circulating) assets flow of the vendor $P_V(t) Q(t) = \frac{1}{T_V} \int_0^t M_V(t) dt$	Electric current through the induction coil $I_L(t) = \frac{1}{L} \int_0^t U_L(t) dt$

Formulae relating to radio-electronic components in the table use the following notations:

$U_C(t)$ is the voltage drop at the capacitor C ;

$I_C(t)$ is the electric current through the capacitor C ;

$U_L(t)$ is the voltage drop at the inductance coil L ;

$I_L(t)$ is the electric current through the induction coil L .

At that, as shown in Fig. 1, both the economic components (the buyer and the vendor) and the radio-electronic components (the capacitor and the inductance coil) are combined in a similar way, forming similar functional links. Then, it is quite natural to expect that processes in them have a similar mathematical description.

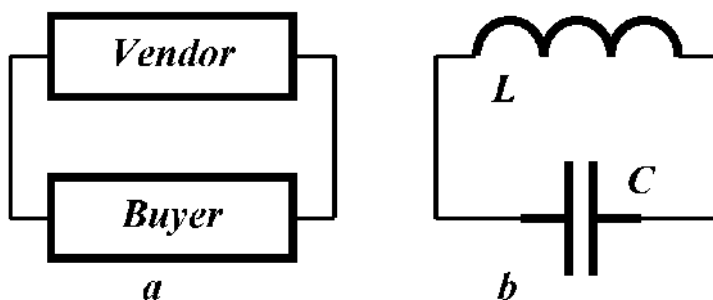
In economics the process, usually referred to as the ‘goods-money-goods’ process, must apparently correspond to the expression

$$M_V(t) = -M_B(t) \quad (6)$$

or

$$M_V(t) + M_B(t) = 0 \quad (7)$$

Formula (6) reflects the fact that in the isolated economic link under consideration (Fig. 1a) one of the transaction parties always makes the payment, and the other party accepts the payment. As a result, the total amount of circulating assets,



according to expression (7), remains unchanged (zero for the example under consideration).

Fig. 1. Simplest oscillation links in economics and radio-electronics, where a sustained oscillation process is observed

Let us suppose, for the simplest case under consideration, when there is only one vendor and only one buyer, that $Q_V(t) = Q_B(t) = Q(t)$ and $P_V(t) = P_B(t) = P(t)$, then, using formulae (1), (3), we find from (7) the expression

$$T_V \frac{d[Q(t)P(t)]}{dt} + \frac{1}{T_B} \int_0^t Q(t)P(t)dt = 0 \quad (8)$$

Substituting (1), we get **the second-degree linear differential equation describing the 'goods-money-goods' process** under consideration.

$$T_V T_B \frac{d^2 M_B(t)}{dt^2} + M_B(t) = 0 \quad (9)$$

The solution of the equation has the form

$$M_B = A \sin \omega_0 t + B \cos \omega_0 t \quad (10)$$

where A and B are the constants of integration which are found from the initial conditions $M_B(t)|_{t=0}$ and $\frac{dM_B(t)}{dt}|_{t=0}$;

$\omega_0 = \frac{1}{\sqrt{T_B T_V}}$ is the resonance frequency of the simplest economic link under investigation.

It is easy to notice that the expressions (7) and (9) are very much similar to the expressions

$$U_L(t) + U_C(t) = 0 \quad (11)$$

$$LC \frac{d^2 U_C(t)}{dt^2} + U_C(t) = 0 \quad (12)$$

which, as is known, describe processes in the electric circuit (Fig. 1b) often referred to as an electric oscillation LC-circuit. Consequently, the economic circuit given in Fig. 1a can be referred to as an economic oscillation link.

Formula (11) in the electric circuits' theory is referred to as the second Kirchhoff's law (this is certainly its simplest notation). This is why in economic circuits' theory formula (7) can also be referred to as the second Kirchhoff's law in its economic interpretation. It is also possible to demonstrate that the first Kirchhoff's law is true for the economic circuits' theory, and formulae (1) – (5) correspond to the Ohm's law (also in their economic interpretation).

Moreover, the analogy described above holds true for more complicated situations, as well (see Fig. 2). Indeed, in oscillation links presented in Fig. 2 – both the economic and the radio-electronic ones – compared to the first case, additional, the so-called dissipating elements (from Latin *dissipatio* – dissipation), are present. They are called dissipating for

the reason that they dissipate the energy of oscillations, causing the latter to become damped. In the radio-electronic oscillation link (Fig. 2b) this is the resistor R . In the economic oscillation link (Fig. 2a) here belong the elements which withdraw a part of circulating assets (a bank and a tax administration in the example under consideration).

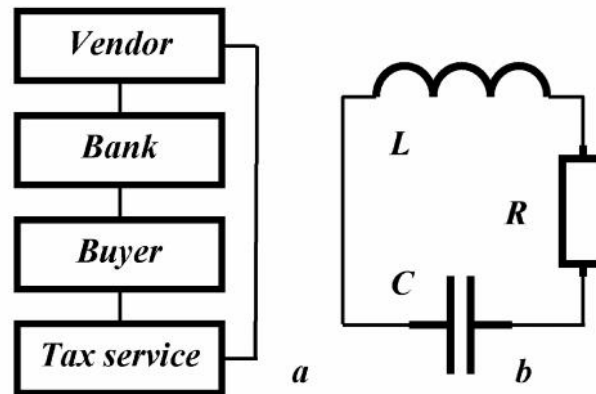


Fig. 2. Simplest oscillation links in economics and radio-electronics, where a damped oscillation process is observed

Therefore, processes in them are described with somewhat different, compared to (9) and (11), differential equations. For the radio-electronic oscillation link (Fig. 2b) this differential equation has the form

$$LC \frac{d^2 U_C(t)}{dt^2} + RC \frac{dU_C(t)}{dt} + U_C(t) = 0 \quad (13)$$

and for the economic oscillation link – the following form (for simplicity, both differential equations are given without derivation)

$$T_V T_B \frac{d^2 M_B(t)}{dt^2} + T_B (\alpha + \beta) \frac{dM_B(t)}{dt} + M_B(t) = 0 \quad (14)$$

Their solutions are damped oscillations, which are mathematically identical

$$M_B(t) = e^{-\sigma_0 t} (A \sin \omega_0 t + B \cos \omega_0 t) \quad (15)$$

$$U_C(t) = e^{-\sigma_0 t} (A \sin \omega_0 t + B \cos \omega_0 t) \quad (16)$$

where α is the relative current amount of the vendor's tax payments;

β is the relative current amount of the buyer's payments to the bank for making money transfers to the buyer;

A and B are the integration constants;

$\omega_0 = 1/\sqrt{T_B T_V}$ is the resonance frequency of oscillations in the economic oscillation link;

$\omega_0 = 1/\sqrt{LC}$ is the resonance frequency of oscillations in the radio-electronic oscillation link;

$\sigma_0 = (\alpha + \beta)/2T_V$ is the decay of oscillations in the economic oscillation link;

$\sigma_0 = R/2L$ is the decay of oscillations in the radio-electronic oscillation link.

As can be seen, the analogy between the economic and radio-electronic oscillation processes is indeed observed in the oscillation links plotted in Fig. 2. It is observed in many other situations, as well.

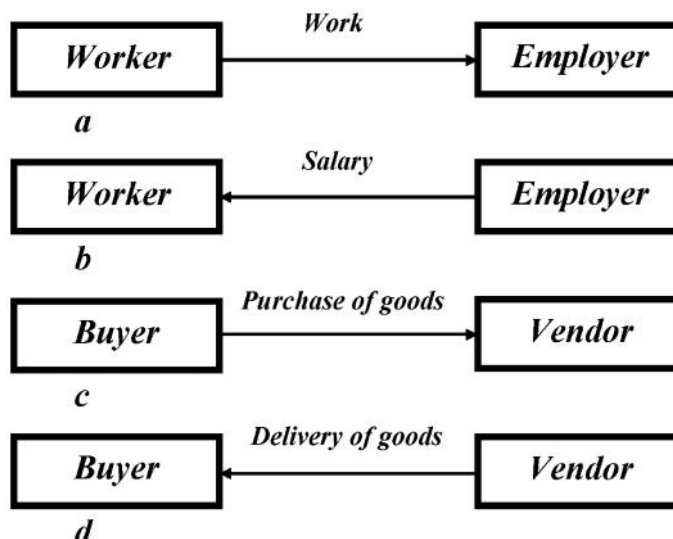


Fig. 3. The content of the oscillation process in isolated economic oscillation links plotted in Fig. 1a and 2a

Thus, **radio-electronic devices and processes are**, indeed, the aforementioned **white box with regard to the black box of economics and economic processes**. Recognition of this fact allows developing the economic theory which will completely meet the criteria of the exact sciences.

However, using this analogy requires being cautious and avoiding violating it as a result of certain incorrect actions. For example, in the electric oscillation circuit (Fig. 1b or 2b) the oscillation process in any of its phases has one and the same physical meaning determined by the motion of electrons. As for the isolated economic oscillation link (Fig. 1a or 2a), the oscillation period includes four successive processes with a different content, where business partners perform different functions. At first (Fig. 3a), the vendor is an employer and a manufacturer, and the buyer is an employee who manufactures goods at the vendor's enterprise. Then (Fig. 3b), the employer pays remuneration to the employee. After that (Fig. 3c), the employee turns into a buyer and pays the employer-vendor the cost of a purchase. Finally (Fig. 3d), the vendor delivers the purchased goods to the buyer.

Since the economic oscillation link under consideration (Fig. 1a) is assumed to be isolated for simplicity, the full oscillation period must include all the successive actions described above. For example, the condition is fulfilled if workers of an automobile plant purchase cars produced by it. If the condition above is not fulfilled, the oscillation process becomes impossible.

In more complex multi-link oscillation systems the content of the oscillation process can certainly be different; moreover, it can differ even in various links of the oscillation system.

However, even if the succession of actions described above is observed, the 'goods-money-goods' process in the economic link under consideration will not be oscillating, if all payments and deliveries are not enforced according to the sine law (e.g., made by a computer on a daily basis), which is never the case at present. Consequently, the economic links given in Figs. 1a and 2a are only potentially oscillating. In fact, the oscillation process described above has never been implemented in economics.

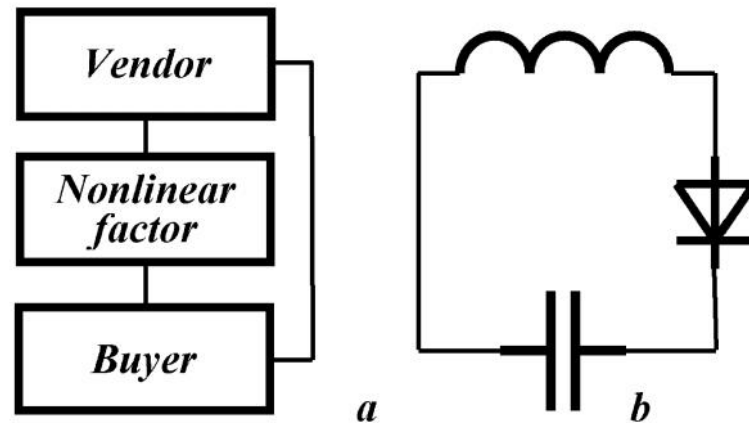


Fig. 4. Non-linear links

In this respect, it is natural to ask: what is the point of all these complications and does the economy need these oscillation processes? They turn out to be very necessary, because they provide for a more efficient use of circulating assets than currently observed. Indeed, given the current payment schedules in the form of infrequent (e.g., monthly or quarterly) payments, money works inefficiently, because the economy always experiences either surplus or shortage of it to solve its current tasks. This is why part of the money always remains idle. If sinusoidal payment schedules are used in economic oscillation systems, circulating assets will be fully used at any time and yield significantly larger returns.

Moreover, the economic oscillation systems described above will make it possible to use completely new processes which will significantly improve the efficiency of economic activity. For example, here belong processes widely used in resonant processes engineering, or processes used in wired structure systems, as well as many other processes known in radio-electronics and computer technology.

The most important point is that it is these complications that allow eventually developing the economic theory belonging to the exact sciences, which will be able to develop just as consistent and efficient systems as radio-electronics.

For better understanding of the following discussion, it is noteworthy that isolated economic and radio-electronic links may be non-linear, as well (their conditional examples are presented in Fig. 4). Processes in the non-linear economic link (Fig. 4a) and the non-linear radio-electronic link (Fig. 4b) are described with very similar non-linear differential equations:

$$T_V T_B \frac{d^2 M_B(t)}{dt^2} + T_B F[M_B(t)] \frac{dM_B(t)}{dt} + M_B(t) = 0 \quad (17)$$

$$LC \frac{d^2 U_C(t)}{dt^2} + CR[U_C(t)]C \frac{dU_C(t)}{dt} + U_C(t) = 0 \quad (18)$$

They (both the links and the differential equations) are referred to as non-linear for the reason that they include at least one non-linear element – $F[M_B(t)]$ or $R[U_C(t)]$, the value of which depends on the current value of the function under investigation – $M_B(t)$ or $U_C(t)$. In the radio-electronic link presented in Fig. 4b, the non-linear element is the diode. In the economic link given in Fig. 4a, the non-linear element is, for instance, the fact that the buyer, e.g., in a supermarket, always pays to the vendor, but the vendor never pays to the buyer. Non-linear circuits and the corresponding non-linear processes are often used both in economic and radio-electronic links which are not oscillating, and which are not the subject of the given research. This is why, in the economic link given in Fig. 4a, this circumstance is referred to as the 'non-linear factor', and not as the 'non-linear element', which is absent in the situation under consideration.

By the way, this example demonstrates very well that it is not easy to make the analogy between the economic and radio-electronic circuits.

4 “THE INVISIBLE HAND” OF ADAM SMITH

The problem of building crisis-proof sustainable economy is one of the major issues for governments of all countries and top-managers of the global economy. It is well known that both the abstract socialism as a fully regulated economy and the abstract capitalism (*laissez faire*) as a completely free economy, have their shortcomings and their advantages:

- socialist economy was developing very slowly, but experienced no crises;
- capitalist economy is developing much faster, but suffers from economic crises.

Thus, all countries are currently looking for their own intermediate ways of economic development, in the form of this or that variety of regulated capitalism (i.e., with elements of socialism). However, many existing economic schools [3], [7] have not reached an agreement upon this intermediate way. As a result, different countries have chosen different ways. However, an indisputable knowledge base necessary for any national leader to make a confident choice of a justified course of economic development is still lacking. This is why voters of all countries are still offered new and different economic agendas, none of which is capable of preventing economic crises for the reasons discussed above.

Therefore, a new approach towards solving the problem is suggested below. It will allow building the crisis-proof economy.

Economists often use the specific term ‘the invisible hand’ introduced by Adam Smith 1723 – 1790) [17], when they face manifestations of powerful and unclear forces driving the society in their unpredictable direction, often despite the efforts of government heads and top-managers of the economy.

For instance, in 1929 – 1930 the US gross national product suddenly dropped to 67% of the previous years. This became the national economic tragedy which is known in US history as the Great Depression.

Just think about it: both in 1929 and in 1930, the US economy had approximately the same labour force and approximately the same fixed assets. However, in 1929 huge growth of production was observed (stock quotations were exceptionally high), and in 1930 the stock market ‘collapsed’ and a 33% decline in production was recorded! Over these years, the country suffered neither a war, nor a natural disaster, nor an epidemic. Just somehow, one and the same economy was prosperous in 1929, and deteriorated in 1930. What was the reason? What drastic changes occurred in the US economy in 1930? There is still no answer. The Great Depression does not give in to any rational explanation [18].

Indeed, according to the Cobb-Douglas production function [19] $Q = AL^\alpha K^\beta$, the production volume Q depends on two slowly varying production factors: L (labour costs) and K (capital costs). Thus, the economy of any country is not supposed to experience any crises, and production volume is supposed to gradually increase year over year, following population growth (1-2% per annum) and fixed assets growth (3-4% per annum). However, in fact, something unpredictable keeps happening in economic development, and short-term sustainable growth is rather an exception than a rule.

The state of affairs means only one thing: there is the third, more powerful factor, which plays the role of a switchboard for progress or regress. This unknown third factor is, in fact, the major one defining the process of economic development. However, it is still unidentified by the economic science, despite all the efforts taken to define it.

This is why one of the major and urgent problems of theoretical economics is still to detect ‘the third factor’, to identify the mysterious ‘invisible hand’, which plays such an important part in the development of the global economy.

However, if long-term research failed to reveal the third factor among the objective circumstances influencing economic processes, it is possible to presume that it is the subjective, or, in other words, the human factor. This was the conclusion made as a result of research reported in [20]. Let us briefly review it.

As was demonstrated above, in the idealized simplest market link (Fig. 1a or 2a) the ‘goods-money-goods’ process is mathematically described with the linear differential equation (9) or (14).

Its obvious solution is an oscillation process, because the current assets must circulate between the buyer and the vendor. However, this oscillation process has nothing in common either with the Elliott waves [21], or with the seasonal fluctuations of business activity (e.g., in agriculture), or with the economic cycles of Kitchin, Juglar, Kuznets or Kondratiev [22], and it has nothing to do with economic crises.

Moreover, this oscillation process in economics is still unknown, because the conditions for its realization have never been created. They cannot be created in a random way. This is quite natural, because houses are not built in a random fashion, cars are not assembled at random, and computers are not made randomly. Constructive activities always require certain knowledge, which economics is still lacking.

This is why, the simplest links of the commodities market in Fig. 1a and 2a were said to be idealized and only potentially oscillating. Actual oscillation links always include (see Figs. 1a and 2a) not only the buyer and the vendor (as well as other market participants – third parties, banks, tax authorities, etc.), whose behaviour is described by functions (1) – (5), but ‘the invisible hand’, as well – the human factors they introduce, because actual market participants are common people with common human foibles, habits and other peculiarities. This is why, they are not always reliable, sometimes they are forgetful, often prone to emotions, illnesses, other random factors and unforeseen circumstances. As a result, for the actual links of the commodities market shown in Fig. 5a,b, the process will be described not with linear differential equation with constant coefficients (9) and (14), but with linear differential equations with variable coefficients (or, in other words, with parametric differential equations)

$$T_V T_B H_V(t) \frac{d^2 M_B(t)}{dt^2} + H_B(t) M_B(t) = 0 \quad (19)$$

$$T_V T_B H_V(t) \frac{d^2 M_B(t)}{dt^2} + (\alpha + \beta) T_B H_{B+TS}(t) \frac{dM_B(t)}{dt} + H_B(t) M_B(t) = 0 \quad (20)$$

where $H_V(t)$ is the human factor taking into account the behaviour of the vendor,

$H_{B+TS}(t)$ is the human factor taking into account the behaviour of the bank and the tax administration;

$H_B(t)$ is the human factor taking into account the behaviour of the buyer.

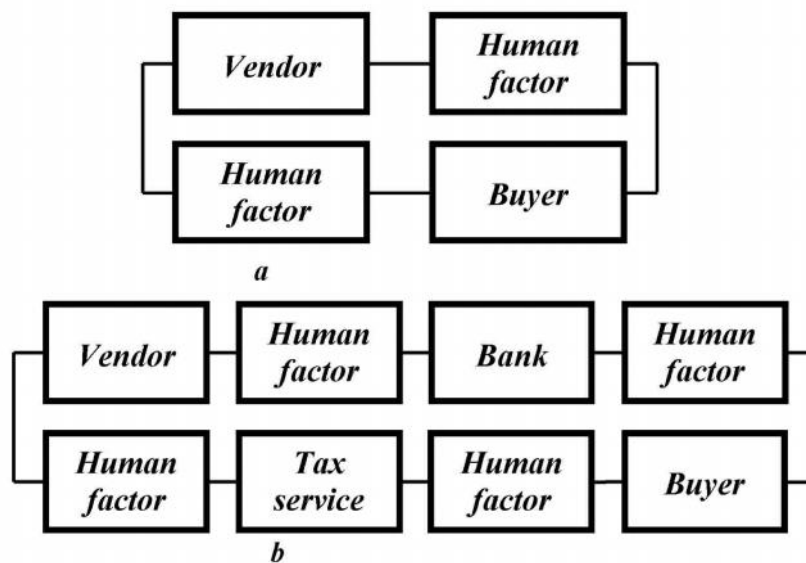


Fig. 5. Actual functional schemes of the simplest oscillation links in the economy

Since in the parametric differential equations (19) and (20) the coefficients $H_V(t)$, $H_B(t)$ and $H_{B+TS}(t)$ are different random functions of time, their solutions are also random functions of time. They cannot be found analytically.

Processes in the real capitalist economy generally comprise many similar unpredictable processes in simple economic links. Therefore, the global economy depends on the rapidly varying human factors $H_V(t)$, $H_B(t)$ and $H_{B+TS}(t)$ to a much greater extent than on the slowly varying production factors $L(t)$ and $K(t)$ mentioned above. Due to this fact, it is basically unpredictable and uncontrollable.

There is other evidence of the significant influence of the human factor on the economy. Thus, the social choice theory suggested by Arrow [23] argues that conciliation of social interests is provided for only by dictatorial regulations. Basically the same conclusion was made by Gibbard [24] after investigating other aspects of choice mechanism given the very general assumptions. In fact, this is just the statement of the conclusion made herein, worded using different terms.

Therefore, the conclusion that the Great Depression phenomena is accounted for by the human factor is quite justified.

The foregoing also fully explains the fact that the Soviet Union never suffered from economic crises. The matter is that the plan-based Soviet economy provided for the fulfilment of conditions minimizing the influence of the human factor $\lim H_V(t) \rightarrow \text{const}$, $\lim H_B(t) \rightarrow \text{const}$ and $\lim H_{B+TS}(t) \rightarrow \text{const}$, i.e., the functions $H_V(t)$, $H_B(t)$ and $H_{B+TS}(t)$ were almost constant. This is why parametric differential equations (19) and (20) in the Soviet economy were transformed into linear differential equations with constant coefficients, which made economic processes fully controllable.

5 NEW CRISIS-PROOF ECONOMIC TOOLS

Thus, *in order to avoid economic crises in the capitalist economy, the influence of the human factor in it must be minimized*, i.e., fulfilment of the conditions $\lim H_V(t) \rightarrow \text{const}$, $\lim H_B(t) \rightarrow \text{const}$ and $\lim H_{B+TS}(t) \rightarrow \text{const}$ must be provided for. However, this has to be done in a different way than in the Soviet Union.

To find out how this can be achieved, let us specify that the human factor may be internal and external.

The internal human factor is understood as a spontaneous unpredictability of behaviour of market participants due to their unreliability, illnesses, forgetfulness, imperfections of contracts or verbal arrangements regulating their activities, rumours, panic, and other similar reasons.

The external human factor is understood as the unpredictable behaviour of market participants determined by random external influence upon them by other persons and companies – competitors, public officials, criminal structures and other similar reasons.

Therefore, it is obvious that, in order to minimize the influence of the human factor in the market capitalist economy, some new economic tools [25] are necessary, because the existing economic tools have not been able to offset it. These tools must be different for the internal and the external human factors.

5.1 MINIMIZING THE INFLUENCE OF THE INTERNAL HUMAN FACTOR

Let us refer to the new economic tool aimed at minimizing the influence of the internal human factor as the business-interface [20], by analogy with a similar term used in computer engineering. Let us recall that an interface in computer engineering is understood as a hardware and software means of connecting various nodes and devices. It is clear that if, for instance, plugs and sockets of these devices are different, or even if the plugs are correct, but mismatching signals are fed to the matching pin of the plug and the socket, the computer will not operate. This is why all interfaces in computer engineering are strictly defined.

This is why we shall refer to business-interfaces as the payment (commodity-money) means of connecting market process participants, as a result of which, the vendor must supply the buyer exactly the goods ordered by the buyer, and get exactly the payment specified in the price-list. However, this is not enough. In order to avoid the destructive economic consequences caused by the human factor (remember the Great Depression), every detail of the business-interfaces must be defined; this will enable implementing oscillation processes in economic links. Thus, the corresponding contracts must contain all the details providing for:

- linearization of the economic process, which must be described with a linear differential equation with constant coefficients; to this end, all non-linear and parametric elements (or factors) must be respectively removed from the economic system;
- temporal variation of the circulating assets flow as close to the sine law as possible (it can be easily implemented using computers);
- strict and close adherence to contractual obligations by both the vendors and the buyers; breach of these obligations must inflict penalties as severe as those practiced in socialist countries for violation of labour discipline.

Thus, the primary function of the business-interfaces is to support and regulate the circulating assets flows. This is why an important part in their implementation will be played by banks, whose activity will also change the economic outlook of their clients. Moreover, certain amendments and clarifications will have to be made in the national and international legislation.

All vendors and all buyers inevitably have numerous business relationships with other vendors and buyers; for this reason, any actual economic system is multi-link and multi-related. This is why, it will be necessary to optimize the structure and parameters of these economic systems. In particular, an international system of operating frequencies must be

developed, tied to the natural cycles of agricultural works, forestry engineering, construction works, transportation, and other seasonal businesses. Similarly, computer engineering uses clock frequencies; television uses clock rates, etc.

Some particular examples of the business-interfaces for oscillation economic processes are discussed in [15], [16]. However, at least several hundred business-interfaces taking into account different particular cases relevant to business partners can be suggested. Therefore, it is advisable to publish a corresponding reference book, and introduce a special course of lectures teaching business-interfaces in economic schools.

Implementation of business-interfaces may bring up the question of whether their use can lead to the same grave consequences as the plan-based socialist economy due to the excessive regulation of economic activity, in particular, to the suppression of rights and freedoms. The answer is – no, it cannot, because business-interfaces will operate only for the term of a transaction, i.e., from the moment it is made to the moment it is settled, and only to the extent of the transaction, for the business partners indicated in the transaction. The latter, indeed, will have no freedom of disregarding the terms of the transaction; they will be committed to settle it. If you wish, after making a transaction, business partners will find themselves, to a certain extent, in socialism.

Similarly, nature, providing for the variety of lifestyles of various creatures, left them no choice of neglecting their duties of reproduction.

However, other people, as well as business partners beyond the extent of their transaction, will fully remain in capitalism. They will be completely free to choose what to buy or not to buy, to produce or not to produce, to hire and to fire; they will choose their occupation and place of residence, vote freely, and exercise their civil liberties and so on.

Therefore, the economy reformed as suggested above will be both capitalist and socialist: for the term of contractual obligations and to the extent of their settlement by the partners it will be socialist, and in all other respects for them and for all other people it will be capitalist. This economy will become ultimately fair and, thus, will ease social tension.

5.2 MINIMIZING THE INFLUENCE OF THE EXTERNAL HUMAN FACTOR

In order to minimize the influence of the external human factor, another economic tool is suggested, namely, the new global/regional information network TV•net [26], [27], which is free from all the shortcomings of the Internet. This information network will enable businesspeople to find business partners and make profitable transactions without having to resort to the unwanted third parties. Thus, businesspeople will have guaranteed confidentiality of their business connections, and will be able to avoid the unwanted influence of any third parties.

However, the only currently available global information network, the Internet, is hardly suitable for business purposes due to its numerous shortcomings. Indeed:

- it does not provide for guaranteed information security, i.e., protection from computer viruses, spyware, hackers, spam and other network threats;
- the www contains few if any promptly updated reliable serious information necessary for business and other intellectual activities, and, on the contrary, contains a lot of junk information;
- information retrieval time (not to be confused with information transmission time) is quite long, i.e., all search engines work not efficiently enough;
- copyright and proprietary rights (by hackers) are often infringed.

Due to the above, the Internet is often used, in fact, to resist (how else can we refer to the infringement of copyright and proprietary rights?) the fair capitalist business.

The TV•net, on the contrary, due to absence of packet-switched communication and use of one-way broadband (television or fibre-optic) communication lines:

- completely solves the problem of guaranteed information security, because it does not have the feedback communication lines used in the Internet for unauthorized access to information in the users' PCs;
- provides for zero information retrieval time, as information is broadcast to the users immediately as it is received and verified, and then stored in their personal data bases;
- provides for efficient noise reduction and protection from unauthorized access to communication lines due to noise-combating codes and cryptographic encoding;
- greatly enhances its functional capabilities due to the use of numerous new highly demanded services:

- the trading service which allows creating a global online-store;
- the exchange service which allows creating a global universal e-exchange;
- the administrative service which provides for efficient management of any institutions – ministries, banks, institutes, corporations, etc.;
- the educational service which offers mass education at the top level [28];
- the analytical service which allows implementing human-computer super-intelligence [8], [29], [30] – an alternative to the artificial intelligence whose development has faced a dead end; and so on.

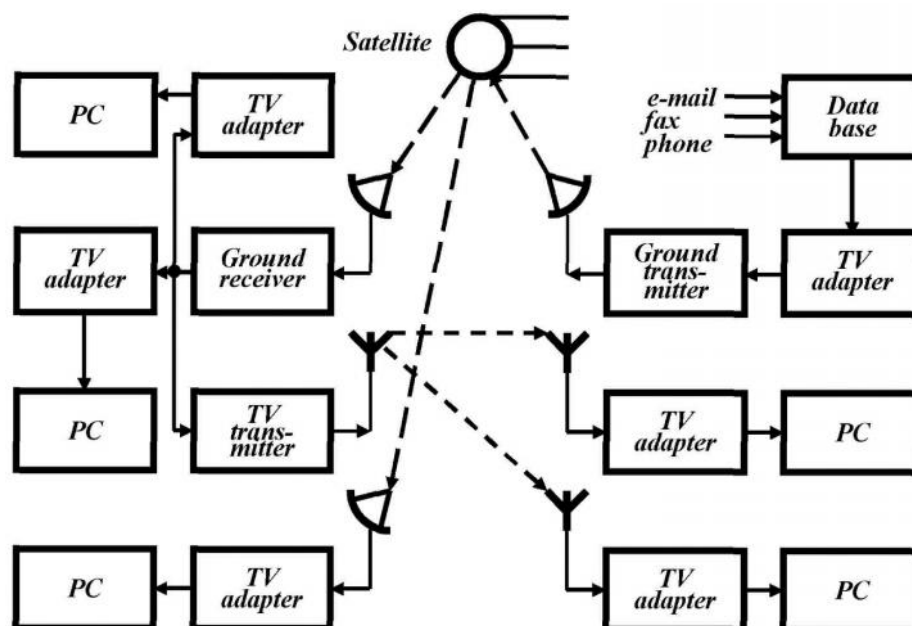


Fig. 6. An example of the simplest implementation of the TV•net information network without feedback lines

Let us briefly describe the new services offered by the TV•net information network.

The trading service of the TV•net information network is the most easy and low-cost to implement, because its deployment requires mostly organizational support. As can be seen (see Fig. 6), almost everything necessary for its implementation is already available in the market. Therefore, it can be quickly deployed in any region with a TV broadcasting network, both on-air and cable, and even away from cities, if satellite broadcasting channels are used. To deploy a small local network (e.g., for one particular city), there is no need to use satellite repeaters. For a comparatively large regional or global TV•net network, satellite repeaters are necessary. However, those used for TV broadcasting can be employed, just as well.

Nowadays, the TV broadcasting network, in particular, satellite network, is so well developed and available at any place on Earth, that the main expense item for the deployment of the TV•net network is no longer required. Owners of the TV•net network do not have to launch their own satellites, because almost every satellite repeater has back-up facilities and communication lines not used to their full capacity at night. Computer information can be broadcast via the TV•net network at any time, as it will be received by the users' PCs 24 hours a day, and will be stored until it is required.

The trading service operates as follows. The users-buyers, for a certain subscription fee, connect to the TV•net information network via TV adapters, similar to modems used to connect to the Internet. The procedure is identical to subscribing to the pay-tv network. The only difference is that instead of the TV channels, the users choose the headings from the classifier. At that, the users PCs may be connected to the TV•net network either via cable TV lines, or via on-air or satellite TV, at their discretion.

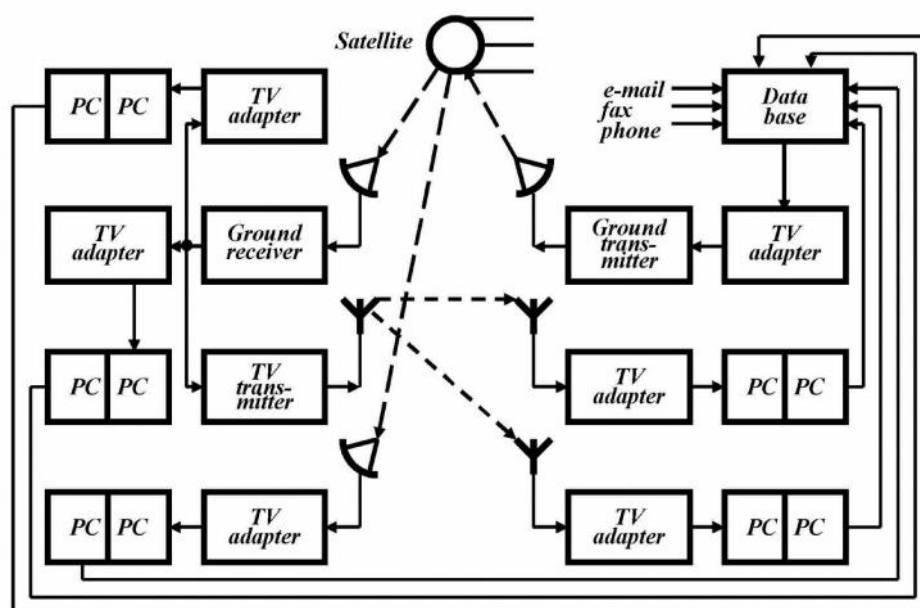


Fig. 7. An example of the simplest implementation of the TV•net information network with feedback lines

The subscribers-vendors are also connected to the TV•net for subscription fee, and regularly transmit (via any communication lines, including e-mail over the Internet) to the data base the most detailed information about the goods and services they offer. Similarly, offers of other forms of business partnership, including trade enquiries, can be submitted to the data base. In the data base, the information received is classified by the administration personnel and regularly broadcast via a TV adapter, where it is encoded and sent to a TV transmitter in the respective region (this link is not shown in Fig. 6 for simplicity). Then, via a television broadcasting network, it is transmitted to the users' PCs, and broadcast to users of other regions via satellite repeaters (Ground transmitter, Satellite, Ground receiver). The users can make their choices and purchases they need based on the corresponding criteria with the help of their PCs, either manually or using simple software.

In addition, guaranteed information security is provided for the users, since they are not connected to the Internet, and connected to the TV•net via one-way television broadcasting lines. Similarly, a TV viewer is not afraid that any information about him can be sent to the TV centre. If the users need to send any information via the Internet (e.g., order the delivery of the purchased goods), they will have to use a different PC (see Fig. 7). However, in this case, the protected PC connected to the TV•net, and the unprotected PC connected to the Internet must not have any communication between each other (except for removable disks and USB-cards).

Thus, services of the TV•net information network will be paid for by both the buyers and the vendors. Operating such a TV•net network will be quite a profitable business, may be, even more profitable, than TV advertisement.

It is easy to see that the suggested trading service, in terms of its purpose, is very similar to online-stores, and seems to be needless. However, the difference is in the amount of services offered: online-stores belong to small and medium business, and the trading service of the TV•net information network is large business and can result in the creation of a global 24/7 online-store. Therefore, as any large business, it allows generating higher profits. Consumer confidence to large business will also be higher.

The exchange service is almost identical to the trading service, with one exception: goods and services are traded not at fixed prices, but at auction prices and by the rules. Therefore, implementation of this service requires the TV•net information network to be deployed with feedback connection (Fig. 7).

Depending on the type and volume of bids, e-exchanges operating within the TV•net can certainly be both regional and global, commodity and stock, FX and others.

Naturally, the larger region the service covers, the more profit it can generate for its owners, similarly to the trading service.

The administrative service provides for guaranteed secure informational services for banks, public offices, corporations and any other large, medium and small market participants which currently are suffering from hacker attacks through the Internet, and are also vulnerable to other network threats. Therefore, the benefits of the administrative service are obvious.

A peculiarity of implementation of the TV•net information network in terms of the administrative service is tougher requirements to information security, which can be fully met due to additional use of cryptographic encoding and protected local area networks both at the input and at the output. The simplest example of implementation of such a TV•net network is given in Fig. 8.

Furthermore, in order for the top-managers of these institutions to make reasoned and highly efficient decisions, it is necessary:

- to quickly upload all available up-to-date information on any problem requiring a solution into the memory of their PCs; we shall thus refer to it as the personal memory;
- to quickly and correctly evaluate the information available in the personal memory in order to reveal the dominating trends in their respective field, which will enable them to make definitely successful decisions.

This task is addressed by another service – the analytical one.

The analytical service, thus, can help its users in revealing trends and regularities. However, within the context of conventional concepts, nothing else can be suggested to solve the problem but the interpolation and extrapolation algorithms; although, this is also quite useful.

Therefore, let us formulate the task in a different way – the analytical service, along with its other functions, is aimed at the development of the human-computer super-intelligence, as an alternative to the artificial intelligence. Since there is no conventional definition of intelligence – either human or computer – let us specify that hereinafter human intelligence is understood [8], [29], [30] as a set of intellectual sub-systems which includes the low-factor rational thinking, the multi-factor unconscious thinking and some other sub-systems. The most important one in the set is the sub-system of the multi-factor unconscious thinking. The term is used because many people at present do not even suspect it exists. This is confirmed by the fact that people still do not know why they go to sleep, because they believe that in sleep they are uselessly idle and, moreover, are more defenceless. However, nature is wiser than people and does not do anything useless. Therefore, it turns out that nature makes us go to sleep (when all human input and output senses, as well as the low-factor rational thinking governing human activities, are off) in order for us to use all our intellectual resources to process information accumulated in the wakeful state. This is why there is a proverb: “Take counsel with your pillow”, or “If you have a problem – sleep on it”. This is why, when you are sick, in the morning your temperature is lower than at night. This is why many scientific discoveries were made in sleep. And only for this reason humans have survived as a biological species.

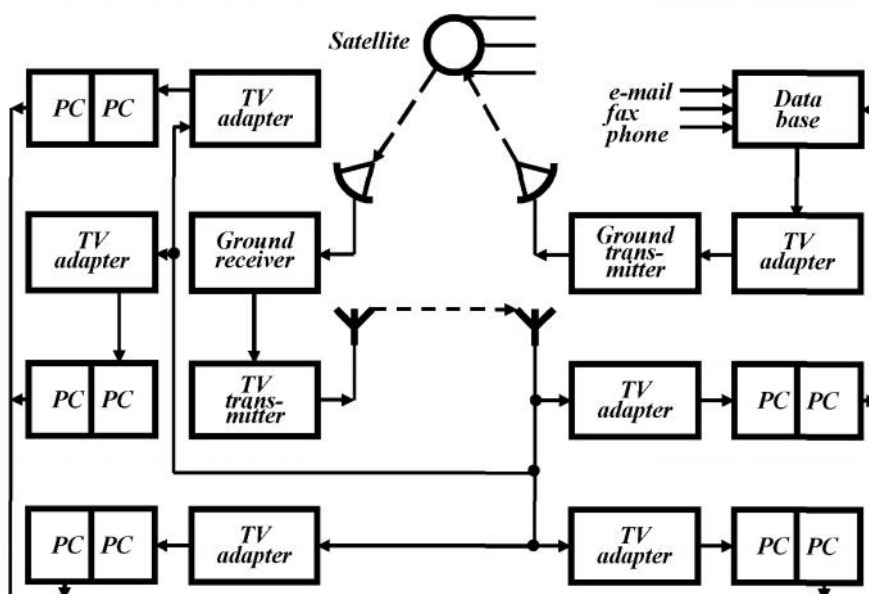


Fig. 8. An example of the simplest implementation of the TV•net information network using LANs

As for low-factor rational thinking, people need it for active day-to-day activities necessary for life support – getting food, doing work, and so on. It is referred to as low-factor for the reason that humans think with visual images (therefore people have dreams in the form of visual images and not in any other form) which are not more than three-dimensional. To make sure it is really so, try to imagine the simplest four-dimensional object – a hypercube. Processes in the real life, however, may depend on tens and hundreds, and even more factors (e.g., the economy, illnesses, weather, etc.).

Consequently, we can say that the rational low-factor thinking solves tactical tasks, and the unconscious multi-factor thinking performs strategic tasks.

Computer intelligence, usually referred to as the artificial intelligence, tries to simulate human low-factor thinking. Moreover, the artificial intelligence is often intended to meet the ambitious goal of surpassing human intelligence, i.e., to teach a computer to solve intellectual tasks without a human and instead of a human. However, this is a utopia. After 60 years of research devoted to the problem of artificial intelligence, scientists have not been able to teach a computer to tell, for instance, a dog from a cat.

Nevertheless, some scientist have developed the technological singularity concept [31], which reads that no later than 2030, following the successful solution of the artificial intelligence problem, an Internet-based computer civilization will emerge. It is not specified what this computer civilization will make of the human civilization; however, it is assumed that the process of development of the computer civilization is impossible to stop, because the countries which will try to hamper the process will be condemned to economic, military and technical underdevelopment, with all the respective consequences.

In fact, all these allegations are deceptive. Since humans possess the multi-factor thinking, and computers do not have it, humans will remain unattainably more advanced information machines than computers in the foreseeable future. The delusion about the superiority of computer intelligence seems to stem from the fact that computers are able to successfully solve complicated mathematical problems which cannot be solved by people either mentally or on paper. Many people believe that solving mathematical problems is an extremely intellectual activity. However, we should not forget that computers, contrary to humans, can solve only the tasks which are unambiguous and clear. Try to define clearly, for instance, how to tell a dog from a cat. Computers are unable to solve other, more ambiguous problems, which are prevailing in the real life. People, on the contrary, successfully solve them all the time. Therefore, computers are merely big and complicated calculators. Their intelligence is exactly at this level.

Donald Michie, Head of the Alan Turing Institute, wrote on the issue [32] that the current development of computer engineering makes it impossible even to try to approach the problem of artificial intelligence.

Many years later basically the same idea was expressed by V. M. Kuklin, Professor at Kharkov University [33]. He wrote that when solving the problem of artificial intelligence, scientists are unable to reproduce the attainments of nature even to the slightest degree.

Thus, the problem of artificial intelligence must be understood as it was formulated from the very beginning – as a research aiming at the investigation of human intelligence with the help of computer experiments. No more than that.

At present, given the phenomenal achievements of engineers and scientists in terms of computer advancement, it is time to define a new problem – the problem of human super-intelligence, which is understood herein as the development of human-computer systems able to solve multi-factor tasks. The matter is that human intelligence created by nature was not designed to use the multi-factor unconscious thinking to solve scientific and other intellectually demanding problems – centuries ago, people were busy with other things. If eventually people turned out to be able to solve intellectually demanding problems, this testifies only to the possibility of further substantial development of human intelligence, both by means of intellectual training (which is actually done by scientists) and by means of additional involvement of computer resources (which is suggested herein).

We will consider both possibilities, however, in the reverse order. We will first discuss the controllable and regular, contrary to the process of intellectual inspiration, use of the unconscious multi-factor human thinking in the wakeful state. What do scientists do when they are solving an intellectually demanding problem, i.e., when they are revealing a trend or discovering a regularity? They solve two problems in turn. First, they take all the imaginable multitude of factors and define the significant ones, which, if changed, noticeably influence the result under investigation. Then, having chosen the most significant of all the factors, they search for a mathematical relationship between them and the result under investigation. Finally, the result is taken down as a scientific law.

As can be seen, computer assistance in this research can be very helpful. Before commencing the research, a user needs, first of all, to create in their PC a personal data base by quickly downloading from the information network all the reliable information relevant to the subject of the research. However, this is completely impossible given the current information

retrieval techniques in the WWW. On the other hand, this task can be quickly and easily performed by the TV•net information network in its realization shown in Fig. 6, except that the data base must contain the information necessary for top-managers, scientists, businesspeople, analysts of special services and other intellectual users.

Then, the corresponding software (e.g., factor analysis, or, in the simplest case, by key words) allows finding in all the ocean of information the pieces which presumably contain the significant factors. Next, these pieces of information must be studied and processed by human, in particular, multi-factor, thinking. Naturally, at this last stage of research, different software for enhancing the multi-factor intelligence can be helpful, similar to the existing software enhancing the low-factor rational intelligence.

Certainly, these tasks can be performed by supercomputers, as well. However, there are very few of them, they are very expensive and completely engaged in solving the most foreground problems. At the same time, these problems can be solved by personal computers, too, especially taking into account that important discoveries have often been unforeseen, spontaneous, and made by individual scientists. Here belong, for instance, discoveries of radioactivity, the DNA structure, the Internet, semiconductors and many other things. Let me at once answer those willing to object regarding the circumstances under which the semiconductor devices were discovered. I agree that after the World War II huge financing was allocated to the investigation of radio-electronic systems and components. In 1973 Leo Esaki, Ivar Giaever and Brian David Josephson won the Nobel Prize for discovering the tunnel diode. However, in fact, the first tunnel diode was made by physicist O.V. Losev back in 1922 [34]. It was even widely used at that time. However, no one was able to explain how it worked. Back then, even the term “semiconductor devices” did not exist.

This is why it is extremely important for the systems of human-computer super-intelligence to be accessible to all users, including talented individuals in their unplanned and ungoverned entrepreneurial, scientific and other intellectually demanding activities. Just as we need both small and large business, scientific research must also be performed not only by large groups of scientists, but by individual scientists, as well.

The educational service, in addition, is immediately relevant to the development of human super-intelligence, firstly, for the reason that creative thinking is developed in the course of education, and secondly, because creative people often have to get additional training or to be retrained.

The objectives of education can, certainly, be different – getting knowledge, mastering skills, intellectual or physical development, and so on. Therefore, taking into account that intellectual work is getting more and more demanding nowadays – even to stay rich, you must make certain intellectual efforts, otherwise you will turn poor – the major objective of education must, obviously, be the intellectual development of people.

The educational service which solves this problem operates as follows. Using the computer-television broadcasting network – the TV•net (see Fig. 6), its users, independently or via their educational institutions, receive and download to their PCs:

- textbooks and work-books supplied with a large number of hyperlinks to other sections of textbooks (other textbooks, as well) and FAQ sections;
- supplementary further reading;
- problem books with detailed solutions of typical problems and advanced problems;
- learning and developing, learn-as-you-play and other software.

As is well-known, the quality of education depends on how well individual peculiarities of students are taken into account. The point is that all people have a different body of mastered knowledge (due to individual differences in abilities, background, thinking, etc.). Thus, new knowledge is learned well only in the case it is based on the previously mastered knowledge. The art of teaching lies in the ability to take into account all these circumstances as much as possible. Naturally, the principle of learning based on the previously mastered knowledge is never fully observed in the process of collective education, because all people have different basic, well mastered, knowledge. It is poorly realized in self-education (there is no one to ask a question). At present it is best of all implemented in the process of individual education with a tutor.

However, the educational service of the TV•net allows implementing it even better, because a personal computer whose memory contains the information specified above can always help find the additional material explaining any unclear issues (basically what a tutor does). Therefore, education using the service under consideration in terms of its efficiency will be comparable to elite training on a one-to-one basis. This education will be most developing and aimed at further use of the human super-intelligence systems.

Thus, the service described above suggests new technical means aimed at the new strategy of education in order to improve the quality of education. The new strategy can be referred to as the developing learning, because, contrary to the

current teaching techniques, its objective is not merely to acquire knowledge, but to promote the skills allowing for the most efficient creative application of this knowledge in further practical activity. Therefore, developing learning means promotion of skills aimed at using the information obtained, as well as searching for the necessary information.

Developing learning will require new textbooks and workbooks. The currently available textbooks are not suitable for the purpose, because the material is often presented in an excessively dogmatic way in the form of, allegedly, absolutely true knowledge. However, developing learning requires textbooks which, first of all, teach to think. Therefore, they must not only present the knowledge, but explain the often difficult way this knowledge was obtained. Sometimes it is useful to analyse certain hypotheses rejected by science at present. It is necessary to explain that science has few absolute truths.

People who want to become super-intellectuals must not be deceived even in primary school, to say nothing about universities. They ought to know that groping for knowledge is an extremely hard work. Therefore, they must get used to not getting the ready-made knowledge, but to obtaining the knowledge themselves. In this respect, the learning process must resemble the process of a scientific research, except that at the very beginning it will take place under the supervision and with the help of teachers, then – academic advisors, and finally – independently.

People completing such a course will be prepared to the super-intellectual activity described above to the best advantage.

6 SUMMARY

Thus, it turns out that ‘the invisible hand’ of Adam Smith in economics is the human factor. It is its influence on the economy that makes processes in it be described with systems of parametric differential equations with coefficients in the form of random functions of time. For this reason, the current economy is unpredictable and cannot be efficiently managed, and economic crises in it are inevitable. In particular it is the human factor that accounts for the Great Depression phenomena in the US.

To be able to manage market economy, to make it crisis-proof, the influence of the human factor has to be minimized. To this end, new economic tools must be used. In order to minimize the influence of the external human factor, business-interfaces should be used. In order to minimize the influence of the internal human factor, it is advisable to use the new global information network TV•net, which is completely free from all the shortcomings of the Internet and offers numerous new business- and intellectually oriented services.

The economy reformed this way will be described mostly with systems of linear differential equations, i.e., it will have a mathematical description similar to the mathematical description of radio-electronic systems and processes. Therefore, this economy will become an exact science. It will be possible to use the methods borrowed from the theory of analysis and synthesis of linear electric circuits, from the simulation theory, from the automatic control theory and others. The reformed economy will allow widely using new, previously unknown oscillation processes which provide for significantly more efficient use of circulating assets.

Last, but not least – the economy reformed as discussed above will become crisis-proof and therefore rapidly developing.

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La stratégie d'assouplissement quantitatif des banques centrales face à la crise: Cas de la BCE et la FED

[The quantitative easing strategy of the central banks facing the crisis: Case of the ECB (European Central Bank) and the FED (Federal Reserve System)]

Widad Choukairy¹ et Nafii IBENRISSOUL²

¹Doctorante en sciences économiques,
Université Pierre Mendès,
Grenoble, France

²Enseignant chercheur, Ecole Nationale de Commerce et de Gestion ENCG,
Université Hassan II Mohamedia,
Casablanca, Maroc

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ABSTRACT: The crisis has thrown the disorder on the effectiveness of the monetary policies. Indeed, the intensity of the financial crisis and the downward pressure it exerted on price stability has prompted many central banks to fix their interest rate at levels "historically" low. In September, the Federal Reserve conducts a decline in its rate to reach in December 2008, a floor close to zero, The Central Bank, for its part, has begun the process of falling interest rates in October 2008; which is continued until reaching a rate of 0.75% in July 2012. In a crisis, the fixation of the interest rate by the Central bank which is close to the 0% it is essential in order to stimulate economic activity, but, once the floor is reached, the risk of "liquidity trap" occurs, this leads monetary authorities to rethink their monetary policy and resort to others means of action other than further decline in interest rates. The purpose of this communication is to know whether the adoption by the central banks (European Central Bank and Federal Reserve case) of unconventional monetary policies, especially the policy of quantitative easing, has it enabled expansion of loans to households and finance companies, and therefore, contributed to an economic growth?

KEYWORDS: Financial crisis, quantitative easing, liquidity trap.

RESUME: La crise a jeté le trouble sur l'efficacité des politiques monétaires. En effet, l'intensité de la crise financière et la pression à la baisse qu'elle a exercée sur la stabilité des prix a incité bon nombre de banques centrales à fixer leur taux directeur à des niveaux « historiquement » bas. En septembre 2008, la FED procède à une baisse de son taux directeur pour atteindre en décembre 2008, un plancher proche de zéro, la BCE, quant à elle, a entamé son processus de baisse de taux directeurs en octobre 2008, lequel s'est poursuivi jusqu'à atteindre un taux de 0.75% en juillet 2012. Dans un contexte de crise, la fixation par la banque centrale d'un taux d'intérêt qui soit au voisinage du 0% lui est incontournable afin de pouvoir relancer l'activité économique, mais une fois ce taux plancher est atteint, le risque de « trappe à liquidité » intervient, ceci conduit les autorités monétaires à repenser leur politique monétaire et à recourir à d'autres moyens d'actions autres qu'une baisse supplémentaire du taux d'intérêt. L'objectif de cet article est de savoir si l'adoption par les banques centrales (Cas de la BCE et la FED) des politiques monétaires non conventionnelles, et plus particulièrement la stratégie d'assouplissement quantitatif a-t-elle permis une expansion de crédits accordés aux ménages et aux sociétés de financement, et en conséquence, a contribué à la croissance économique?

MOTS-CLEFS: Crise financière, Assouplissement quantitatif, Quantitative Easing, trappe à liquidité.

INTRODUCTION

Les turbulences bancaires et financières découlant de la crise financière qui a surgit le monde en 2007, ont nécessité une intervention « minutieuse » de la part des banques centrales des pays avancées, les contraignant ainsi à revoir leurs stratégies de politiques monétaires. En effet, la crise de confiance interbancaire, le manque de liquidité, le risque d'insolvabilité, sont tant d'éléments qui ont rendu l'action des banques centrales extrêmement difficile. Cette difficulté est liée d'une part, à l'incertitude quant au déroulement de la situation et d'autre part à l'impact que puisse avoir les décisions prises par les banques centrales sur le fonctionnement du système financier.

Suite à la faillite de la banque d'investissement *Lehman Brothers* le 15 septembre 2008, et en réponse à la crise de confiance et à la réticence des banques à se prêter entre elles. Les banques centrales (BC), la Réserve fédérale américaine (FED) et la Banque Centrale Européenne (BCE) entre autres, ont procédé à une réduction de leur taux directeurs, lesquels ont atteint des niveaux historiquement bas. Ce faisant, elles ont doté les banques commerciales et partant, le système bancaire de toute la liquidité dont ils avaient besoin.

Néanmoins, arrivant à un certain seuil (0,75%¹ pour la BCE, et proche de 0%² pour la FED), le processus de réduction du taux directeur ne peut plus se poursuivre, pour la simple raison que la fixation d'un taux directeur en dessous de zéro est inopérante et est techniquement impossible. C'est ainsi que le recours à d'autres moyens d'actions s'est imposé.

Cela étant, afin d'échapper à la borne inférieure zéro, et de fait, au problème de trappe à liquidité, les BC ont mis en œuvre un certain nombre de mesures non conventionnelles placées sous le nom de « stratégie d'assouplissement quantitatif », à travers lesquelles la BC joue le rôle d'une banque de refinancement.

En effet, l'assouplissement quantitatif est une stratégie non conventionnelle qui consiste à assouplir les conditions de crédit faites aux banques commerciales, il peut s'agir d'augmenter le montant des refinancements consentis aux banques, d'accroître leur durée, d'accepter en collatéral une gamme très large d'actif (BCE) comme il peut s'agir de l'acquisition des titres comme c'est le cas de la FED. L'objectif final est d'éviter un rationnement du financement bancaire, et de ce fait, éviter la récession et la déflation susceptible d'en découler.

Certes, l'adoption d'une telle stratégie a contribué au retour de la confiance sur les marchés interbancaires, néanmoins, ses retombées sur la consommation, la demande et partant, la croissance restent ambiguës.

Le présent article s'interroge sur l'efficacité de la stratégie d'assouplissement quantitatif. La première section présente la synthèse de l'ensemble des travaux théoriques qui se sont intéressés à cette stratégie, en présentant ses origines ainsi que ses techniques telles qu'elles sont adoptées par la BCE et la FED. La deuxième section essaie d'évaluer l'efficacité de cette stratégie non conventionnelle en examinant son impact sur la stabilité financière, sur la distribution des crédits ainsi que sur l'activité économique et ce, aussi bien pour les Etats-Unis que pour la Zone Euro.

1 PRESENTATION DE LA STRATEGIE D'ASSOUPLEMENT QUANTITATIF : REVUE DE LITTERATURE

1.1 AUX ORIGINES DU RECOURS A LA STRATEGIE D'ASSOUPLEMENT QUANTITATIF

Dans un contexte de crise et où les banques centrales se retrouvent dans l'incapacité d'user de leur instrument usuel qu'est le taux d'intérêt directeur. Le recours à des mesures dites « non conventionnelles » de politique monétaire peut s'avérer une solution incontournable. Ces instruments ne peuvent être définis que d'une manière négative au sens où il s'agit des mesures ne faisant pas partie de la conduite habituelle de la politique monétaire (Drumetz et Pfister, 2010).

En effet, le recours à des politiques non conventionnelles ne peut aucunement s'effectuer en temps normal. Selon Drumetz et Pfister (2010), les politiques monétaires non conventionnelles peuvent être adoptées au moment où les canaux habituels de transmission³ de la politique monétaire deviennent défectueux à l'issue du mauvais fonctionnement des marchés financiers et/ou au moment où la conduite d'une politique monétaire expansionniste devient incapable de stimuler l'activité à cause du niveau plancher du taux d'intérêt nominal.

¹ Bulletin mensuel de la BCE (Juillet 2012).

² Leboucher S. (2011), « Les banques centrales en dehors des sentiers battus », *Revue Banque*, n°740, octobre.

³ On en distingue trois canaux : le canal du taux d'intérêt ; le canal du taux de change ; et le canal des prix des actifs.

Si une économie se retrouve dans l'une des deux situations précitées, elle pourrait dans ce cas concevoir des politiques monétaires non conventionnelles, ces dernières peuvent être de deux sortes :

- Une action se traduisant par un accroissement de la taille du bilan de la banque centrale et plus précisément du montant des dépôts des banques commerciales auprès d'elle. Les politiques découlant de cette action sont appelées des « politiques non conventionnelles de quantité » ;
- Une action prenant la forme d'un engagement de la banque centrale quant à la conduite des taux d'intérêt. Les politiques relevant de cette action sont dites politique non conventionnelle de prix.

De notre part, on va s'intéresser aux politiques monétaires non conventionnelles de quantité⁴ et plus particulièrement, à l'assouplissement quantitatif. Il s'agit en effet d'une mesure non conventionnelle qui se traduit par un accroissement important du niveau des réserves bancaires en vue de stimuler la demande des banques en faveur d'actifs plus productifs au travers des effets de composition de portefeuille.

Mise en œuvre pour la première fois au Japon entre 2001 et 2006, la stratégie d'assouplissement quantitatif est selon Bernanke (2009a), une stratégie qui consiste, dans sa forme pure, à accroître le niveau de réserves des banques commerciales, et partant, le niveau de la liquidité bancaire. La conception de cette stratégie a pour objectif de rassurer les banques de la survenue d'une éventuelle crise de liquidité. Quoi que sa mise en place soit récente, la stratégie d'assouplissement quantitatif fait l'objet d'un réel débat théorique entre économistes et chercheurs. Un débat portant aussi bien sur son efficacité que sur les canaux de transmission par laquelle elle va se transmettre au reste de l'économie.

Krugman (2000) suggère qu'un accroissement de l'offre de monnaie et donc la mise en œuvre d'une stratégie telle que la stratégie d'assouplissement quantitatif ne peut avoir d'effet que si elle est accompagnée d'un engagement crédible de la banque centrale, affirmant au public que le stimulus de liquidité sera maintenu tant que les conditions de l'engagement ne seront pas remplies.

Eggertsson et Woodford (2003) quant à eux, considèrent que l'unique moyen pour sortir d'une situation de trappe à liquidité est de contrôler les anticipations formulées par les agents privés, ce faisant, ils excluent tout effet d'un accroissement de la masse monétaire ou d'un changement de la composition du bilan⁵ de la banque centrale. Ils expliquent cela par l'hypothèse de parfaite substituabilité entre la monnaie et les actifs non monétaires quand les taux d'intérêt s'approchent de la borne inférieure zéro.

Selon Koo (2008), toute politique monétaire expansive qui vise à améliorer l'aptitude des banques commerciales à octroyer des crédits est vouée à l'échec et ce, en raison de l'absence de feed-back de la part des emprunteurs. Plus simplement dit, un agent privé qui a des dettes dépassant le montant de ses actifs, est alors un acteur qui ne cherche plus à maximiser son profit, mais plutôt à régulariser sa situation financière en minimisant sa dette. Il refuse ainsi de s'octroyer de nouveaux crédits ou d'émettre de nouvelles obligations et ce, en dépit de la faiblesse des taux d'intérêt.

Contrairement au paradigme néo-Wicksellien, qui suggère que la politique d'assouplissement quantitatif ne peut avoir d'effet direct et qu'elle ne peut agir que de façon indirecte à travers les anticipations, l'approche monétariste, quant à elle, éradique la survenue d'une trappe à liquidité et affirme que l'accroissement de la base monétaire, est apte à agir sur l'économie même si les taux d'intérêt sont proche de zéro. L'inflation est selon cette approche, un phénomène purement monétaire et donc tout choc monétaire se transmet à l'économie réelle en provoquant ainsi un ajustement du prix relatif des actifs réels et financiers et, partant, un ajustement des portefeuilles des agents.

On considère par ailleurs que s'il fonctionne, l'effet de l'assouplissement quantitatif passe par un certain nombre de canaux de transmission. Le premier est la prime de liquidité. En effet, Goodfriend (2000) mettent en avant le rôle de la prime de liquidité comme canal de transmission de l'assouplissement quantitatif à l'économie. Selon eux, du fait de l'imparfaite substituabilité entre la monnaie et les autres actifs (obligations et actions), et compte tenu de la différence qualitative entre ces actifs, un accroissement de la base monétaire incite les agents privés à réduire le niveau exigé de la prime de liquidité des actifs non liquides, diminuant ainsi leurs rendements. Ce mécanisme de transmission a l'aptitude de relancer l'activité économique non pas à travers une baisse des anticipations de taux courts futurs, comme le suggère l'approche néo-

⁴ Les politiques non conventionnelles regroupent aussi bien l'assouplissement quantitatif (*quantitative easing*) que l'assouplissement qualitatif (*credit easing*).

⁵ On fait référence à ce propos à la stratégie d'assouplissement qualitatif, laquelle implique un changement de la composition du bilan de la banque centrale.

Wicksellienne, mais par une baisse des taux d'intérêt de long terme. Selon Bernanke et al, (2004), l'assouplissement quantitatif se transmet à l'économie à travers un effet de signal. En fait, selon eux, la stratégie d'assouplissement quantitatif est un outil efficace pour assister la BC à crédibiliser son engagement et de fait, à maintenir son taux directeur à un niveau plancher pour une durée plus longue.

Metzler (1995)⁶, quant à lui évoque un autre canal de transmission qu'il appelle « effet de richesse ». Cet auteur suggère que malgré la contrainte due au taux d'intérêt zéro, l'accroissement de la base monétaire permet d'augmenter la consommation et ce via l'effet de richesse qui incite l'agent privé à faire des dépenses supplémentaires, stimulant ainsi l'activité.

1.2 L'ADOPTION DE L'ASSOUPLEMENT QUANTITATIF PAR LA BCE ET LA FED

• Les instruments utilisés par la BCE : Un arsenal plus renforcé

Le 8 octobre 2008, la BCE décide d'ouvrir les vannes de la liquidité. Les opérations principales de refinancement sont en effet menées à taux fixe et sont servis dans leur intégralité. La réticence des banques à se prêter entre elles et la détérioration du marché monétaire suite à l'intensification de la crise financière ont accentué la dépendance des banques commerciales à l'égard du refinancement de l'eurosystème. Une telle situation a incité voire contraint la BCE à intervenir pour doter les banques ayant un besoin de financement, de la liquidité suffisante au sens où le mécanisme habituel de distribution de la liquidité via le marché monétaire était fortement détérioré et réellement touché par la crise. Ce faisant, l'Eurosystème cherchait à éradiquer l'incertitude quant au montant de liquidité alloué à chaque banque.

Avant la crise financière, les banques pouvaient prévoir le niveau du taux marginal de l'opération principale de refinancement du fait de sa stabilité au fil du temps. Et donc, l'incertitude inhérente à l'adjudication et ses conséquences étaient plus ou moins limitées. Néanmoins, à partir de mi-septembre 2008, le taux marginal a dépassé les 40 points de base (pb) et le taux moyen des opérations principales de refinancement s'est situé à plus de 70 pb au-dessus du taux de soumission minimal. Un tel contexte a amené le conseil des gouverneurs de la BCE le 8 octobre 2008, à adopter une procédure d'appels d'offres à taux fixe pour les opérations principales de refinancement, la totalité des soumissions étant servie au taux en vigueur pour ces opérations.

Pour se refinancer auprès de la BC, une banque commerciale doit disposer de collatéraux pour garantir son emprunt. Ceci dit, les actifs présentés en guise de garantie doivent être éligibles, c.à.d. qu'ils doivent répondre à un certain nombre de critères, lesquels sont bien entendu, définis par la BC. Il s'agit en fait des critères qui vont du lieu d'émission, de la procédure d'émission, jusqu'à la qualité des actifs en question (le type d'émetteur et la qualité de sa signature), en passant par la monnaie de libellé.

Suite à l'intensification de la crise, le conseil des gouverneurs de la BCE a décidé, le 13 octobre 2008, de compléter la procédure d'appels d'offres à taux fixe intégralement servis annoncée une semaine plus tôt, par une nouvelle série de mesures, lesquelles, ont cette fois, porté sur les actifs éligibles admis en garantie des opérations de garantie de l'Eurosystème, les modalités d'adjudication des opérations de refinancement et des opérations de fourniture de liquidité en dollars.

Par ailleurs, les interventions de l'Eurosystème ne se sont pas limitées au marché interbancaire, mais ont également, concerné certains segments du marché des titres jugés importants dans le financement des banques de la zone euro. Le 7 mai 2009, le conseil des gouverneurs a décidé de mettre en œuvre un programme d'achat d'obligations sécurisées (Covered bond purchase programme – CBPP), qui avait pour principal objectif de contribuer au redressement du marché des obligations sécurisées.

En effet, entre le 6 juillet 2009 et le 30 juin 2010, l'Eurosystème a procédé à des achats fermes d'obligations sécurisées libellées en euros et émises dans la zone euro dont le montant nominal total préannoncé s'élève à 60 milliards d'euros. Ainsi, au 31 décembre 2009, l'Eurosystème a procédé à l'achat des obligations sécurisées pour un montant de 28 milliards d'euros (24% sur le marché primaire et 76% sur le marché secondaire).

⁶ Metzler (1995) fait l'hypothèse que, parmi les actifs, seules les obligations sont parfaitement substituables à la monnaie. Les changements des taux d'intérêt de court terme, étant transitoires, n'affectent donc pas les décisions de consommation.

- **Les instruments utilisés par la FED : La ruée vers l'innovation**

La Term Auction Credit Facility (TAF) constitue l'une des premières innovations de la FED en matière d'accès à la liquidité. C'est en fait une refondation de la Discount Window. Dans le cadre de cette opération, la réserve fédérale dote les banques commerciales et institutions de dépôt faisant preuve de solvabilité, de la liquidité, laquelle prend la forme d'un prêt admettant en collatéral une gamme très large d'actifs.

Elle s'effectue dans l'anonymat, assure les montants très importants (60 Md\$), permet à la liquidité d'aller là où elle n'allait plus et laisse du temps aux banques pour savoir comment réagir face à la crise de liquidité qui frappe une gamme élargie d'actifs. Ainsi, la liquidité distribuée par la TAF (60 Md\$) excède celle allouée via les OMO, acronyme anglais de l'Open Market Operations (environ 50 Md\$ d'encours en décembre 2007).

La FED met en œuvre le 7 mars 2008, la Term Repurchase Transaction (TRT) qu'est une nouvelle (OMO) et qui a pour principal objectif d'apaiser les pressions sur les marchés interbancaires. La TRT est en fait une opération dont la maturité est de 28 jours, à l'issue de laquelle la réserve fédérale n'accepte que des MBS (Mortgage Backed Securities) garantis par les GSE (dettes d'agences sponsorisées par le gouvernement).

L'innovation apportée par cette nouvelle (OMO), c'est qu'elle porte sur une maturité plus longue, et dote les primary dealers, d'une liquidité dont les montants sont beaucoup plus déterminants. Ceci dit, malgré la mise en œuvre de cet instrument par la réserve fédérale, aucune amélioration au niveau du marché interbancaire n'a été constatée et le spread continuait de se creuser jusqu'à atteindre 80 pb. Ceci a amené la FED, le 11 mars 2007, à concevoir la Term Securities Lending Facility (TSLF). Il s'agit en fait d'une opération qui prend la forme d'une enchère hebdomadaire, permettant aux primary dealers, d'échanger pendant 28 jours auprès de la FED des titres variés en contrepartie des bons du trésor.

À côté des mesures précitées qui visaient principalement le marché interbancaire, la FED s'est également orientée à la fin de l'année 2008, vers l'acquisition des titres à long terme. La chute des coûts de financement des titres de (GSE), les chocs subis par le marché hypothécaire américain sont entre autres les facteurs qui ont motivé la réserve fédérale à mettre en œuvre le premier programme d'achat de titres spécialement orienté GSE. La FED prévoit, dans le cadre de ce programme, des achats de dettes des GSE dont le montant s'élève à 100 milliards de dollars ainsi que des achats de MBS garantis par les GSE pour un montant de 500 milliards de dollars. En mars 2009, à l'issue d'une détérioration de l'activité économique et des piètres perspectives sur le marché immobilier, la réserve fédérale étend ses programmes d'achat, les ramenant respectivement à 200 et 1250 milliards pour les dettes des GSE et les MBS garanties par ces dernières.

Enfin, Afin d'agir de réduire le niveau des taux à long terme et de fait, influencer de manière favorable sur les conditions de financement en du secteur privé, la FED s'engage d'acquérir, le 18 mars 2009, des obligations à long terme du Trésor américains dont le montant total s'élève à 300 milliards de dollars. Il s'agit là de la première vague de l'assouplissement quantitatif Quantitative Easing (QE1) qui implique une augmentation de la taille du bilan de la banque centrale sans pour autant en affecter la qualité en termes de risque.

Il était évident qu'au terme du premier programme d'assouplissement quantitatif, la FED allait retomber au point mort. Les cours des actions stagnaient, le marché du travail ne produisait plus, si oui, cela demeure très insuffisant pour répondre aux besoins de la population, et de fait, contrer la menace du chômage, un PIB trimestriel en deca de la moyenne... Tant d'éléments qui rendent le retour, de l'économie américaine, à son état normal extrêmement complexe.

Il paraissait à ce titre convenable de lui doter d'une nouvelle impulsion, laquelle a pris la forme d'une deuxième ronde d'assouplissement quantitatif. Mis en place le 3 novembre 2010, ce second programme dont le montant s'élève à 600 milliards de dollars américains, visait plus particulièrement les obligations du Trésor américain. Néanmoins, contrairement à la première ronde d'assouplissement quantitatif, ce second programme ne se souciait pas de la liquidité sur le marché interbancaire, mais cherchait plutôt le moyen de stimuler l'économie, et de fait, rétablir la confiance des investissements.

2 L'EVALUATION DE L'EFFICACITE DE LA STRATEGIE D'ASSOUPLEMENT QUANTITATIF : CAS DE LA BCE ET LA FED

2.1 L'IMPACT SUR LA STABILITE FINANCIERE :

Durant la crise financière et plus précisément au cours de la période de l'intensification de la crise, les banques exprimaient une forte réticence à se prêter entre elles, bloquant ainsi les transactions et exigeant de ce fait, des primes de risque extrêmement élevées sur les montants échangés. Cependant, la stratégie d'assouplissement quantitatif menée respectivement par la FED et la BCE, a contribué à rétablir la confiance au sein des marchés financiers et a de ce fait, permis une détente des taux d'intérêt à travers une détérioration des primes de risque.

Les initiatives de la Réserve fédérale américaine et les mesures que cette dernière a mises en œuvre pour soutenir les banques éprouvant des difficultés liées à leur accès au financement s'avèrent aujourd'hui plus ou moins payantes. Les banques ont repris confiance, et partant, se refinancent plus facilement à des niveaux de spreads très faibles. Ainsi, les marchés interbancaires retrouvent leur fonctionnement d'avant la crise quoique les volumes qui y soient échangés restent largement inférieurs à la période de pré-crise.

En effet, la prime de risque, que l'on mesure par l'écart entre le taux sur les prêts interbancaires à trois mois et le taux sur les titres publics de même échéance, London Inter-Bank Overnight Rate (LIBOR), a repris son niveau d'avant crise et ce, depuis octobre 2009. Les titres publics à trois mois évoluent depuis fin 2008 autour de 0,2 %, les taux sur les prêts interbancaires de même échéance (LIBOR) sont passés de 1,3 % fin mars à 0,3 % fin septembre⁷.

Considéré comme un indicateur de stress des marchés financiers à court terme et après avoir été supérieur à 100 pb au moment de l'intensification de la crise financière, l'écart entre le LIBOR et l'OIS (taux Overnight Interest Swap), est revenu à un niveau sans tension. En revanche, malgré ces évolutions, la confiance ne s'est pas totalement rétablie au sens où l'on assiste toujours à des écarts élevés surtout en ce qui concerne les échéances longues. On prend à cet effet le cas du spread entre le LIBOR et l'OIS à un an, lesquels tardent à converger.

Après la baisse jugée de « temporaire » en début de l'année 2009, Les taux publics à dix ans oscillent entre 3,3 % et 3,75 %. Cependant, les taux à trente ans véhiculent des signes de reprise depuis l'automne 2009. Cette reprise ne concerne pas toutefois les taux hypothécaires, lesquels ont pu profiter du programme d'achats de titres engagé par la FED.

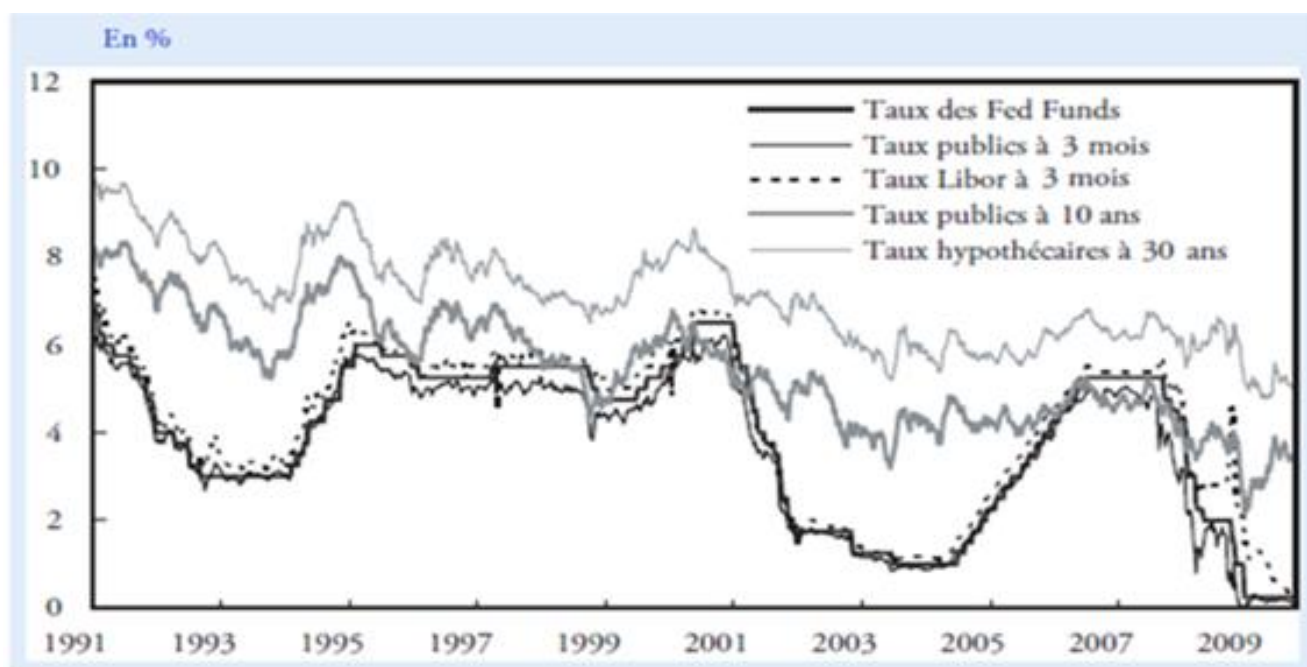


Fig. 1. Taux d'intérêt exprimés en %

Source : Blot C., Mathieu C., Riffart C. et Schweisguth D. (2011), « Politiques monétaires : panser l'avenir », *Revue de l'OFCE*, n°113, avril.

Concernant la BCE, la stratégie d'assouplissement quantitatif a, de la même manière que la réserve fédérale, permis la réduction des écarts entre les différents taux interbancaires et le taux directeur, lesquels ont retrouvé des niveaux qui n'avaient pas été atteints depuis juillet 2007. On peut à cet effet prendre l'exemple du taux Euribor qui, en septembre 2009, est devenu inférieur au taux directeur (respectivement 0,8% et 1%).

⁷ Blot C., Mathieu C., Riffart C. et Schweisguth D. (2011), « Politiques monétaires : panser l'avenir », *Revue de l'OFCE*, n°113, avril.

Toutefois, les taux interbancaires pour des maturités de 6 à 12 mois sont les seuls qui persistent et de fait, restent supérieurs au taux directeur (respectivement 1,1 et 1,3 % en septembre 2009). On a donc observé peu à peu un décalage de tous les taux interbancaires vers le bas, une fois les tensions apaisées.

Une autre manière d'évaluer l'état du marché interbancaire est de s'intéresser aux primes de risques entre les taux interbancaires et des taux de même maturité sur des actifs sans risque. A cet effet, on fait référence à l'écart entre le taux EURIBOR (des prêts en blanc sans garanties) à 3 mois et le taux EUREPO à 3 mois (dont les prêts sont garantis), ce dernier reste supérieur de 0,2 point par rapport au niveau d'avant la crise.



Fig. 2. Spread entre taux interbancaires et actifs moins risqués en %

Source : Bentoglio G., et Guidoni G., (2009), « les banques centrales face à la crise », revue de l'OFCE, septembre.

De même, l'écart entre le taux EURIBOR à 1 an et un actif sans risque liquide de même maturité qui peut être une obligation publique a visiblement diminué, mais reste tout de même élevé le comparant au niveau pré-crise.

Toutefois, en dépit de la détérioration du niveau des taux du marché interbancaire, les banques commerciales font toujours appel à la BCE, notamment via des opérations supplémentaires de refinancement à long terme. Au delà des soumissions aux opérations de refinancement, c'est le recours massif aux facilités de dépôts qui confirme que la BCE continue à se substituer au marché interbancaire. Alors que les placements faits à ce taux réduit attiraient à peine 6 milliards d'euros et dix établissements en moyenne en 2006, cent quatre-vingt-sept établissements de crédits ont eu recours à ces facilités fin mars 2010 pour un montant total de près de 300 milliards d'euros (graphique ci-dessous).

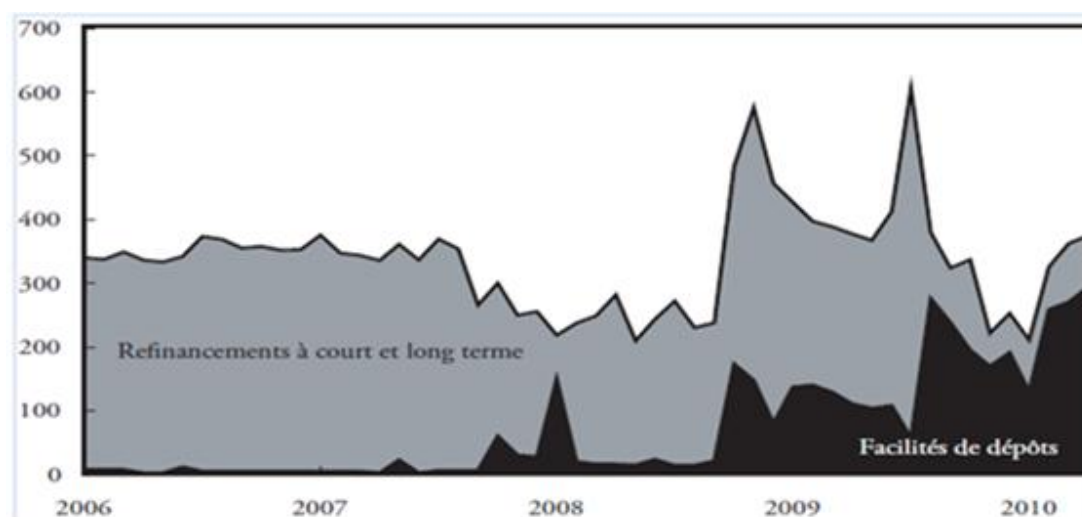


Fig. 3. refinancement et facilités de dépôts

Source : Blot C. et Riffart C. (2011), « politiques monétaires : à hue et à dia », département analyses et prévisions de l'OFCE, Revue de l'OFCE, n°117, avril.

D'autant plus, le taux EONIA (Euro OverNight Index Average), indicateur de la rémunération sur le marché interbancaire des prêts au jour le jour, reste légèrement supérieur au taux des facilités de dépôt qui s'établit à 0,25 % depuis le mois de mai 2009. De l'ensemble de ces évolutions découlent un constat déterminant à savoir que certes, l'incendie est maîtrisée grâce aux interventions respectives de la FED et la BCE mais encore faut-il noter que l'on est encore loin d'une situation qui ressemblerait à celle d'avant la crise.

2.2 L'IMPACT SUR LA DISTRIBUTION DES CREDITS

Malgré l'amélioration du fonctionnement des marchés financiers, et donc de l'offre de crédit, la demande ne réagit que partiellement. Si l'on suit l'évolution des crédits à la consommation, on va constater que ces derniers suivent une tendance baissière qui s'est davantage aggravée suite à la crise financière, et ce, malgré l'assouplissement des conditions de crédits. Ce n'est qu'à la fin de l'année 2010, que ces crédits marqueront une reprise qui tout de même, reste légère.

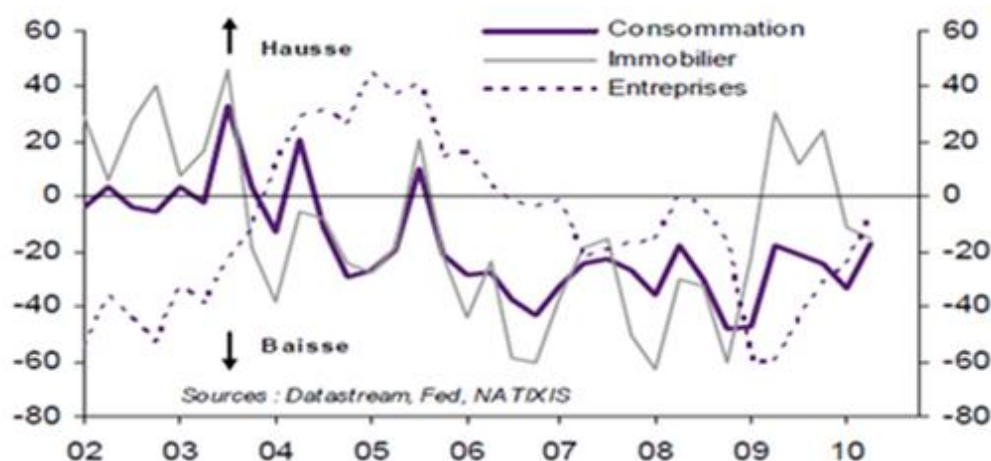


Fig. 4. Evolution de la demande de crédit (Enquête Réserve Fédérale)

Source : Natixis (2010), « Dans quelles conditions le Quantitative Easing permet-il de sortir de la déflation ? », Natixis, n°346, 15 juillet.

En effet, l'absence de redémarrage du crédit peut être attribuée à l'absence de demande de crédit, qui empêche les banques de prêter même si elles disposent de liquidités abondantes. Prenons l'exemple des ménages américains, ces derniers se trouvent dans une phase de « désendettement », leur taux d'endettement est ainsi passé de 135 % du fin 2007 à 121 % en fin 2010. Pour l'heure actuelle, l'ajustement financier, reste pour eux, un élément prioritaire.



Fig. 5. L'évolution des crédits bancaires accordés aux ménages

Source : Natixis (2011), « Peut-on parler réellement de reprise économique aux Etats-Unis et dans la zone Euro ? », Flash éco, Natixis, 19 mai.

Le même constat ressort du côté des entreprises. Sauf qu'il faut noter qu'inversement aux ménages, les entreprises américaines ne se retrouvent pas dans une situation d'ajustement financier mais font plutôt face à une insuffisance de demande qui leur est adressée. La résultante étant une forte détérioration des prêts consentis aux entreprises à partir du premier trimestre 2009. Et de la même manière que pour les ménages, les enquêtes révèlent un assouplissement dans les conditions de crédits octroyés par les banques aux entreprises à partir du troisième trimestre de l'année 2009, mais la demande de crédits des entreprises industrielles et commerciales n'a cessé de se détériorer et ce jusqu'à la fin de l'année 2010 où elle reprend que très légèrement.



Fig. 6. L'évolution des crédits consentis aux Entreprises

Source : Natixis (2011), « Peut-on parler réellement de reprise économique aux Etats-Unis et dans la zoneEuro ? », Flash éco, Natixis, 19 mai.

De part la faiblesse de leur besoins en capital, les entreprises préfèrent plutôt recourir à l'autofinancement, lequel voit sa part grandir à partir de 2008. Ainsi, le taux d'autofinancement des entreprises américaines a atteint 75,4 % au troisième trimestre 2009, un sommet jamais atteint depuis 1976.

En somme, les flux nets des crédits bancaires aux ménages et aux sociétés non financières (SNF) ont été négatifs en 2009, exception faite des crédits commerciaux, lesquels sont devenus positifs au second semestre 2009. De telles tendances affirment qu'en dépit de tous les signes du rétablissement de l'offre de financement, la demande de crédit et les émissions de titres restent en deçà du niveau de pré-crise.

Le constat est similaire dans la zone euro. En effet, les mesures prises par la BCE se sont incontestablement répercutées sur le coût du crédit, mais ce n'est pas pour autant que les volumes de crédits accordés se sont améliorés. La baisse des taux directeurs par la BCE s'est transmise aux taux débiteurs des banques commerciales de la Zone Euro sur les nouveaux prêts aux entreprises pour des échéances de court terme. Néanmoins, l'écart entre ces taux et le taux directeur qui s'était aggravé avec la crise reste plus ou moins volatile. Ainsi, Pour les crédits accordés, dont le montant excède 1 million d'euros, l'écart n'est pas très loin de son niveau normal (+ 0,3 point).

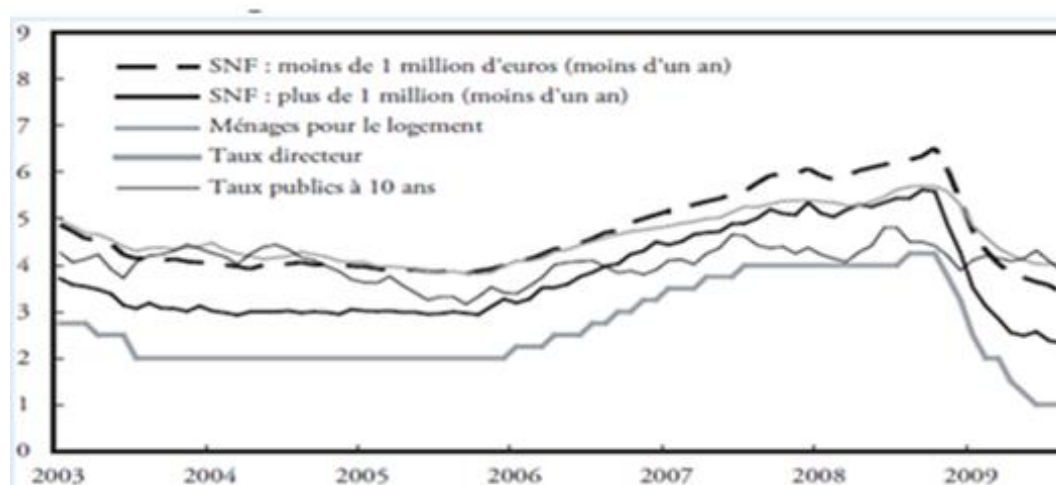


Fig. 7. L'évolution des taux bancaires débiteurs

Source : Blot C., et Riffart C. (2011), « Politiques monétaires : histoire sans fin », *Revue de l'OFCE*, n°119, octobre.

Cela étant, la réaction des taux débiteurs suite à la baisse des taux directeurs de la BC constitue l'un des premiers signaux positifs dans la transmission de la politique monétaire à l'économie. Mais encore faut-il noter que l'insuffisance des prêts consentis à l'origine de l'absence de la demande des ménages et SNF en limite incontestablement la portée.

En effet, les banques affirment, à l'issue de l'enquête trimestrielle menée par la BCE en 2009 qu'elles ont éradiqué tout durcissement au niveau de leurs conditions de crédit. Ceci dit, malgré cet assouplissement, la production de crédits consentis aux SNF marque un net recul (graphique ci-dessous), qui s'explique en fait par la poursuite de l'ajustement de l'investissement productif.

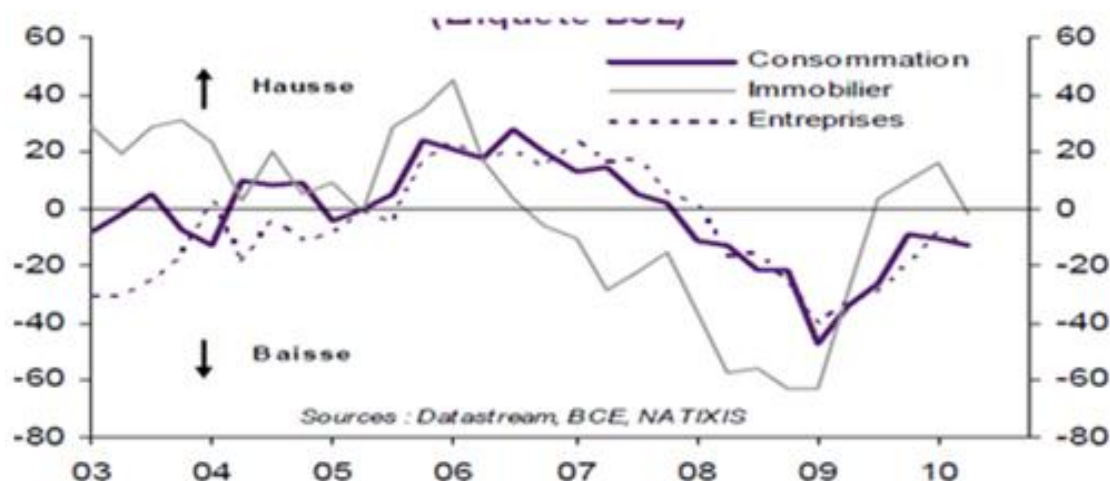


Fig. 8. Zone Euro : l'évolution de demande de crédit (enquête BCE)

Source : Natixis (2011), « Peut-on parler réellement de reprise économique aux Etats-Unis et dans la zone Euro ? », *Flash éco*, Natixis, 19 mai

Du côté des ménages de la zone euro, la production de crédits a poursuivi sa hausse au cours de la deuxième partie de l'année 2010. En moyenne, sur les six derniers mois, les ménages ont reçu 73 milliards d'euros de crédits par mois, dont 59 milliards pour le financement de prêts immobiliers. Il s'agit d'un montant qui excède de 10 milliards celui observé au second semestre 2009, mais qui tout de même, reste inférieure de 20 milliards d'euros au montant observé au second semestre 2006, cela pour dire que malgré la reprise, on est toujours éloigné du niveau d'avant crise.

2.3 L'IMPACT SUR L'ACTIVITÉ ÉCONOMIQUE

Les signes de la reprise de l'activité sont apparus aux Etats-Unis à partir du second semestre 2009. Néanmoins, cette reprise ne s'est pas accompagnée d'un renforcement des bases de la demande, c.à.d. que l'on a pas assisté à l'issue de cette reprise, à un accroissement de l'emploi, qui peut être à l'origine d'un accroissement des revenus, et partant la consommation, laquelle à son tour stimulera la demande des ménages, la production des entreprises et de fait, l'investissement.

Le niveau extrêmement élevé du chômage, l'incertitude accrue qui marque les perspectives d'évolution de leurs revenus futurs et la détérioration de leurs revenus courants justifie amplement, le désendettement que privilégient les ménages américains. Lequel à son tour, porte atteinte à l'activité de financement des banques. Quant aux SNF, ces dernières souhaitent, elles aussi, minimiser leur exposition financière, en raison de la multiplication des faillites mais également en raison du risque de déflation qui pèse lourd sur leurs décisions d'investir.

Face à l'incertitude et donc aux risques de voir leur situation financière se détériorer, ménages et entreprises, ensemble, jouent les prudents. Dès lors, les conditions de prêts qui peuvent paraître attractives n'ont pas tout simplement aucune prise sur la demande de prêts et de fait, aucun effet sur la demande.

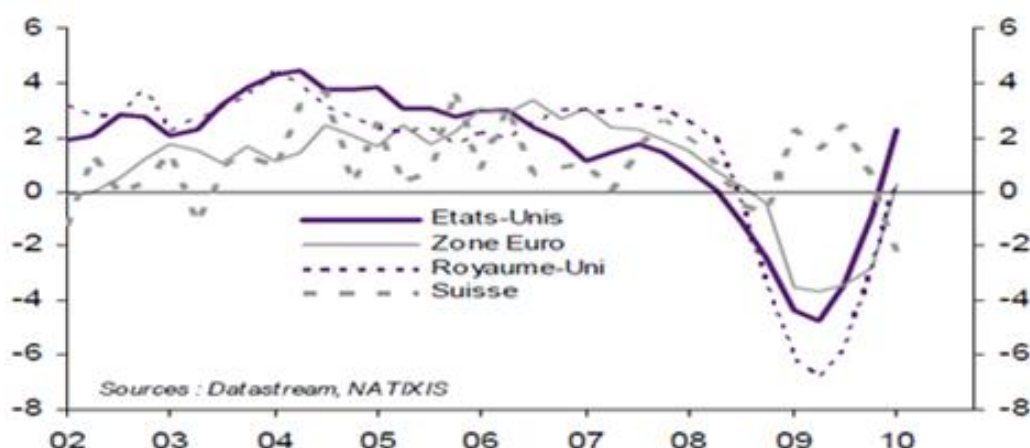


Fig. 9. L'évolution de la demande intérieure aux Etats-Unis et dans la zone Euro

Source : Natixis (2011), « Peut-on parler réellement de reprise économique aux Etats-Unis et dans la zone Euro ? », *Flash éco*, Natixis, 19 mai.

Ainsi, l'insuffisance de la demande a induit à un fort ralentissement de l'inflation en 2010. Les prix à la consommation ont progressé de 1,1 % sur un an, et si l'on se reporte à l'inflation sous-jacente dénuée des composantes volatiles notamment l'énergie et l'alimentation, la progression ne sera que de 0,8 %.

Malgré qu'il y ait des signes indiquant une certaine vigueur économique, la croissance reste largement inférieure au niveau pré-crise. L'économie américaine reste enfoncée dans un long processus de désendettement, qui mettra plusieurs années pour se normaliser. Compte tenu de la morosité des perspectives de croissance américaine, la FED conservera éventuellement sa politique de taux d'intérêt zéro sur une période plus longue. L'augmentation de la masse monétaire a permis à l'économie d'amortir les chocs certes, mais cet amortisseur disparaîtra avec la fin de la seconde vague de l'assouplissement quantitatif.

Il serait à ce niveau intéressant de savoir si la stratégie d'assouplissement quantitatif a été efficace pour favoriser la reprise de l'économie aussi bien des Etats-Unis que de l'Europe, une reprise de la croissance qui va permettre un retour aux équilibres naturels aussi bien de l'emploi que de la production.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Output-gap %	0,265	0,035	-1,821	-5,987	-4,764	-3,697	-2,686	-2,004	-1,415	-0,871	-0,415
Taux de croissance en %	2,673	1,947	0	-2,633	2,834	2,758	2,872	2,723	2,729	2,732	2,677
Taux de chômage en %	4,608	4,617	5,8	9,275	9,633	8,537	7,751	6,994	6,315	5,707	5,185

Fig. 10. Prévisions du FMI de l'Output-Gap, du taux de croissance et du taux de chômage

Source : FMI

Les prévisions ci-dessous, donnent un output-gap supérieur à son niveau d'avant crise jusqu'en 2012 (-0,415 contre 0,035 en 2007). Cela étant, en dépit de la stratégie d'assouplissement quantitatif de la FED, l'output-gap ne sera pas comblé avant l'an 2016. Quant à l'analyse du rythme de la croissance, cette dernière paraît un peu moins pessimiste, au sens où les prévisions indiquent que celle-ci se stabilise autour de 2,7% après 2011. Ce qui équivaut le taux de croissance obtenu avant la

crise. Pour ce qui est du taux de chômage, les prévisions affirment que le taux d'avant crise ne sera obtenu qu'en 2016. De telles prévisions nous permettent de conclure que la politique monétaire menée par la FED ne se traduit pas par des effets nets sur l'activité et ce, même à long terme.

Par ailleurs et de la même manière que les Etats-Unis, ce n'est qu'au second semestre 2009, que l'activité économique européenne montrera des signes de stabilisation. Les taux de croissance trimestriels sont redevenus positifs aux troisièmes et quatrièmes trimestres 2009 et ce, après cinq trimestres consécutifs de croissance négative. L'IPCH (l'indice de prix à la consommation harmonisé) est redevenu positif en novembre 2009 et a atteint 0,9 % en décembre 2009, l'inflation devait donc restée modérée.

Après une croissance de 0,4 % en 2008, la consommation des ménages de la zone euro a fléchi de 1 % en 2009, ne témoignant d'aucune reprise au fil du temps, à la différence du PIB qui, après une baisse de 4 % sur l'ensemble de l'année, est reparti au deuxième semestre.

En 2010 et 2011, la consommation des ménages ne devrait plus pénaliser la reprise du PIB de la zone euro. Sa contribution à la croissance, négative ou nulle depuis le printemps 2008 redeviendrait très légèrement positive à partir du second trimestre 2010, et se renforcerait légèrement un an après. Les dépenses des ménages ne devraient cependant pas dépasser 0,3 % de croissance en 2010 et 1 % en 2011.

Pour ce qui est de l'investissement, l'année 2009 a été une année noire pour la Zone Euro, le niveau d'investissement a baissé de près de 11 % par rapport à l'année 2008. Cette chute s'explique bien entendu par la faiblesse de la consommation privée.

	2006	2007	2008	2009	2010	2011	2012	2013
Croissance du PIB réelle en %	3,3	3,0	0,3	-4,2	1,8	1,6	0,2	1,4
Taux d'inflation en %	2,5	2,1	3,3	0,3	1,6	2,6	1,6	1,2
Taux du chômage en %		7,4	7,5	9,4	9,9	9,9	10,3	10,3
Output Gap en %	0,97	2,08	1,13	-3,52	-2,80	-2,25	-1,68	-1,16

Fig. 11. Les prévisions de l'OCDE de la croissance, du taux d'inflation et du taux de chômage

Source : OCDE

Comme nous pouvons le constater à travers le tableau ci-dessus, les prévisions donnent un output-gap supérieur à son niveau d'avant crise jusqu'en 2012 (-0,415 contre 0,035 en 2007). Cela étant, en dépit de la stratégie d'assouplissement quantitatif de la zone euro, l'output-gap ne sera pas comblé avant l'an 2016. Quant à l'analyse du rythme de la croissance du PIB, cette dernière paraît un peu moins pessimiste, au sens où les prévisions indiquent que celle-ci se stabilise autour de 2,7% après 2011. Ce qui équivaut le taux de croissance obtenu avant la crise. Pour ce qui est du taux de chômage, les prévisions affirment que le taux d'avant crise ne sera obtenu qu'en 2016.

3 CONCLUSION

On peut à travers l'évaluation de l'impact de la stratégie d'assouplissement quantitatif affirmer que sa transmission à la sphère réelle reste plus ou moins ambiguë. Certes, les tensions sur les marchés financiers se sont nettement détériorées mais encore faut-il noter que l'on est toujours incapable d'obtenir des niveaux de pré-crise. Les écarts de production restent extrêmement négatifs, le chômage demeure élevé et le risque d'une déflation est toujours présent, signe que la stratégie n'a eu aucun effet net sur l'activité mais a uniquement amorti les chocs subis par les économies précitées suite à la crise financière.

Quant à ses retombées sur la distribution de nouveaux crédits, il s'est avéré que les ménages continuent à privilégier le désendettement et les entreprises, l'autofinancement. Un tel comportement bloque la reprise de l'activité de crédits malgré l'assouplissement des conditions de crédits. On ne peut donc pas dire qu'il s'agit d'une stratégie efficace au sens où finalement, elle n'arrive pas à mordre sur les dépenses des ménages et des sociétés non financières. C'est cette incapacité de l'assouplissement quantitatif d'affecter la demande qui explique la persistance des écarts de production très négatifs et des taux de chômage extrêmement élevés.

De telles conditions incitent les banques centrales à maintenir leur vigilance et les contraignent par ailleurs, de poursuivre leur politique monétaire accommodante jusqu'à ce que les signes de reprises soit réellement solides.

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Measuring Semantic Similarity in Grids Using Ontology

karamollah Bagherifard^{1,2}, Mehrbakhsh Nilashi¹, Othman Ibrahim¹, Norafida Ithnin¹, and Lasisi Ayodele Nojeem³

¹Faculty of Computer Science and Information Systems,
Universiti Teknologi Malaysia,
Skudai, Johor, Malaysia

²Department of Computer Engineering,
Islamic Azad University, Yasooj branch,
Yasooj, Iran

³Faculty of Computer Science and Information Technology,
Universiti Tun Hussein Onn Malaysia

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ABSTRACT: Grid computing, a new and broad area of research, aims at sharing available information and resources through the use of computers over the network. To use the new applications of grid, it is necessary to adapt the modern software components and assembled information resources in a flexible format. Web services incorporate the necessary capabilities in achieving this goal called grid services. Due to the exponentially increasing amount of data, documents, resources and services available on the web, finding an acceptable agreement between the user and the abilities of web or grid service as well as forming an appropriate composition of service components for performing requested operation are critical issues. Measuring the similarity of services is an important and valuable solution that is used in some practical reasoning such as replacement of a service with another and combination of services and applications. Also, because the measuring the service similarity needs an appropriate semantic model, therefore, in this paper a semantic model based on OWL ontology language for services is presented and thus, similarity measure is provided. We find a semantic model for services and then provide a method for measuring the similarity between two services. A mathematical model for solving given problems is also proposed. The results evaluated by F1 measure obviously show the improvement of accuracy against previous method.

KEYWORDS: Grid, Web Services, Similarity, Semantic Web.

1 INTRODUCTION

The grid can be considered as a network layer services that allow users to access the set of distributed and computing resources, applications, and data resource. A grid service causes the entire network to be viewed as a seamless information processing system accessed by users at any situation. The concept of grid services emanated in 1990 providing solutions for resource sharing with high performance that deals with huge amount of computing of large data [2]. To use the new applications of grid, it is necessary to adapt the modern software components and assembled information resources in a flexible format. With respect to this and changes in procedure of a set of protocols, grid has been transformed to an application and a service-oriented method. Open Grid Service Architecture (OGSA) incorporates the grid techniques and web services. A grid service, in brief, is a Web service that follows a specific set of rules (institutions and intermediaries) that define how the user interaction with the Grid services [14].

With exponentially increasing amount of data, documents, resources and services available on the web, finding an acceptable agreement between the user and the abilities of web or grid service as well as forming an appropriate composition of service components for performing requested operation are critical issues because humans are not able to provide effective and efficient means for the description of services, components and objects that are available on the web [16].

Measuring the similarity of services is an important issue in many applications such as service discovery, service composition and recommendation. Due to the increasing number of services, measuring the service similarity needs an appropriate semantic model as proposed in this paper. We proposed a semantic model based on OWL ontology and in regard to this model, we use semantic similarity for calculating services similarity [17, 1]. The remainder of the paper is structured as follows:

Semantic model in services is described in the Section 2 for further discussion. Also, semantic similarity methods are presented in Section 3 and afterward, using semantic services models and semantic similarity methods in Section 4. A solution to the described problems is provided in Section 5 and finally, evaluation of proposed method and conclusion is given in Section 6 and 7 respectively.

2 SEMANTIC SERVICE

The question that arises here is why the grid needs semantic? The answer is, first, the development of the grid without the use of Semantic Web technologies is thus reducing transparency for users [1], because interpreting and managing the huge volume of resources by human (users) is not easy. Using semantic web technology in interpreting the resources, users' effort and attempts will be reduced and the use of resources will be effective and efficient [12]. The languages that describe the service such as WSDL; only consider the Syntactic description of the service [8] and the information about what the services performs is not provided to the user. Therefore, the user has to provide additional explanations about the service. We have presented a semantic model for service and applied OWL ontology languages to model services. In this system, each Web service is a class and relations between them are modeled based on the OWL ontology tags.

Classes of the tags ontology are displayed based on OWL [18]. Each class may include a subclass by OWL and Subclass tag is displayed in OWL language. In these models, the class that includes sub-class, represents a combination of services. Each class has a feature name that specifies the service name. In this paper, six properties are considered for each service that through features, definitions in the OWL ontology language is modeled [5]. A service has its own specific non-functional descriptions such as location, characteristics and so on. All these features are included into the characteristic called metadata. In addition, we consider a special feature called the usage which represents applications of service. For each service, we consider a feature called "IS-A" and last feature is reference that represent the resources in which will be consumed by web services or grid. Figure 1 shows the features of a service in the ontology.



Fig. 1. Features of Service

Input features indicate the type of input data that are necessary condition for running the previous service. Output features indicate the type of output data and results service and "IS-A" feature reflects the service that is the current service components. This feature is important in several respects [6]. Through that, sub-services of compound service can be specified. Its main use is to determine the relation similarity among services between services that in next section further studies will be investigated.

3 CONCEPT OF SIMILARITY MEASURING

After defining a semantic model for services, it is necessary to present a method for measuring the similarity between two services. Therefore, in this section some of similarity measure is introduced, two methods are considered for semantic similarity. At the end of this section, a vector similarity measure is also expressed.

3.1 SIMILARITY MEASURING BASED ON THE CLASSIFICATION

One of the existing relationship between the concepts is "IS-A" relationship. Using this relationship, we are able to classify the related concepts. If C be a set of concepts, therefore, the classification of concepts is defined as $\tau(C, \leq)$ that $C \leq C'$ means C IS-A C' [19, 7].

In this method, two concepts as one ontology should be placed where it tends to be grouped in one class. If two concepts are different in the two ontologies, they are therefore merged and form a unified ontology [3]. The similarity between two concepts is defined as [7]:

$$\sigma(C, C') = 1 - \delta(C, C') \quad (1)$$

Where $\delta(C, C')$ indicates weighted distance between two concepts. In classification for any concepts C , the weight $W(c)$ exists and $ccp(c_1, c_2)$ is the weight of common father for two concepts c_1 and c_2 . With considering these definitions, the value of $\delta(c, c')$ is calculated as :

$$\delta(c_1, c_2) = [w(ccp(c_1, c_1) - w(c_1)) + w[ccp(c_1, c_2) - w(c_2)]] \quad (2)$$

The concepts weight of classification is calculated by [19,7] :

$$w(n) = \frac{1}{k^{L(N)+1}} \quad (3)$$

In this equation, $L(N)$ indicates the length of path to the node N in the classification tree and K denotes a pre-defined value greater than 1 that here value 2 is considered. This model has two main properties: (1). in high levels, the concept differences are more than existing differences in the lower levels. (2). the distance between two concepts is more than difference between child and parent. For example consider the Figure 2, in this Figure we want to calculate the similarity degree between two concepts car and truck that following steps are performed as shown in Figure 3.

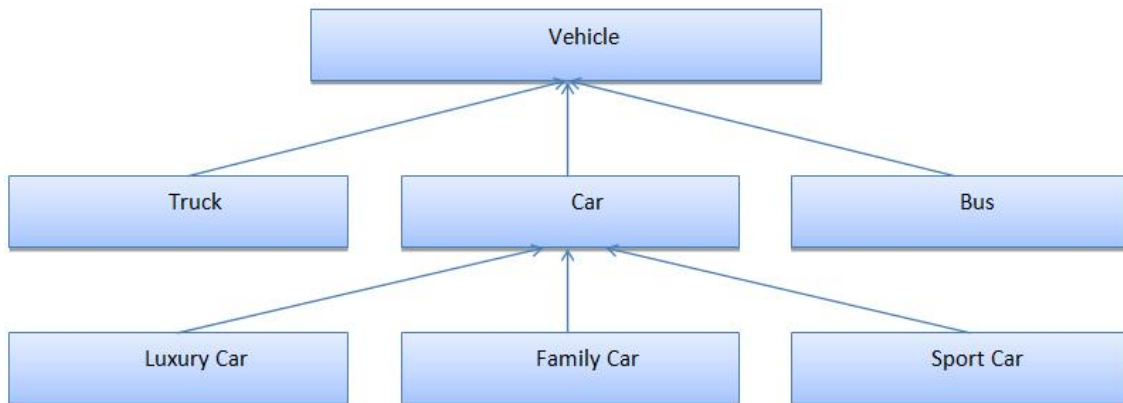


Fig. 2. An example of concept classification

$$\begin{aligned}
 \omega(Vehicle) &= 0.5 \\
 \omega(Truck) &= 0.25 \\
 \omega(SportCar) &= 0.125 \\
 \delta(Truck, Vehicle) &= 0.5 - 0.25 = 0.25 \\
 \delta(SportCar, Vehicle) &= 0.5 - 0.125 = 0.375 \\
 \delta(Truck, SportCar) &= 0.25 + 0.375 = 0.625 \\
 \delta(Truck, SportCar) &= 1 - 0.625 = 0.375
 \end{aligned}$$

Fig. 3. Steps for calculating similarity degree between two concepts car and truck

3.2 MEASURING THE SIMILARITY BASED ON FEATURES

In the previous methods for calculating the semantic similarity of concepts, only the classification structure of concepts was considered and other concepts and features were overlooked. Each concept has a number of features and a set of object features [6].

Different characteristics of the concept are identified by features. For example, consider two of the Person of the Father. One concept of Person [6,7] can have a property of a data type called the Father and Father concept can have a property as SubClassOf of a relation related to this concept. Father also has a relationship as HasChild with Person that is defined as following:

$$\begin{aligned}
 F(\text{Person}) &= \{(\text{type, class}), (\text{HasName, String})\} \\
 F(\text{Faher}) &= \{(\text{type, class}), (\text{HasHame, String}), \\
 &(\text{SubClassOf, Peron}), (\text{HasChild, Person})\}
 \end{aligned}$$

In the example above, because the Father is one SubClass of Person then inherit the HasChild property. Two more general properties are important rather than a particular property of a concept. Similarity between two concepts c_1 and c_2 can be defined as follows [6].

$$\sigma(c_1, c_2) = \frac{2 \times |f(c_1) \cap f(c_2)|}{|f(c_1) \cap f(c_2)| + |f(c_1) \cup f(c_2)|} \quad (3)$$

The success of these measures depends on the degree of context properties. In most of the current ontologies only relationship between concepts in ontology is defined and rest relationships are ignored. In this type of ontology similarity, measuring between two concepts based on feature cannot be useful, and the result is often not acceptable.

Vector model. Words or concepts indicators in this model (e.g., questions and documents), are defined as weighted. The matching degree of two vectors denotes the similarity degree between them. Two concepts are considered in the t dimension space and similarity between text and question is defined by similarity between p_i and q_i vectors.

Dice measuring. This method is used for measuring similarity between two concepts defined as vectors. The equation 5 for this measuring method is formulated as

$$sim_{dice}(d_s, q_i) = \frac{2 \times [\sum_{k=1}^n (w_{s,k} \times w_{i,k})]}{\sum_{k=1}^n w_{s,k} + \sum_{k=1}^n w_{i,k}} \quad (4)$$

4 SERVICE SIMILARITY

Similarity between services can be looked at from several aspects that each of these similarities in respect to the functional problem is useful. In the following we will address three aspects of the service similarity [9, 10].

$$\Pi(c_1, c_2) = \begin{cases} \frac{\max_{c1 \in C1, c2 \in C2} \{\Pi(C1 - c1, C2 - c2) - \sigma(c1, c2)\}}{\min\{|C1|, |C2|\}} & C1 \neq \Phi, C2 \neq \Phi \\ 0 & C1 = \Phi \vee C2 = \Phi \end{cases} \quad (5)$$

4.1 SIMILARITY BETWEEN INPUTS OF TWO SERVICES AND THEIR OUTPUTS

Similarities between the inputs and outputs of the two services are an appropriate method for measuring the similarity of web services. The inputs and outputs of a service is in fact a collection of elements, we consider each element as a concept. In principle, for measuring of similarity between inputs in two services, similarity between two set of concepts must be calculated [9]. Ganjisaffar [1] developed a model for measuring the similarity between a set of concepts; in this model semantic similarity measure methods (classification and feature similarity measuring) are used (Equation 5).

Similarity between two services is defined as sum of inputs and outputs similarity in two services as shown in equation 6.

$$F1(S_1, S_2) = \frac{\Pi(I1, I2) + (\Pi(O1, O2))}{2} \quad (6)$$

4.2 METADATA SIMILARITY BETWEEN TWO SERVICES

Based on the above methods, similarity between two services is calculated through their input and output and content services have been unnoticed. In some application cases, the contents and concept of the services are also considered. For this reason, we present the similarity measuring among metadata services. A reasonable method to calculate similarities between metadata is the vector model that we introduced in this paper. Metadata for each service is considered as two vectors W_1 and W_2 and similarity of two services is identified from similarity of metadata [20, 21].

$$F2(S_1, S_2) = \text{sim}_{Dice}(W_1, W_2) \quad (7)$$

4.3 FUNCTIONAL SIMILARITY OF TWO SERVICES

As mentioned earlier, for each service, a feature called usage is considered and through this feature it is possible to identify the functionality of any services. In this method, the similarity of services is measured based on their application. Applications can be considered as a concept and the similarities between them are calculated through classification similarity measure [4, 9, 11].

$$F3(S_1, S_2) = \sigma(S_1, S_2) \quad (8)$$

5 FUNCTIONAL CASES: COMBINING SERVICES

Once a request by available atomic services is not fulfilled, it is possible to fulfill this request using the proper integration and composition of existing services. The process of gathering atomic services to create an integrated and coordinated combination set is called combining services that fulfills the larger and more complex purpose than what is done by the individual atomic services [13, 15]. Indeed, the possibility of integrating and combining the services by different organizations for fulfilling the user request is one of the factors that services become attractive.

5.1 SELECTING APPROPRIATE SERVICE FOR COMBINING

When two services are combined, the input of second service is equivalent to the output of first service. Therefore, inputs and outputs data types and application of them must be compatible to each other [2, 13]. Here the similarity between inputs and outputs is not necessary but the similarities between the output of the first service and an input of second service

is important. Therefore, equation F1 is defined as follows with S_1 , S_2 , O_1 and I_2 denoting first service, second service, output of first service and input of second service, respectively

$$F1(S_1, S_2) = \Pi(O_1, I_2) \quad (9)$$

In addition to the inputs and outputs similarities, the conceptual and practical similarity of service is also considered. Using the equation 10, the two services are combined if the high similarity between them is obtained.

$$\begin{aligned} \text{similarity}(S_1, S_2) &= W1 * F1(S_1, S_2) + W2 * F2(S_1, S_2) + W3 * F3(S_1, S_2) \\ W1 + W2 + W3 &= 1 \end{aligned} \quad (10)$$

5.2 SELECTING APPROPRIATE SERVICE FOR REPLACEMENT

When running the service, the sub service failed and therefore, this causes the halt of running in whole service. Our solution is finding and replacing the similar service with failed service. For measuring similarity of services in this functional case, three combinations of functions F1, F2 and F3 are offered.

$$\begin{aligned} \text{similarity}(S_1, S_2) &= W1 * F1(S_1, S_2) + W2 * F2(S_1, S_2) + W3 * F3(S_1, S_2) \\ W1 + W2 + W3 &= 1 \end{aligned} \quad (11)$$

6 EVALUATION

For evaluating and demonstrating accuracy of the proposed method, we used the F1 and the evaluating results are given in the following (see Figure 4 and 5).

$$\text{Precision} = \frac{\text{size of hit set}}{\text{size of top-N set}}$$

$$\text{Recall} = \frac{\text{size of hit set}}{\text{size of test set}} \quad (12)$$

$$F1 = \frac{2 * \text{Recall} * \text{Precision}}{(\text{Recall} + \text{Precision})}$$

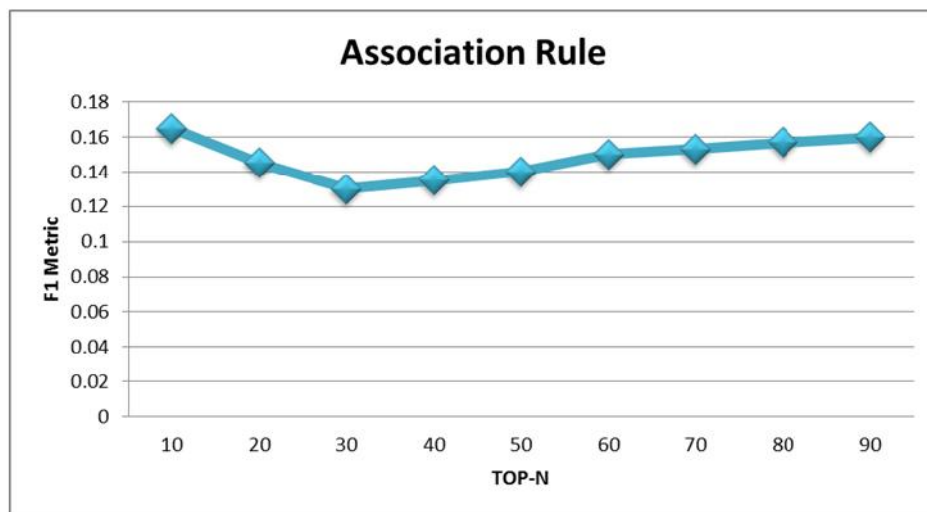


Fig. 4. F1 result for similarity measuring in previous method

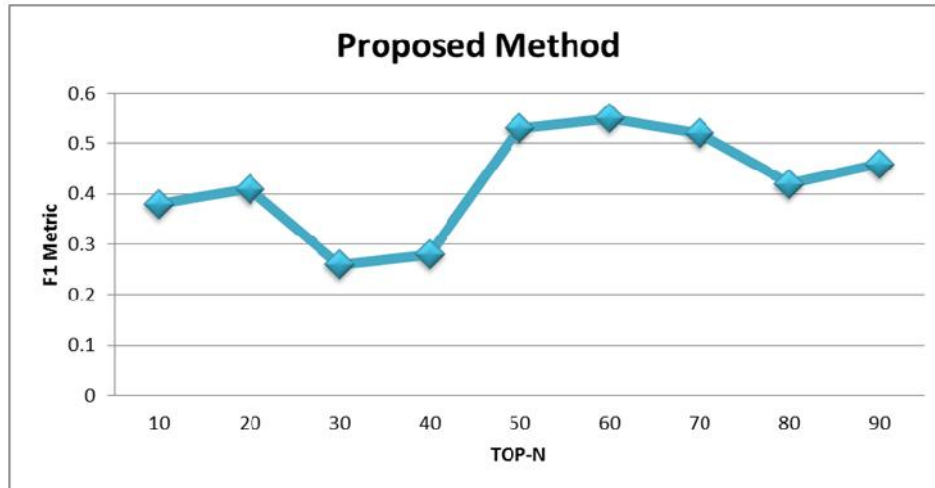


Fig. 5. F1 result for similarity measuring in proposed method

7 CONCLUSION

In this paper, methods for similarity measure among services were presented. The main advantage was incorporating concept in the proposed methods and similarity of services is calculated based on concept. Through measuring the similarity of services, models for combining and replacing the services also were presented and especially these models consider the issue of application of services. This consideration causes the accuracy enhancement in selecting appropriate service. The results evaluated by F1 measure obviously show the improvement of accuracy against previous method. Similarity measuring was calculated between 0.13 and 0.17 for the previous method while in the proposed method it was calculated between 0.26 and 0.55, thus showing an improvement of the accuracy.

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Investigation into fouling factor in compact heat exchanger

Masoud Asadi¹ and Dr. Ramin Haghighi Khoshkhoo²

¹Department of Mechanical Engineering,
Azad Islamic University Science and Research branch,
Tehran, Iran

²Department of Mechanical Engineering & Energy engineering,
Power and Water University of Technology,
Tehran, Iran

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ABSTRACT: Fouling problems cannot be avoided in many heat exchanger operations, and it is necessary to introduce defensive measures to minimize fouling and the cost of cleaning. The fouling control measures used during either design or operation must be subjected to a thorough economic analysis, taking into consideration all the costs of the fouling control measures and their projected benefits in reducing costs due to fouling. Under some conditions, nearly asymptotic fouling resistances can be obtained, and this suggests a somewhat different approach to the economics. Fouling is a generic term for the deposition of foreign matter on a heat transfer surface. Deposits accumulating in the small channels of a compact heat exchanger affect both heat transfer and fluid flow. Fouling deposits constricting passages in a compact heat exchanger are likely to increase the pressure drop and therefore reduce the flow rate. Reduced flow rate may be a process constraint; it reduces efficiency and increases the associated energy use and running costs. Maintenance costs will also increase. Fouling remains the area of greatest concern for those considering the installation of compact heat exchangers. The widespread installation of compact heat exchangers has been hindered by the perception that the small passages are more strongly affected by the formation of deposits. In this paper different types of fouling and treatment are presented.

KEYWORDS: Compact Heat exchanger, Fouling Factor, Fouling Resistance.

1 INTRODUCTION TO FOULING IN COMPACT HEAT EXCHANGERS

Obviously, compact heat exchangers are unsuitable for fluids containing large particulate material or debris. However, the high shear forces, low wall superheat and homogeneous flow distribution typical of compact heat exchangers reduce the formation and adhesion of deposits on the heat transfer surfaces. Also, the use of more corrosion resistant materials with smoother heat transfer surfaces further reduces the formation of deposits [1].

Section 2. examines the generic types of fouling that can occur in heat exchangers and outlines possible solutions. Section 3. examines the effects of fouling in more detail for different exchanger designs and section 4. provides further information on minimizing the risk of fouling at the specification stage. It is assumed that the specifier of the heat exchanger will have knowledge of the nature of the process stream. However, this will not always be the case, as plant and stream changes can occur sometime after units have been installed.

The adoption of heat exchangers has been affected by the perception that those with small channels are likely to foul [2]. Care should be taken when selecting compact heat exchangers for use in situations where mechanical cleaning is impossible. In these cases provision for chemical cleaning must be made. However, gasketed plate heat exchangers are frequently easier to clean than shell and tube types, provided other parameters permit their use [3].

There are two primary problems associated with the small flow passages used in most types of compact heat exchanger:

- The possibility of the heat exchanger acting as a filter for large particles, with these particles forming a filter cake at the inlet to the exchanger.
- The rapid increase in flow resistance resulting from the deposition of only a small thickness of material on exchange surfaces that might pass unnoticed in conventional shell and tube heat exchangers [2].



Fig. 1. Crystalline Fouling on a Plate and Frame Exchanger

The risk of partial blockages turning into complete blockages is also very much higher for compact heat exchangers than for shell and tube heat exchangers, and the difficulty of clearing such blockages, either by mechanical or chemical treatment, is also greater [4]. However, the ability of a compact heat exchanger to filter out material has proved useful in certain applications. In some gas-gas units, the small channel size has caused fibres to collect on the front face of the heat exchanger, instead of in the core where they would be more difficult to remove.

The effect of fouling depends on the deposit location. This, in turn, depends on the fouling mechanism and so on fluid composition. The effects of fouling are likely to be more important for fluid flow than for heat transfer.

For a fluid flow the factors that influence the effect of fouling are:

- The narrowness of the passages, which are relatively easily blocked by particles and fibres.
- The fact that only a small amount of material is required to achieve blockage.
- The difficulty of removing any blockage (although this depends on experience). Judging the effects of fouling on heat transfer need to take into account:
 - The thickness of the deposit, its nature and the area covered.
 - The relationship between the clean heat transfer coefficient and deposit resistance.
 - The implications for design fouling resistance and the irrelevance of TEMA [14] values.

2 TYPES OF FOULING AND TREATMENT

For convenience, fouling is generally classified under one of the following six headings, depending on the mechanism causing the deposition [5-8]:

- Crystallization or Precipitation Fouling.
- Particulate Fouling (Siltng).
- Biological Fouling.
- Corrosion Fouling.
- Chemical Reaction Fouling.
- Freezing or Solidification Fouling.

2.1 CRYSTALLISATION OR PRECIPITATION FOULING

Crystallization or precipitation fouling occurs when a solute in the fluid stream is precipitated out and crystals are formed, either directly on the heat transfer surface or in the fluid, and subsequently deposited on that surface. When the fluid concerned is water, calcium or magnesium salts are deposited, frequently referred to as scaling. Figure.1 shows a plate fouled by crystalline calcium phosphate deposits.

For normal solubility salts (e.g. sodium chloride), this type of fouling decreases with increasing heat transfer surface temperature, as the solubility increases. For the more troublesome inverse solubility salts (e.g. Calcium sulphate, calcium phosphate, calcium silicate, calcium carbonate, magnesium hydroxide and magnesium silicate), the solubility decreases with increasing temperature [8]. Hence, these salts are prone to forming deposits on surfaces where heat is transferred to water, either during cooling or evaporation.

It is important to identify the highest cooling water temperature that is likely to occur in a heat exchanger with narrow channels to determine the appropriate water strategy.

Solution

Crystallization or precipitation fouling is normally avoided either by pre-treating the fluid stream (e.g. by adding acid to cooling water to remove bicarbonate) or by the continuous addition of chemicals to reduce or eliminate deposit formation.

If deposits do form, they can often be removed by treatment with appropriate chemicals, e.g. by adding acid to remove carbonates. Care must be taken to ensure that the cleaning chemicals are compatible with the construction materials used for the exchanger.

Mechanical methods, such as the high-pressure lances that are often used to clean shell and tube heat exchangers, are unlikely to be of use for compact heat exchangers because of their small passage size.

2.2 PARTICULATE FOULING (SILTING)

Particulate fouling (or silting) occurs when solid particles from the fluid stream are deposited on the heat transfer surface. Most streams contain some particulate matter, originating from a variety of sources. Small particles are less likely to be removed from the surface than large ones. The combination of particles with condensation or other sticky forms of fouling can produce a deposit that is much more adhesive and difficult to remove than the individual components on their own. An example would be a combination of paper fibres and polymer adhesive from ink in a printing works heat recovery unit.

A particulate deposit may also provide a mechanism for keeping a surface wet. This may have implications for corrosion (e.g. the formation of an acid condensate from combustion gases).

Solution

Purely particulate fouling can be reduced by the use of sufficiently high fluid velocities. If the deposit also contains matter that acts as an adhesive, a solvent or other chemical treatment will be required to remove the adhesive. Chemical dispersants that affect the surface charges on solids can also assist in avoiding deposit formation.

Mechanical removal, e.g. by brushes, may be feasible, if access is available. Air rumbling, i.e. the temporary addition of air or of nitrogen to the liquid stream is frequently used to dislodge particulate or biological deposits.

Larger particles can easily be filtered out, and a suitable strainer could be located upstream of a compact heat exchanger where such particles are expected. The application of a severe pressure pulse can remove silting, but its effect on the mechanical strength of the exchanger must be considered.

Several other factors alleviate fouling in compact heat exchangers. The use of corrosion resistant materials minimizes fouling by upstream corrosion products and the specific design of compact heat exchangers gives high wall shear stresses. Designers should ensure that there are no flow dead spots.

2.3 BIOLOGICAL FOULING

The deposition and growth of organisms on surfaces cause biological fouling. The organisms most likely to cause problems in compact heat exchangers are bacteria, which can thrive even if the concentration of nutrients in the water is less than one part per million.

Bacteria grow over a wide range of temperatures. Bacterial growth may physically constrict flow passages or can generate a corrosive environment (e.g. sulphate reduced to hydrogen sulphide is corrosive to most materials, including common stainless steels).

Solution

Biological fouling is best controlled by treatment with biocides. Non-oxidising biocides are normally alternated to prevent the development of bacterial deposition. Certain biocides kill the bacteria, but do not remove the biofilm accumulation, but some are available with detergent properties that disrupt the film. Oxidising biocides, such as chlorine and ozone, oxidise the biofilm as well as killing the bacteria and may therefore require higher concentrations to be effective.

Compared with a conventional shell and tube exchanger, the relatively low surface area and the lower fluid inventory in a circuit with a compact heat exchanger should reduce the amount of biocide required. The well-defined flow in the small channels also aids rapid diffusion of the treatment chemical to the biofilm.

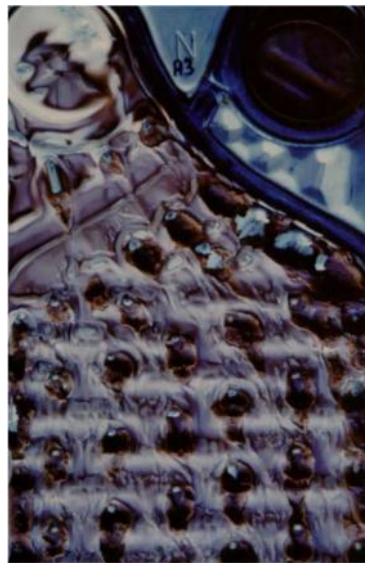


Fig. 2. Reaction Fouling (Protein Deposition) on a Plate and Frame Exchanger Plate

2.4 CORROSION FOULING

Corrosion fouling results from either a chemical reaction involving the heat transfer surface, or the transportation of corrosion products from elsewhere in the circuit and their deposition in the heat exchanger. Corrosion can also take place under the deposits, e.g. as a result of the formation of electrolytic oxygen concentration cells.

Solution

Corrosion fouling is best minimized at the specification stage by choosing materials that are resistant to corrosion in the fluid stream whenever possible. Alternatively, it is possible to dose with corrosion inhibitors, although the environmental impact of this approach must be considered. Cathodic protection can also be used, but care must be taken to ensure that the conditions do not form cathodic scales (calcium and magnesium salts) in hard waters and brines [9].

If a stainless steel heat exchanger is stored in a moist, salt-laden environment, measures should be taken to protect the surfaces. Amounts of salt as low as 1.0 mg/l could result in stress corrosion cracking.

Compact heat exchangers are usually made of the more corrosion-resistant materials. Several types have nodissimilar metals or other materials present, making corrosion attack on the heat exchanger surfaces predictable, unless unforeseen impurities are present in the fluid streams [10].

2.5 CHEMICAL REACTION FOULING

Chemical reaction fouling occurs when one or more constituents in the process fluid react to form a viscous or solid layer on the heat transfer surface, which is not itself involved in the chemical reaction. Such reactions are mostly polymerizations, and the deposit that is initially formed may turn from a tar to a hard coke or similar material that is more difficult to remove. Figure 2. shows protein fouling of a plate exchanger from the dairy industry.

Solution

The rate of chemical reactions increases exponentially with temperature, making it possible to minimise chemical reaction fouling by careful control of fluid and surface temperatures and by reducing residence times at high temperatures. Temperatures should not be increased to achieve the required heat transfer as this will make the fouling problem rapidly worse. It should be much easier to control chemical reaction fouling in a compact heat exchanger than in a conventional shell and tube exchanger because of the high degree of temperature control and low residence times. Compact heat exchangers have lower hold-up and residence times than conventional shell and tube exchangers.

2.6 FREEZING OR SOLIDIFICATION FOULING

Freezing or solidification fouling occurs when the temperature of the process fluid is reduced sufficiently to cause freezing at the heat transfer surface.

Solution

This type of fouling is the easiest to control, particularly in compact heat exchangers, where the small mass and low fluid inventory allows rapid clearance of the fouling by increasing the temperature to melt the deposit. In some cases, channels may be incorporated in the exchanger to allow a hot fluid stream to be introduced to melt material, such as hydrates. Compact heat exchangers offer a closer temperature approach and greater control over stream temperature.

3 THE FOULING RESISTANCE (R_f)

In the thermal design of heat exchangers, fouling is conventionally taken into account by using an additional thermal resistance value, R_f , called the 'fouling factor' or 'fouling resistance', when calculating the overall heat transfer coefficient. Fouling reduces the overall heat transfer and, for a given duty, extra surface has to be provided to ensure that the required heat transfer is achieved [7].

In most cases fouling resistance is time dependent, with zero fouling initially. Frequently fouling resistance builds up to an equilibrium point where the rate of fouling removal is equivalent to the rate of deposition. Depending on the value of this 'asymptotic' fouling resistance, this may or may not allow continuous operation without cleaning. Alternatively, fouling resistance may continue to increase necessitating a cleaning action at some point.

Thermal resistance values are often taken from the standards recommended by TEMA [14]. These are dedicated to shell and tube heat exchangers and, as such, are generally not applicable to compact heat exchangers. Using the TEMA [14] values is likely to result in excessively high additional surface requirements. This is because the implied deposit thickness may give very high pressure drops in small channels. It is generally found that much lower fouling resistances than those recommended by TEMA [14] can be used for plate and frame heat exchangers. Measures such as filters to avoid compact heat exchanger blockages have encouraged some industries (e.g. the cryogenics industry) to adopt fouling resistance values of zero. Some manufacturers may add 10 - 25% extra surface to allow for uncertainties in design codes and other factors, of which fouling may be one. This should not be used as an excuse to reduce the flow velocity.

3.1 FOULING IN PLATE AND FRAME EXCHANGERS

Plate and frame heat exchangers were originally developed for the dairy industry. However, their application in the chemical process industry is increasing rapidly, where they begin to replace tubular heat exchangers in several traditional applications. While there is plenty of information about the governing equations for clean operation, information for fouling conditions is scarce. As shown in the following equation the percentage excess surface area increases with increasing clean heat transfer coefficient for a given heat duty [11].

$$\frac{A_f}{A_c} = 1 + U_{clean} R_f$$

Where

A_f : is the surface area after fouling

A_c : is the clean surface area

U_{clean} : is the clean heat transfer coefficient

R_f : is the fouling resistance

This puts a heavy penalty on compact heat exchanger types such as plate and frame heat exchangers if, because of ignorance or because of cautiousness, the TEMA[14] fouling resistances for shell and tube heat exchangers are used. Typical clean overall heat transfer coefficients for plate and frame heat exchangers are about 3000 W/m²K, for shell and tube heat exchangers about 1000 W/m²K. A design fouling resistance of 0.3 m²K/kW corresponds to 30% oversize for a shell and tube heat exchanger and to 90% oversize for a plate and frame heat exchanger. Most manufacturers of plate and frame heat exchangers recommend that the excess surface should not exceed 25% of the heat transfer surface area calculated for the clean duty.

The fouling resistances listed in Table.1 have been recommended for plate and frame heat exchangers. Due to the non-uniformity of flow distribution and deposit formation, measured pressure drop increases are significantly higher than values predicted using an average deposit thickness calculated from the fouling resistance.

Table 1. Fouling Resistances for Plate and Frame Heat Exchangers

Fluid (Water)	Fouling Resistances($m^2 K / KW$)	
Demineralized or distilled	0.009	
Hard	0.043	
Soft	0.017	
Treated cooling tower water	0.034	
Coastal sea water	0.043	
Ocean sea water	0.026	
River water	0.043	
Engine jacket	0.052	
Lubricating oil	0.017	- 0.043
Vegetable oil	0.017	- 0.052
Organic solvents	0.009	- 0.026
Steam	0.009	
General process fluids	0.009	- 0.052

Effect of Process Parameters on Fouling

Cooper [2] investigated cooling water fouling using a plate heat exchanger. The water was chemically treated before entering the heat exchangers. Some of the important results of this investigation are given in Figure 3.

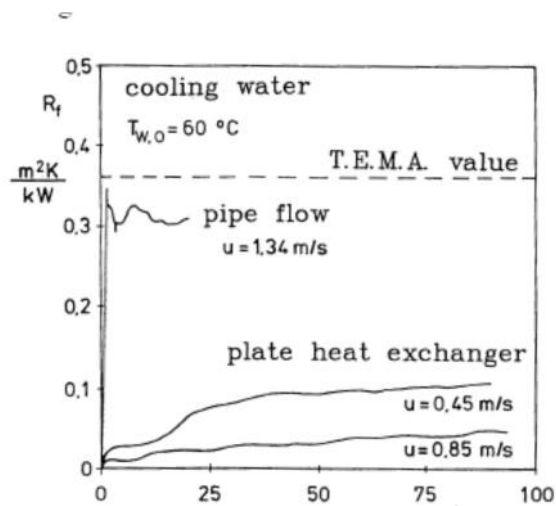


Fig. 3. Comparison of Fouling in Plate and Frame, and in Shell and Tube Heat Exchangers (after Cooper) [2]

The fouling resistance in the plate and frame heat exchanger is significantly lower than in the shell and tube heat exchanger, despite the typically lower flow velocities. If the flow velocity is increased, the fouling resistance decreases similarly as it is found for shell and tube heat exchangers [12]. This is also demonstrated in Figure.4 which shows the asymptotic value as a function of the surface temperature halfway up the plates.

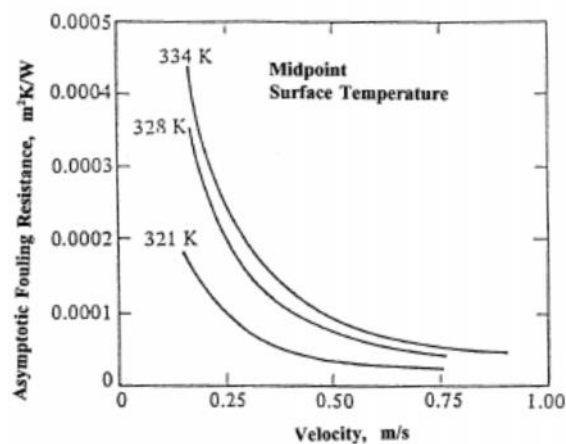


Fig. 4. Fouling Resistance in a Plate and Frame Heat Exchanger as a Function of Flow Velocity and Temperature

Novak [3] studied the fouling behavior of Rhine River water near Mannheim (Germany), and of Öresund seawater in Sweden. For both waters, mainly biological fouling was observed. The fouling resistances increased almost linearly over the period observed. Table 2. summarizes the effects of flow velocity on fouling rates.

Table 2. Fouling Rates of Rhine River Water for a Surface Temperature of 25°C [3]

Type	u m/s	t Pa	dR_f/dt $10^4 \text{ m}^2\text{K/kWh}$
Plate heat exchanger	0.13	6.7	7.4
Plate heat exchanger	0.19	14.5	4.3
Plate heat exchanger	0.77	190.0	0.6
Spiral plate exchanger	0.43	7.5	5.0

For constant flow velocity, Novak [3] found that maximum fouling occurred at a surface temperature of about 35°C, due to the preferred living conditions of biological matter. Bansal and Müller-Steinhagen[4-6] investigated pure crystallisation fouling from CaSO_4 in various plate heat exchangers. The rate of deposition increases with increasing wall temperature and bulk concentration and decreasing velocity. With increasing flow velocity, both the initial fouling rate as well as the absolute value of the fouling resistance decreases. Due to blockage of the outlet flow distribution area, the increase in pressure drop may be significantly higher than the increase in thermal fouling resistance. Chemical reaction fouling is strongly affected by the surface temperature that determines the reaction rate.

Effect of Plate Design

Two low velocity zones exist in the plate channels, opposite to the inlet and outlet ports. In these zones, shear forces are at a minimum and the wall temperature is close to the temperature of the heating medium. Both conditions promote the formation of deposits. The extent of the stagnant zones depends on the design of the flow distribution section. It decreases with increasing flow velocity.

Kho [7] studied the various possibilities of providing excess heat transfer surface area for fouling. Figure.5 shows that minimum fouling occurs if the 20% excess surface area is provided by a two-pass arrangement of the original plates, followed by the use of larger plates with the same width, followed by larger plates with standard width/height ratio. The poorest performance is obtained when the excess surface is simply added as parallel plates. The actual plate geometry (angle, amplitude and wavelength of corrugations) affects the formation of deposits. Delplace et al. [8] found that deposition from whey protein solutions on herringbone plates is only half of that of straight corrugations, for otherwise identical conditions.

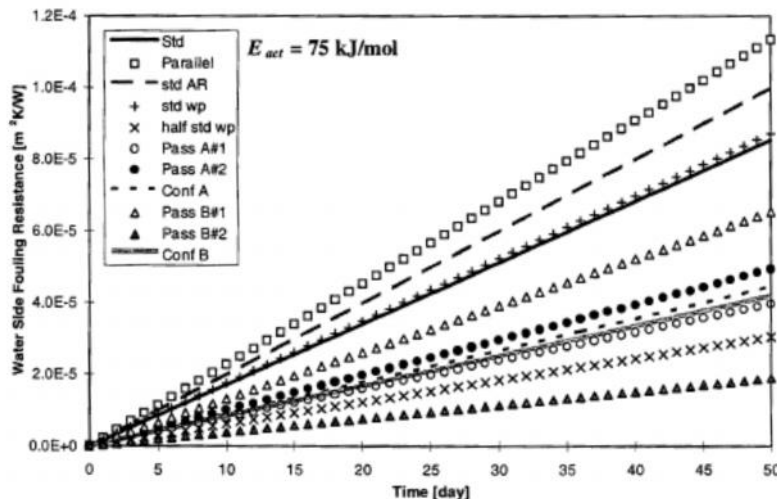


Fig. 5. Effect of Plate Arrangement on Fouling

Plate heat exchanger designs with extra-wide plate gap are available for applications with significant particulate content or severe fouling.

For all types of fouling, the delay time decreases with an increase in surface roughness. Heat exchanger plates usually have smoother surfaces than pipes, because of the manufacturing process itself and because the lower area requirement allows more expensive surface preparation. Electropolished plates with a surface roughness below 0.5 μm are commercially available, and are commonly used in food processing industries. Investigations with plate surfaces modified by Magnetron Sputtering, Physical Vapor Deposition and other technologies which can provide low surface energies are presently underway [9-10].

3.2 FOULING IN PLATE-FIN HEAT EXCHANGERS

Plate-fin heat exchangers are brazed/welded compact heat exchangers with a heat transfer surface density of about ten times that of tubular heat exchangers. Typical applications are cryogenic, chemical/petrochemical and hydrocarbon offshore installations. Molecular sieves and 100 μm filters are used in cryogenic installations to remove particulate matter or components that may freeze-out on the heat transfer surfaces.

Systematic investigations have been performed on particulate fouling [11] and on river water fouling [12].

For 3 μm ferric oxide particles suspended in water, no blockage of plain fin or wavy fin channels was observed. Wavy fin channels fouled more than plain fin channels. All experiments showed asymptotic behavior. Higher deposition rates were obtained for non isothermal conditions and at higher bulk temperatures. Maximum deposition occurred at a Reynolds number of about 1500.

Fibrous and biological material partially blocked the inlet of the aluminum plate-fin test sections when used with river water that was filtered through a 1 mm mesh. Some deposition was found at locations where corrosion of the aluminum had occurred. In the wavy fin test section, a thin, uniform deposit of fine mud was observed. Pressure drop for the plain finning increased linearly with time, whereas asymptotic behavior was found for the wavy finning. The initial slope of the relative pressure drop versus time curves was $5.8 \times 10^{-8} \text{ s}^{-1}$ for the plain fins and $1.71 \times 10^{-7} \text{ s}^{-1}$ for the wavy fins. For the latter, an initial deposition rate of 4.8×10^{-12} and an asymptotic fouling resistance of $6 \times 10^{-6} \text{ m}^2 \text{ K/W}$ were measured.

4 PREVENTING FOULING EFFECTS

4.1 DESIGN STAGE

Identify at an early stage the extent to which process streams are likely to cause fouling. The following points give general guidance.

Circuit Configuration

Closed loops are unlikely to present significant fouling problems. Working fluids in refrigeration or power cycles, for example, should not cause any fouling in a well-engineered and maintained system. Open loops are prone to fouling, and may require the installation of filters to remove particles, fibres etc., as well as regular chemical treatment to prevent biological growth, the deposition of scale, and corrosion. In open systems, check the possibility of using self-cleaning strainers and of installing systems for biocide dosing, the application of scale inhibitors, etc., to control fouling [13].

Once-through streams need to be examined on a case-by-case basis and appropriate action taken if the stream warrants it. If water treatment is constrained by environmental concerns, consider installing an untreated primary cooling water circuit with a secondary clean circuit serving the plant. The other benefits of compact heat exchangers may make this worthwhile. Where a closed cycle system is not an option, consult with the equipment supplier(s) and give detailed consideration to:

- Fouling margins.
- Optimal flow rates.
- Control of heat exchanger operation.
- Upstream fouling prevention.
- In-exchanger fouling control/removal.

Alternatively consider a specific compact exchanger design able to handle the fouling projected.

Performance Monitoring

On larger installations, or where an exchanger duty is critical for a process, exchanger monitoring can give early indication of cleaning thresholds or failure conditions. Monitoring can either be continuous or intermittent as necessary. Progressive fouling will become evident by increases in the pressure drop through the heat exchanger. It is also essential to measure the stream flow rate because a pressure drop increase may be compensated by reduced flow. Inlet and outlet stream temperatures may also be measured. In some cases it may be useful to calculate heat transfer coefficients on a regular basis from the parameters measured above.

Fluid Velocity

Fluid velocity has an effect on fouling. Any reduction in velocity associated with a lower throughput may increase fouling and necessitate more frequent heat exchanger cleaning. Take this into account when considering the operational flexibility necessary for the process.

Modular Design

Wherever possible, adopt a modular design that uses relatively small heat exchangers. These units can be individually removed for cleaning without total process shutdown. Installing multiple heat exchangers will have economic implications to be considered during design and specification including additional piping complexity.

Cleaning

Where a compact heat exchanger cannot be disassembled for mechanical cleaning (e.g. welded, brazed or diffusion bonded heat exchanger cores), install filtration equipment upstream. Another alternative is to consider chemical cleaning, possibly using a separate cleaning loop. If chemical cleaning is to be used, ensure that:

- The system is designed to allow the introduction and complete removal of the cleaning fluids used (no dead-legs).
- The cleaning fluids are compatible with the compact heat exchanger and associated pipework over the full temperature range.

In extreme circumstances small exchangers can be baked in an oven enabling the burnt fouling to be removed by rinsing with water or a detergent. Baking to remove serious fouling is unusual, as heating temporarily to such high temperatures will damage most heat exchangers.

Hydraulic Measures

Pulsating flows, reversing the fluids, or stopping the cold fluid intermittently can inhibit some types of fouling, but expert advice should be taken before adopting such techniques, as they can make some fouling problems worse. Air rumbling, i.e. the temporary addition of air or of nitrogen to the liquid stream is frequently used to dislodge particulate or biological deposits.

Cleaning-in-Place Plants

Automatic cleaning-in-place (CIP) plants can be linked to a process plant for cleaning pipes, tanks and heat exchangers internally. Figure 6. shows the layout of a typical CIP plant.

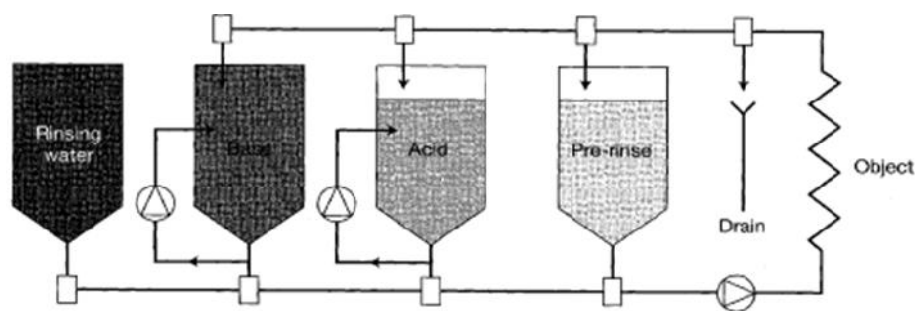


Fig. 6. Layout of a Typical CIP Plant

A typical CIP procedure takes place in five stages:

- A pre-rinse with cold water, helping to displace the product in the system.
- A rinse in an alkaline solution at approximately 80°C.
- A rinse in cold water.
- A rinse in acid solution at approximately 70°C.
- A rinse in cold water.

The cleaning time required depends on the equipment being cleaned and the fluids and temperatures used: it varies from thirty minutes for tanks to five hours for evaporators. In some cases, cleaning time may be reduced by introducing a short acid rinse prior to the alkaline cleaning, thereby helping to remove possible mineral deposits. Single-pack chemicals are also available that remove protein and mineral deposits at the same time.

CIP may be used for removing many types of fouling, including biological slime, rust, scale and organic matter. An example of the efficiency of CIP in removing cooling water deposits is shown in Figure.2. In this example, biological fouling from Rhine river water was removed by a slowly circulating alkaline solution at 60°C [3].

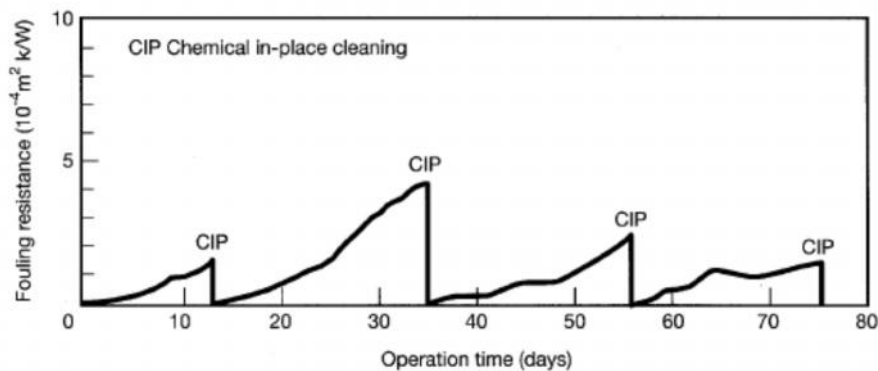


Fig. 7. Reduction of Fouling Resistance by CIP (after Novak)

Typically spent CIP solutions must be treated before release to the environment or recovered for reuse.

4.2 INSTALLATION

If fouling is likely to reduce the run time of a compact heat exchanger, consider installing two identical units in parallel. If one becomes fouled, the flow can be diverted through the other. The principle is the same as incorporating a bypass on a waste heat recovery unit to permit cleaning or to avoid plant shutdown in the event of a failure. Take extra care when installing, hydraulically testing and commissioning to avoid fouling and possibly corrosion.

4.3 OPERATION AND MAINTENANCE

Effective operational experience includes the following.

Check Design Limitations

Be aware of the design limitations of the selected compact heat exchangers. A tight design can limit operational flexibility, and optimum performance and minimum fouling will only be achieved when the unit is operated at, or near, its design conditions. For instance any reduction in the velocity of a cooling water stream may increase fouling.

Adequate Training

Make sure that all staff are fully trained in compact heat exchanger operation. Failures have occurred where non-specialists in heat exchangers were unaware of operating practices and experience.

Routine Preventive Maintenance

Compact heat exchangers are more vulnerable to the effects of fouling or blockage than conventional shell and tube heat exchangers. Therefore, give the same high priority to the relevant preventive measures - filters, chemical dosing etc. - as to ensuring that equipment, such as the main pumps, remains serviceable.

Failure or Blockage Procedures

Establish clear procedures for failure situations. When a failure occurs during operation, the general rule is to contact the manufacturer as soon as possible. Mechanical failure during operation may occur because liquids freeze or because of over pressurization, explosion, damage etc. If any of these occur, contact the manufacturer to discuss the possibilities of repair.

Decide on contingency plans for dealing with a blocked compact heat exchanger, such as cleaning in situ, blocking off the affected layers of a plate-fin heat exchanger, or switching to standby/replacement units.

The mechanical failure of one or more layers in a plate-fin heat exchanger or similar type of compact design need not involve complete replacement. Layers may be blanked off to allow continued operation. In some designs up to 10% of the layers may be blanked off. However, you should consult your equipment supplier before proceeding in this way.

Overhaul Procedures

Establish clear maintenance and overhaul procedures. Some compact heat exchangers can be sent off-site to be overhauled. This is particularly beneficial in the case of gasketed plate heat exchangers, as the gaskets are refitted to manufacturers' standards. If heat exchangers with gaskets are reassembled on site, ensure uniform gasket compression to minimize the risk of leaks. Use gaskets supplied by the heat exchanger manufacturer. With all reassembly, it is important to ensure that the manufacturer's recommendations are followed.

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Effects of Phosphorus and Nitrate in Wastewater Shahinshahr City Use for Oil Refinery

Rohollah Rezaei¹ and Amir Samimi²

¹Esfahan Oil Refining Company,
Research and Development Branch,
Isfahan, Iran

²Department of Chemical Engineering, Mahshahr Branch,
Islamic Azad University,
Mahshahr, Iran

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ABSTRACT: Polymeric phosphates in detergents are used widely in construction and hence have a significant concentration in the wastewater. Phosphate may result in sewage and industrial waste is waste from the body. Phosphate caused a rapid growth of aquatic plants such as algae and it is disturbing factor in the treatment processes. For example, concentrations in the range ppm 2/0 in order to reduce the turbidity of water contract will play the role of the intruder. Nitrogen gas (N₂) and the primary component of natural gas and the atmosphere is extremely stable. Nitrogen is a component of proteins. Chlorophyll and Nitrogen also is found in many biological compounds. Nitrate fertilizers polluting groundwater and surface water sources are in nature. Presentation of the nitrate concentration in milligrams per liter (Mg NO₃\L) or milligrams per liter nitrogen as nitrate (Mg NO₃-N\L) has caused many problems and errors. There is no significant difference between the two units. The combination of infection for humans in Europe the nitrate directive committee row is non-toxic compounds. This paper examines the effects of phosphate and nitrate in the plant in ShahinShahr Use of water, steam Oil Refinery reviewed and analyzed and the results are listed at the end.

KEYWORDS: Phosphate, Nitrate, Water Pollution, Water Treatment.

1 INTRODUCTION

A: PHOSPHORUS

Exclusively to the phosphate phosphorus (PO₄-3) is found in the aquatic environment. There are several forms of phosphorus, including orthophosphates; condensed phosphates (follower, Meta-and poly-phosphates) and organic compounds are phosphates. This Even a minor component of the plant or animal tissue are considered. Building well-wide polymeric phosphates in detergents used, so have a significant concentration in the wastewater, Phosphate may result in sewage and industrial waste is waste from the body. Phosphates are not toxic and have no restriction on the Understand human health or bring other organisms directly, but indirectly serious threat to water quality is considered materials. Phosphate caused a rapid growth of aquatic plants such as algae and it is disturbing factor in the treatment processes. For example, concentrations in the range ppm 2/0 in order to reduce the turbidity of water contract will play the role of the intruder. Phosphorus in the water as a nutrient for growth microorganism considered. Orthophosphate and phosphorus in waters generally are classifide, orthophosphate of nutrients in the water is considered to be one of those problems, growth resulting in corrosion and biological will follow. Orthophosphate the project within 4 months was measured in two poly-phosphate and all experiments were carried out in the period under Vanadomolybdo phosphoric Colorimetric Method No. 4500-PC measurements were below standard. Standard Methods 09/12/2011 Shaheen refinery town on total phosphorus, mg\L 87/6 and it orthophosphate mg\L 8/5 was determined to be the result of the mg\L 07/1 and 15% of the total phosphorus forms in water. Polyphosphate if a water source is more than 75% of total

phosphorus, phosphate treatment can be ignored. But given the repeated testing the figures come on 22/12/2011 and for total phosphorus, 3/5 orthophosphate and thus 61/1 poly phosphate (23% of the total), remove excess phosphate in water treatment plant design must be applied. Based on the research conducted and the results observed orthophosphate input to refineries should be close to zero. In addition to the problems mentioned above in the discussion of this matter, is increase the efficiency of corrosion inhibitors. According to the Environmental Protection Agency, the amount of in cooling towers less than ppm 5/1 is a must. According to a study in Orange County, Florida power plant that uses wastewater for cooling purposes, the value of p less than ppm 1 shall be controlling. The Palo Verde plant also recycles America project, the range of less than 0.5 milligrams of l. But according to the standards listed and the results of the what water, phosphate for the treatment is close to zero.

Table 1. Results Phosphate (Artvjsfat) Falcons Improved Water and City Water Dorcheh

Mg/L		DATA
What water	Falcon Shahinshahr	
0	6/1	2010/12/08
0/01	5/3	2010/12/09
-	7/41	2010/12/11
0	5/9	2010/12/13
-	6/11	2010/12/14
0	6/45	2010/12/16
-	5/2	2010/12/18
0	5/8	2010/12/20
-	5/3	2010/12/22
0	5/9	2010/12/24
-	6	2010/12/26

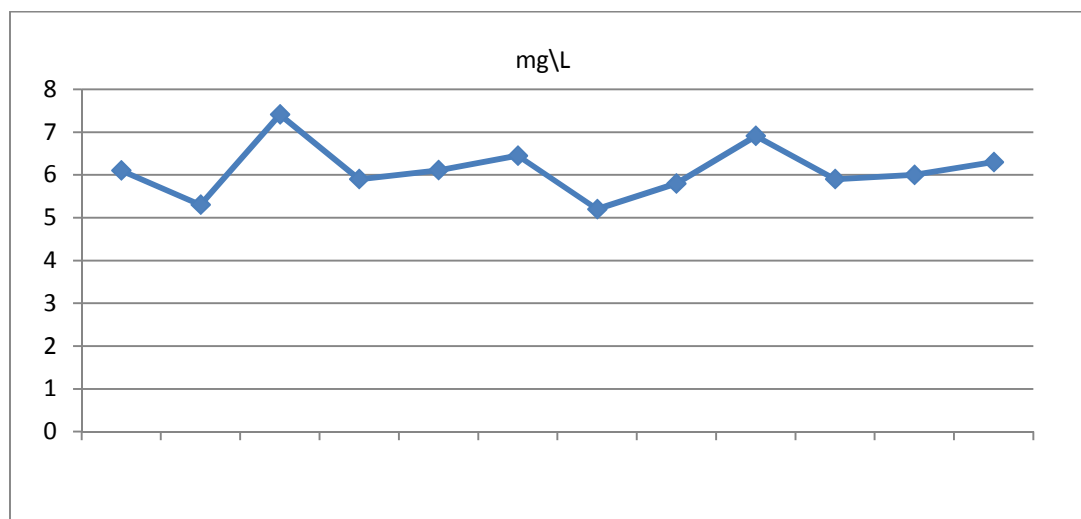


Fig. 1. Results in Phosphate-Falcons Reclaimed Water

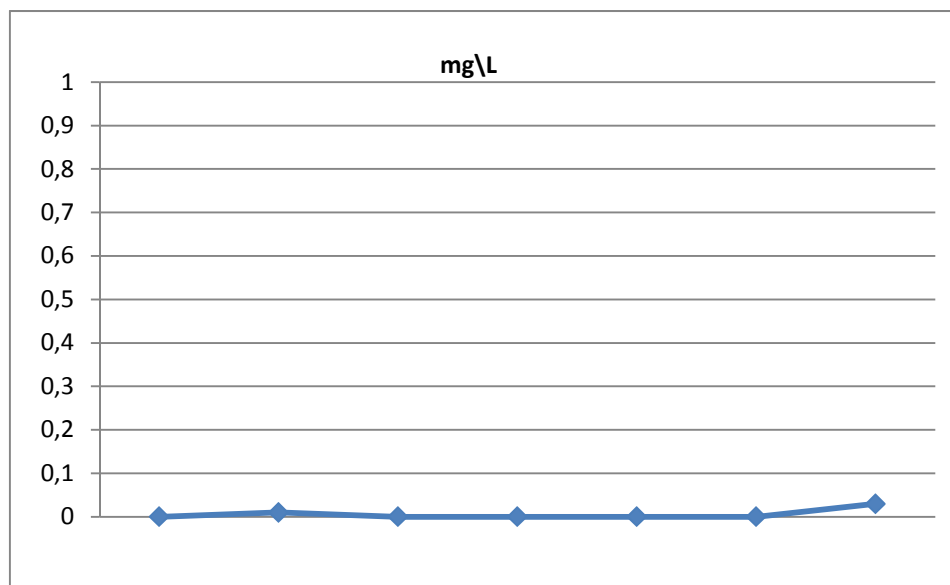


Fig. 2. What Results Phosphate Supply Water

According to available data, a consistent trend of Shahin phosphate in treated wastewater and the average ppm 11/6 is.

Table 2. Summarizes the Two Locations with the Standard Phosphate

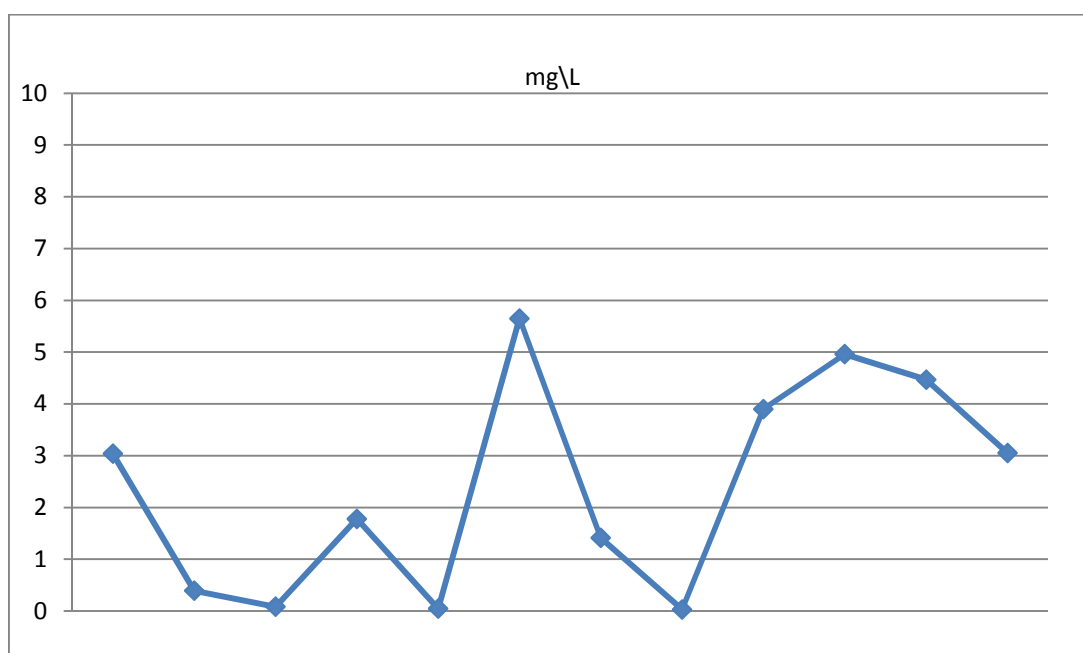
Standard Range	What the Average Water	Average Effluent Shahinshahr	
0-1	NIL	6/11	Mg/L

B: NITRITE

Nitrogen gas (N_2) and the primary component of natural gas and the atmosphere is extremely stable. Under conditions of very high energy, the gas reacts with oxygen (burning with flame or electrical discharges) of this reaction, nitrogen oxides occur. Although a small number of Capable of biological species to nitrogen dioxide to the nitrogen in the aquatic environment mainly comes from sources other than atmospheric nitrogen. Nitrogen is a component of proteins. Chlorophyll and Nitrogen also is found in many biological compounds. After the death of animals, plants or microbial decomposition of complex Examples of proteins into amino acids and then to ammonia (NH_3) are. If there is oxygen, ammonia to nitrite (NO_2^-) and then to nitrate (NO_3^-) is oxidized. Other sources of nitrogen in the water systems of animal excrement, chemicals (especially compounds used as fertilizer) and is discharged waste stream. The sources of nitrogen may Natural and waste water can penetrate. Nitrite standard by Germany TRUMPF Inc. ppm 1 is less often due to the unstable nature of this compound is not very important, and therefore more attention on directly into Natural and waste water can penetrate. Nitrite standard by Germany TRUMPF Inc. ppm 1 is less often due to the unstable nature of this compound is not very important, and therefore more attention..... Colorimetric method 4500- NO_2 -B Standard Issue Standard Methods for the Examination of Water and Wastewater was measured.

Table 3. Results of Nitrite in Water and Waste Water Shahinshahr City

Mg/L		Date
Dorche Water	Wastewater Shahinshahr City	
0/02	3/04	2010/12/08
0/023	0/39	2010/12/09
-	0/082	2010/12/11
0/046	1/78	2010/12/13
-	0/046	2010/12/14
0/006	5/65	2010/12/16
-	1/41	2010/12/18
0/01	0/03	2010/12/20
-	3/9	2010/12/22
0/003	4/96	2010/12/24
-	4/47	2010/12/26

**Fig. 3. Results in Reclaimed Water Nitrite Shahinshahr**

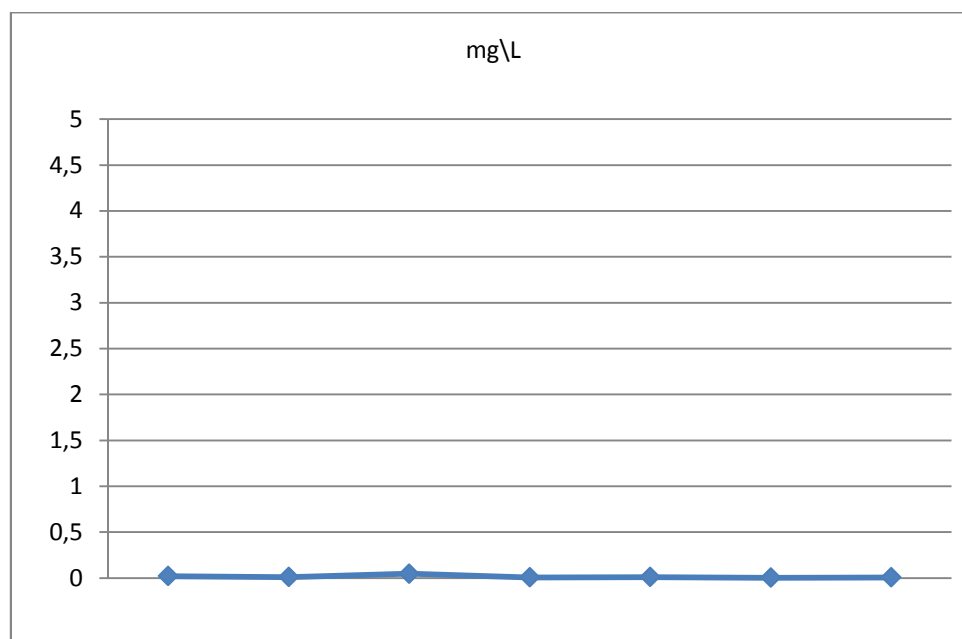


Fig. 4. What Results from Water Supply

According to available data, Shahin Shahr nitrite in wastewater by almost no uniform trend could be due to lack of proper maintenance and operation of biological wastewater treatment reactor inlet flow rate increases when (precipitation) Zemestan as well as reducing is temperature. Average concentration to ppm 5/2, which is scheduled to present a strategy for reducing, controlling and even these parameters are listed in the report.

Table 4. Summarizes the Situation with Two Locations Nitrite Standard Range

The scope of the standard (Maximum)	What the average water	Average effluent Shahinshahr		
		Long-term	Short-term	
<1	0/015	3/8	2/5	Mg\L

2 CONCLUSIONS

A: NITRATES

Nitrate fertilizers most polluting groundwater and surface water sources are in nature. Presentation of the nitrate concentration in milligrams per liter ($\text{Mg NO}_3\text{ \L}$) or milligrams per liter of nitrate nitrogen in ($\text{Mg NO}_3\text{-N \L}$) has caused problems and errors. There is no significant difference between the two units, for example, $\text{NO}_3\text{ \L}$ 50 mg equivalent $\text{NO}_3\text{-L}_3/11$ mg is. In this discussion, the actual concentration of nitrate is used as the $\text{Mg NO}_3\text{ \L}$ is presented. The conversion of $\text{NO}_3\text{ \L}$ as $\text{Mg NO}_3\text{-N \L}$ must be in 226/0 beat the charges. The combinations of infection for humans, the Nitrates are toxic compounds Europe Committee of instructions in a row. The maximum instruction, 50 to 100 milligrams per liter has been determined. But in 1984, the complication rate of red blood cell deficiency in children, the standard recommended by the World Health Organization to override the limit in terms of the $\text{NO}_3\text{-N \L}$ 10 mg or ($\text{NO}_3\text{ \L}$ 45 milligrams) reduced. Nitrate concentrations in surface waters have been rising in recent years, it has seasonal fluctuations of this fall and winter concentration is at its highest when the project tests this season, decisions based on these parameters is critical. problems the nitrate industry, including increasing the amount of solids is usually not significant, and the nitrates are in the control of boilers fragility. The result of long-term nitrate treatment plant effluent hawk is visible in Figure 6. towers and water nitrate standard input to refineries, according the Global Environment, because of the dangers of and biological problems under control $\text{Mg NO}_3\text{ \L}$ 5 is. But given the supply of water What, Isfahan refinery facilities in

recent years due to drought and low river flow, with an average concentration of aqueous $\text{Mg NO}_3\text{L}$ 18 has been kept in operation.

Table 5. Results in Nitrate Wastewater and Water Supply Shahinshahr

Mg/L		date
	Falcon City wastewater	
4/43	23/91	2010/12/08
4/41	6/64	2010/12/09
-	9/29	2010/12/11
6/19	14/16	2010/12/13
-	18/59	2010/12/14
5/47	13/281	2010/12/16
-	15/05	2010/12/18
6/64	27	2010/12/20
-	22/6	2010/12/22

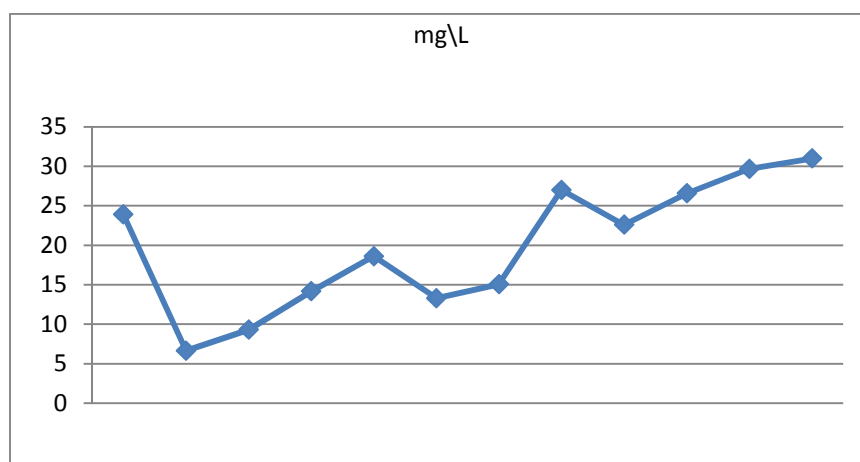


Fig. 5. Results in Reclaimed Water Nitrate Shahinshahr

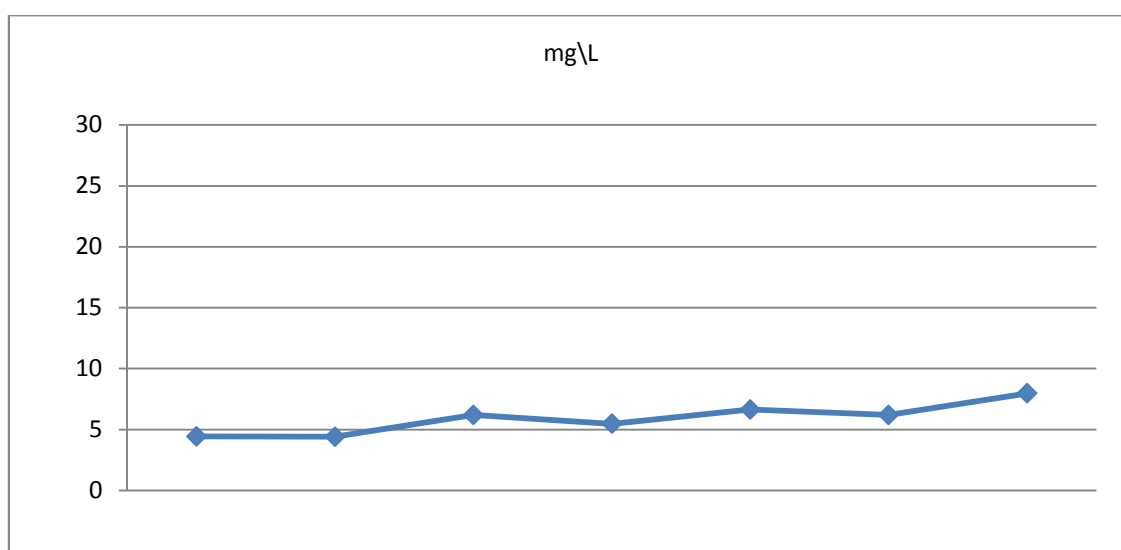


Fig. 6. Conclusions Nitrate Irrigation Water

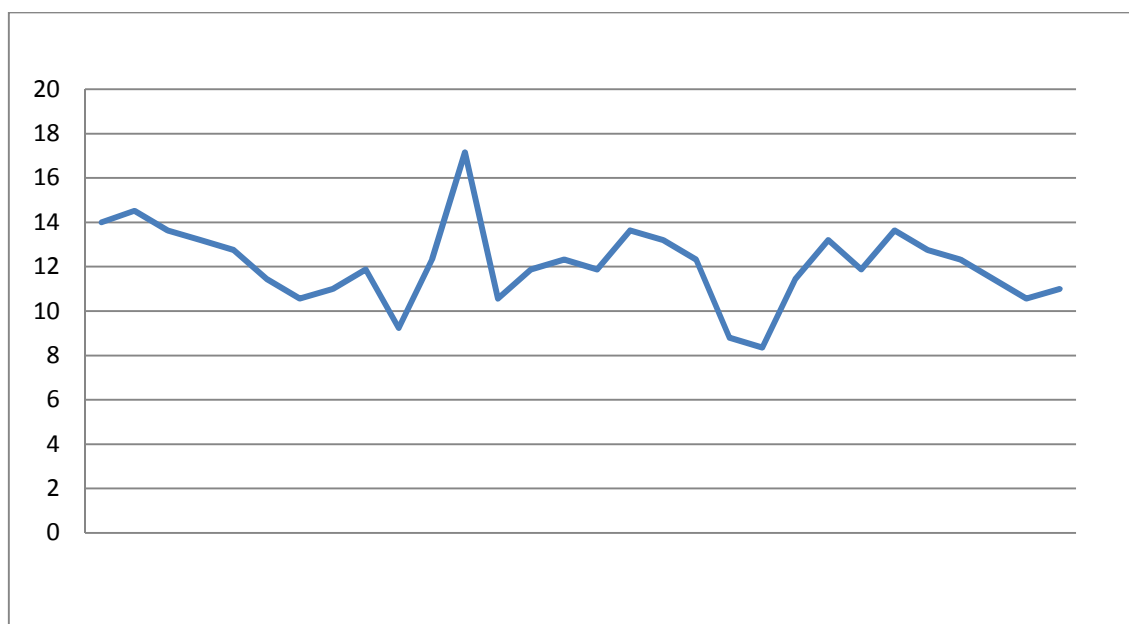


Chart 7. Results in Nitrate Effluent Treatment Plant and Waste Water Laboratory Results of ShahinShahr

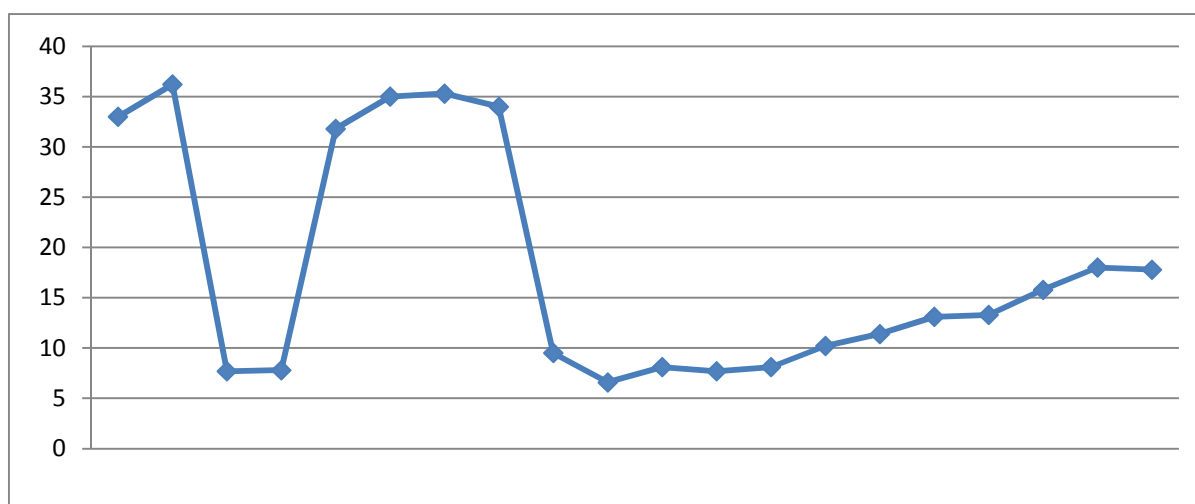


Chart 8. Supply Water Nitrate Results Based on Laboratory Results Oil Refinery

According to available data, the nitrate in the effluent as it can cause no uniform trend of Shahin Shahr almost nitrite, of proper maintenance and operation of biological treatment reactors Dubai house when increasing input (precipitation) low temperatures in winter. Average concentration equal to 8/19 that the amounts of rainfall and drought years, the supply of water what is the same in the cold months of the year, along with rainfall more, Also, due to increased nitr Cold seasons due to lower temperatures and correspondingly reduced biological activity is microorganism the reactor treatment plant in Shahin Shahr. In order to reach the standard of the nitrate concentration of $\text{MgNO}_3 \text{ L}$ 15 is greater than the standard. According to the experiments and researches done, it can be concluded that the wastewater treatment plant Shahin Shahr, Isfahan refineries have great potential for use Drmsarf is especially cooling towers. Health concerns about wastewater serious consideration should be made and the system is secure from any interruption or failure in the disinfection process. Because of the unknown effects of some contaminants present in water is modified due to Isfahan Refinery, would be challenging. Falcon City wastewater treatment plant and transfer its excess refining the human and environmental benefits, the economic benefits of a well to a refinery will bring. There was hardly example effluent what the Falcons at home in water than water and this will reduce sedimentation and other technical issues. Also, lower

concentrations of heavy metals in wastewater treatment plants, water supply Shaheen What improvement in the of refinery workers also pose public health.

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Amir Samimi (Corresponding Author)



(16/05/1983, Isfahan City, Isfahan Province, Iran)

Studied M.SC Chemical Engineering, Master at Islamic Azad University, Iran.

Member of IAENG, Chemical Engineering Committee, Hongkong.

Member of NACE International is the Global Voice of the Corrosion Control and Prevention (U.S.A).

Reviewer in International Journal of science and Engineering investigations, (IJSEI), France.

Reviewer in International Journal of Innovation and Applied Studies (IJIAS), Morocco.

Reviewer in Journal of Environmental Science & Water Resources, Africa.

Young Researchers and Elit Club, Central Tehran Branch, Islamic Azad University, Tehran, Iran.

Have 2 Years Experience in Oil Refinery Company, Iran.

Have 29 Articles in the International Journal, Conference (U.S.A, France, Italy, Indonesia, India, Australia, and Europe Chemical Engineering Conference), and More than 50 Articles in the National Journal, Conference in Iran.

Email: amirsamimi1161@gmail.com

The Challenges Toward Implementation of Information and Communication Technology (ICT) in Secondary Schools in Ondo State, Nigeria

Olufemi Victor ADEOLUWA¹, Olukayode Solomon ABODERIN¹, and Oladele Dennis OMODARA²

¹Department of Curriculum Studies,
Ekiti State University,
Ado-Ekiti, Nigeria

²Department of Curriculum Studies,
College Of Education,
Ikere, Ekiti State, Nigeria

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ABSTRACT: The study investigated the Challenges of Information and Communication Technology (ICT) in secondary schools in Ondo state. It sought to find out the level of access to ICT among secondary school teachers and students. Also the study investigated the level of utilization of ICT for instructional purposes and the attitude of teachers and students towards ICT utilization of ICT in secondary schools.

The study adopted the descriptive survey design. The sample for the study consisted of 450 teachers randomly selected from two hundred and ninety six (296) secondary schools in the eighteen Local Government Areas of Ondo State. A combination of multistage, stratified and simple random sampling technique was used in selecting the sample. A questionnaire titled "Challenges of information and communication technology for secondary schools teachers (CICTSST)" was designed and validated. The data obtained were analyzed using frequency counts, percentages, mean and bar chart. The result of the findings showed that: ICT facilities are not available in schools. Majority of the teachers and students do not have access to ICT. There are significant factors affecting the utilization of ICT for instructional purposes. The study also revealed that teachers show positive attitude toward utilization of ICT in teaching and learning.

KEYWORDS: Challenges, Information and Communication Technology, Implementation, instructional purposes and Secondary Schools.

1 INTRODUCTION

Everyday, Computers become more important factor in today's society because there is virtually no human endeavour where Computer does not find applications. Indeed, we are confronted with computers during working hours and in our private lives. The same applies to communication. Nowadays, we have much more possibilities to communicate with other people as a result of computer networking. Mobile phones, electronic mail, short message service (SMS) and chat-boxes are few examples of the new possibilities actualised through communication. All these new communication means have their own specific way of using them, their own advantages and disadvantages and their own specific group of users.

The Information and Communication Technology (ICT) is one of the important innovations for modern development. The term ICT springs up from the convergence of telecommunication, computing and broadcasting through the use of digital information. It covers any product that will store, retrieve, manipulate, transmit and receive information electronically in a digital form. ICT encompasses the broad fields of information and communications by means of computer and telecommunication; tools that are being increasingly used for organizational or personal information processing in all sectors of economy and the society as a whole.

The upcoming of ICT technologies has its implications on school and education. It is not possible to ignore computers anymore. Education is faced with the challenge to incorporate computers and communication possibilities in a meaningful way. But this challenge has a reason: When used in proper ways, ICT can improve education in many way students have to learn about computers. But other subjects can be taught with computers. The use of computers in education can be more efficient, it can provide better learning results and be made adaptive to the individual learner [7]. The role of technology in teaching and learning is rapidly becoming one of the most important and widely discussed in contemporary education policy. Most experts in education agree that, when properly used, ICT holds great promise to improve teaching and learning [1].

Reference [9] also refer to ICT as electronic or computerized devices, assisted by human and interactive materials that can be used for a wide range of teaching and learning as well as for personal use. Information and Communication Technologies (ICTs) have impacted greatly on teaching, learning, research, and school management in a number of ways. They are electronic technologies used for accessing, processing, gathering, manipulating and presenting or communicating information. When ICTs are employed in education given the right condition, they can accelerate, enrich, and deepen basic skills in reading, writing, mathematics and the sciences, and they can motivate and engage students to learn as they become more independent and responsible for their learning. Reference [6], ICT is a revolution that involves the use of computers, internet and other tele-communication technology in every aspect of human endeavor. The author posited that ICT is a simply about sharing and having access to data with ease. It is regarded as the super highway through which formation is transmitted and shared by people all over the world.

Furthermore, ICTs help to relate academics to the practices of today's work. Information and communication technologies, especially network technologies have been found to encourage active learning, support innovative teaching, reduce the isolation of teachers, and encourage teachers and students to become active researchers and learners.

2 PURPOSE OF THE STUDY

This study is designed to investigate the Status of Information and Communication Technology (ICT) in Secondary Schools in Ondo State.

Specifically, the study examined:

- The level of access to ICT among secondary school teachers and students
- The level of utilization of ICT for instructional purposes.
- The attitude of teachers towards ICT utilization in secondary schools.

3 RESEARCH QUESTIONS

Based on the purpose of this study, the following research questions were generated to guide the study.

1. Are ICT tools available in schools?
2. Do teachers have access to ICT facilities?
3. What are the factors hindering the effective utilization of ICT facilities for instructional purposes?
4. Do teachers have positive attitude toward the utilization of ICT in teaching and learning?
5. Do students have access to ICTs?

4 METHODOLOGY

This study adopted the descriptive design of the survey type. The sample for the study consisted of 450 teachers randomly selected from two hundred and ninety six (296) secondary schools in the eighteen Local Government Areas of Ondo State. A combination of multistage, stratified and simple random sampling technique was used in selecting the sample. Stratified random sampling technique based on urban/ rural location was adopted in the selection of the nine Local Government Areas and five schools from each Local Government Area. Ten teachers were drawn from each school using simple random sampling technique which implies that 50 teachers will be drawn from each Local Government Area giving a total of 450 teachers (respondents).

A questionnaire titled "Challenges of Information and Communication Technology for Secondary School Teachers (CICTSST)" was used to collect the data. The instrument was validated and administered on the respondents through trained research assistants. Data collected were analyzed using frequency counts, percentages, mean and bar chart.

5 RESULTS

The findings of the study are presented below:

Research Question1: Are ICT tools available in schools?

Table 1. Availability of ICT tools in secondary schools

ICTs	N	F	%
Computer	450	429	95.33
E-Mail	450	30	6.67
Internet	450	30	6.67
Digital camera	450	0	0
Scanner	450	2	0.44
Multimedia	450	12	2.67
Projector	450	0	0
VCD Player	450	11	2.44
Satellite T.V	450	0	0

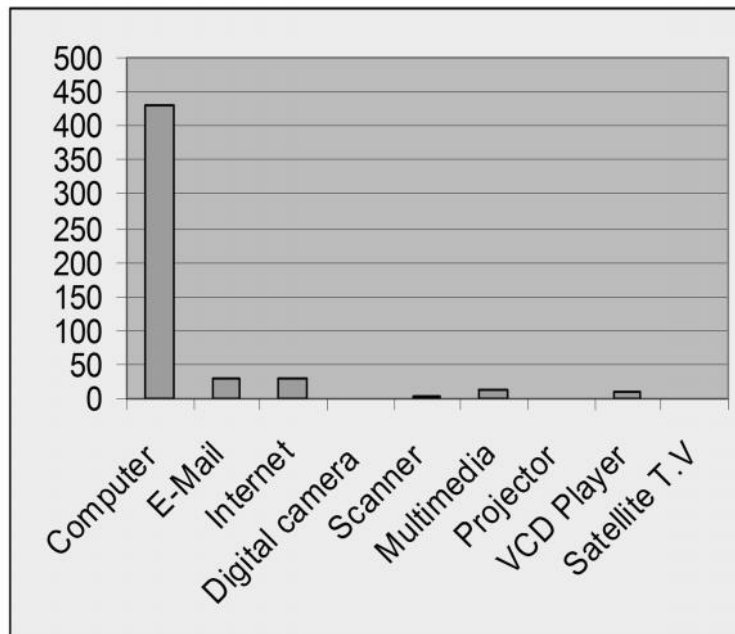


Fig. 1. Graph showing summary of ICT facilities available in secondary schools

Figure 1 shows that aside of other identified ICT facilities; it is only computer that is available in schools.

Research Question 2: Do teachers have access to ICT facilities?

Table 2. Mean summary of teachers' access to ICT facilities in schools

S/N ITEMS	AGREE	DISAGREE	MEAN $\bar{X}$	REMARKS
1. I have computer at home	106	344	2.04	DISAGREED
2. I can operate computer	120	330	2.0	DISAGREED
3. I use computer in the school.	111	339	1.98	DISAGREED
4. I have e-mail and I can check my e-mail address in the school and at home.	107	343	1.97	DISAGREED
5. I have attended computer training and seminar.	112	338	1.99	DISAGREED

Table 2. indicated that majority of the respondents disagreed on items 1-5. This signifies that majority of the teachers in secondary schools do not have computer at home, they cannot operate computer, they do not have access to computer in their various schools, they do not have e-mail addresses talk less of checking their e-mail addresses and they have not attended computer training and seminar. The results indicate that teacher do not have access to ICT facilities.

Research Question 3: What are the factors hindering the effective utilization of ICT facilities for instructional purposes?

Table 3. Mean summary of factors hindering effective utilization of ICT facilities for instructional purposes

S/N	ITEMS	AGREE	DISAGREE	MEAN $\bar{X}$	REMARKS
1.	Teachers lack of ICT skills hinders the usage of ICT in secondary schools.	339	111	3.06	AGREED
2.	Lack of confidence in using ICT hinder the teacher's readiness and confidence in using ICT.	334	116	2.98	AGREED
3.	Insufficient knowledge of appropriate software contributes to non-implementation of ICT.	296	154	2.72	AGREED
4.	Lack of knowledge of how to evaluate the use and the role play by ICT in teaching and learning hinders the confidence of using ICT.	327	123	2.89	AGREED
5.	Insufficient knowledge of how to use ICT equipment hinders the readiness of using ICT.	334	116	2.96	AGREED
6.	Unavailability of infrastructure contributes to non-implementation of ICT policy in schools.	310	140	2.98	AGREED

The result in table 3 showed that the majority of the respondents agreed on the whole items (1-6). This is to say that teacher's lack of ICT skills, lack of confidence in using ICT, Insufficient knowledge of how to use ICT equipment, unavailability of infrastructure, lack of knowledge of how to evaluate the use and the role played by ICT in teaching and learning and insufficient knowledge of appropriate software are factors hindering the effective utilization of ICT facilities for instructional purposes.

Research Question 4: Do teachers have positive attitude toward the utilization of ICT in teaching and learning?

Table 4. Mean summary of teachers' attitude toward utilization of ICT in teaching and learning

S/N Items	AGREE	DISAGREE	MEAN $\bar{X}$	REMARKS
1. ICT makes teaching more efficient	380	70	3.33	AGREED
2. Using ICT makes lesson have fun.	350	100	3.04	AGREED
3. Using ICT improves presentation of materials	360	90	3.18	AGREED
4. Using ICT makes teaching more diverse and encourages individual learning.	307	143	3.31	AGREED
5. ICT assists in carrying out administrative work.	307	143	2.97	AGREED

Table 4 revealed that majority of the respondents agreed on all the items 1-5. This signifies that teachers show positive attitude toward utilization of ICT in teaching and learning.

Research Question 5: Do students have access to ICTs?

Table 5. Mean summary of students' level of access to ICT

S/N	AGREE	DISAGREE	MEAN $\bar{X}$	REMARKS
1. Students have access to ICTs in the schools.	187	263	2.34	DISAGREED
2. My students use computer only during computer lessons.	170	280	2.22	DISAGREED

Table 5 revealed that the majority of the respondents disagreed that students have access to ICT facilities in their schools. This result therefore shows that students do not have access to ICT.

6 DISCUSSION

On the issue of access to ICT facilities in the respondents various schools, the findings showed that aside of other identified ICT facilities, it is only computer that is available in their various schools. This is in disagreement with the report by [2] that ICT equipment like internet, video player, digital camera, data projector is adequate and available in the respondents various schools. Reference [10] confirmed that teachers are indispensable to successful computer education. The ultimate to use or not to use the computer is dependent on the individual teachers. Successful implementation of computer education can only be assured through teachers who acquired the necessary knowledge and skills.

Reference [10] study which investigated teachers' self-efficacy in implementing of computer education in Nigerian secondary school found that:

- Most of the teachers in Federal Government Colleges in Nigeria do not have the needed experience and competence in the use of computer either for educational or industrial purposes.
- A majority of male and female teachers in Federal Government Colleges do not have needed competence in basic computer operations.
- Most of the teachers in Federal Government Colleges in Nigeria do not have the needed skills and knowledge in the use of common computer software.

7 CONCLUSION

The results obtained from the analyses of the data gathered in this research indicated that majority of teachers do not have access to ICT. This is because the ICT facilities are not available for teachers' access. The result showed that factors such as lack of skills, lack of confidence, insufficient knowledge of ICT equipment on part of the teachers, unavailability of infrastructure, insufficient knowledge of appropriate software and lack of knowledge of how to evaluate the use and the role to play by ICT in teaching and learning are factors affecting the utilization of ICTs for instructional purposes. The finding further revealed that teachers' lack of ICT skills hinders the effective implementation of ICT in secondary schools.

The study also shows that application of ICT in the classroom makes lesson very interesting and easy to deliver. The finding of the study also revealed that teachers show positive attitude toward the utilization of ICT in teaching and learning.

8 RECOMMANDATIONS

Consequent upon these findings of this study, the following recommendations were made:

- ICT Professionals should organize individualist training for teachers on how to utilize ICT facilities in solving everyday educational problems.
- Federal, state and local government, corporate bodies and PTA should extend helping hands in the provision of ICT facilities to schools within their locality.
- The government should employ applicants with B.sc(Ed) and B.Ed. Computer education to teach the subject in our secondary schools.
- The government should provide enough funds for schools to purchase computer for instructional purposes and make available suitable computer environment in our secondary schools.
- Conferences, workshops and symposium should be organized to train people and enlighten them on the need for computer education.
- Curriculum developers should make computer education one of the core subjects to be offered in secondary schools.
- The state ministries of education through their local inspectors of education (LIE) should monitor the implementation of computer education program in Nigeria secondary schools.

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An Appraisal of Educational Technology Usage in Secondary Schools in Ondo State (Nigeria)

Olufemi Victor ADEOLUWA¹, Olukayode Solomon ABODERIN¹, and Oladele Dennis OMODARA²

¹Department of Curriculum Studies,
Ekiti State University,
Ado-Ekiti, Nigeria

²Department of Curriculum Studies,
College Of Education, Ikere
Ekiti State, Nigeria

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ABSTRACT: This study examined and appraised the use of Educational Technology in secondary schools in Ondo State South West, Nigeria. The study investigated the level of availability of Educational Technology facilities in schools, attitude of teachers toward educational technology, the perceived benefits of using Educational Technology, the problems facing the use of Educational Technology in secondary schools and Application of Educational Technology in schools by teachers. The descriptive survey design was used for the study. The population consisted of all the teachers and principals of the secondary schools in Ondo State. The sample consists of 400 teachers and 40 principals randomly selected from the secondary schools in Ondo State. A self designed questionnaire tagged Educational Technology and Secondary Schools (ETSS) was used to collect the data for the study. Data collected for the study were analyzed using frequency count, percentage scores, mean and charts. The study revealed that Educational Technology facilities were lacking in schools and teachers and students were to a little extent exposed to the use of Educational Technology. Moreover, the study revealed the perceived benefits of using Educational Technology in schools which include making teaching-learning interesting; helping the distance learning program; Educational technology provide for individual differences; Educational technology makes teaching efficient and effective. However, despite these perceived benefits, the study also revealed some of the challenges facing Educational technology in secondary schools as: Epileptic supply of electricity; misconception of right concept of educational technology; Shortage of specialist in educational technology; inadequate facilities to support full application of educational technology and lack of fund. It was therefore recommended that government should increase the funding of the education sector. There should also be periodic training for teachers on educational technology skills acquisition.

KEYWORDS: Educational Technology usage, Teachers in secondary schools, teaching and learning processes.

INTRODUCTION

Educational technology is one of the latest innovations that have been adopted in Nigeria in a bid to improve the quality of learning. Educational technology identifies and solves educational problems and could employ any desirable way to achieve its set objectives. It has been discovered that modern education faces a lots of problems. The attempts at solving these problems could lead to the use of innovative teaching and learning system. Reference [2] defined Educational technology as the integration of variables in order find out and solve all problems involved in all aspects human learning. The innovative teaching learning system involves the use of Educational technology to achieve the desired instructional objectives. The proper uses of Educational technology and instructional materials have their benefits

in the achievement of a desired goal. Reference [13], says that educational technology ensure proper grasp of subject and develop imagination; they bring past into present and crowd the record of years and even entries into short period of minutes. Reference [14] submits that Educational Technology is far from new. The first to empty an abacus in his mathematics class was making use of technology as every educator who uses overhead projector, tape recorder, television, 'movies, computer and so on to help their students learn better the contents of their courses. His submission points to the proper essence of educational technology as the application of scientific knowledge to teaching and learning of knowledge and skills.

According to [7], some teachers see educational technology as a threat to their profession and would not want to change from their old system of approach. Many teachers do not have the right concept of educational technology. They accord wrong meaning to educational technology. Teaching and learning has gone beyond the teacher standing in front of a group of pupils and disseminating information to them without the students' adequate participation [3]. Educational technology has the capacity higher interactive potential for user to develop their individual and creative abilities. According to [12] educational technology provides productive teaching and learning in order to increase people's creative and intellectual resources especially in today's information society.

For learning to take place, learning environment must be sufficiently made conducive. It must be rich in resources as to provide learning experiences needed by the learner for the expected learning outcomes. The use of different forms of media ranging from audio to visual, audiovisual, model, mock-ups, graphics, projected, non-projected, and realia (real objects) will encourage enabling environment and experiences that can promote learning [11]. According to [4] facilities like computers, radio (tape recorders), television sets, video disc players, bullet boards were available in schools, while some facilities like projectors, electronic notice boards, internets, filmstrips are scanty available in schools.

Reference [8] submission on the relevance of the technology to education particularly as regards to learning in secondary school reaffirms that students must have range of skills to express themselves not only through paper and pencil but also audio, video, animation designed software as well as host of new environment (e-mail, web-sites, message board, etc). It is observed from this submission that there is a need for students to develop learning skills that will enable them to think critically, analyse information, communicate and solve problem.

The roles of educational technology in teaching and learning process cannot be underestimated. The under listed are what [10] considered as the roles of educational technology in teaching and learning:

- Increase the rate of learning and at the same time allow the teacher to use more time on other gainful activities
- Reinforce verbal and visual messages. Pupils would generally find it difficult to understand abstract ideas discussed by their teachers. However, if the abstract ideas are put in form of models, pictures, etc. pupils understand them with ease and they remain permanent in their memories
- Through the use of media, emphasis is placed on realistic learning rather than rote learning
- Instructional media have a way of motivating and arresting pupils' attention. Pupils' curiosity and consciousness get increased and thereby provide a sound environment for realistic and enjoyable teaching and learning atmosphere
- Terms and concepts that are abstract are best illustrated through the use of instructional media.

PURPOSE OF THE STUDY

This study is designed to examine and appraise the use of Educational Technology in Secondary Schools in Ondo State.

Specifically, the study examined:

- Availability of educational technology facilities in secondary schools.
- The attitude of teachers toward educational technology in secondary schools.
- The perceived benefits of educational technology in secondary schools.
- The challenges facing the adoption of educational technology in secondary schools.
- The level of teachers' application of educational technology in teaching.

RESEARCH QUESTIONS

The following research questions were raised to guide this study:

- i) To what extent are the educational technology facilities available for teaching and learning in secondary schools?
- ii) What is the attitude of teachers toward educational technology in secondary schools?

- iii) What are the perceived benefits of educational technology in secondary schools?
- iv) What are the challenges facing the adoption of educational technology in secondary schools?
- v) Do teachers apply educational technology facilities in their teaching?

METHODOLOGY

The descriptive survey design was used for this study. The population for the study consisted of all the teachers and principals of the secondary schools in Ondo State. The sample for the study is made up of 400 teachers and 40 principals randomly selected from 40 secondary schools in the state. A self-designed questionnaire tagged “Educational Technology for Secondary Schools (ETSS)” was used to collect the data for the study. The instrument was validated by research experts in educational technology and test and measurement. The Cronbach Alpha was used to determine the reliability of the instrument and the reliability coefficient was 0.75. The questionnaire was administered by the researchers with the help of research assistants in the state. Personal contacts of the researchers with the respondents enhanced good and prompt response from the respondents. Data collected were analyzed using frequency counts, percentage scores, mean and chart.

RESULTS

Table 1. *Availability of educational technology facilities in secondary schools*

S/N	ITEMS	AVAILABLE	%	NOT AVAILABLE	%
1	Radio(tape Recorders)	190	43.2	250	56.8
2	Television sets	155	35.2	285	64.8
3	Video	201	45.7	239	54.3
4	Bulletin board	217	49.3	223	50.7
5	Computer	270	61.4	170	38.6
6	Charts	268	60.9	172	39.1
7	Filmstrip	158	35.9	282	64.1
8	Internet	90	20.5	350	79.5
9	Electronic notice board	75	17.1	365	82.9
10	Disc Player	168	38.2	272	61.8
11	Textbook	245	55.7	195	44.7
12	Multimedia	130	29.5	310	70.5
	MEAN		41.1		59.9

Table1 above revealed that facilities such as computer, charts and textbooks were available while other facilities such as radio(tape recorders), television sets, video, bulletin board, filmstrip, Internet, electronic notice board, disc player and multimedia were scantily available. This finding is in agreement with [7].

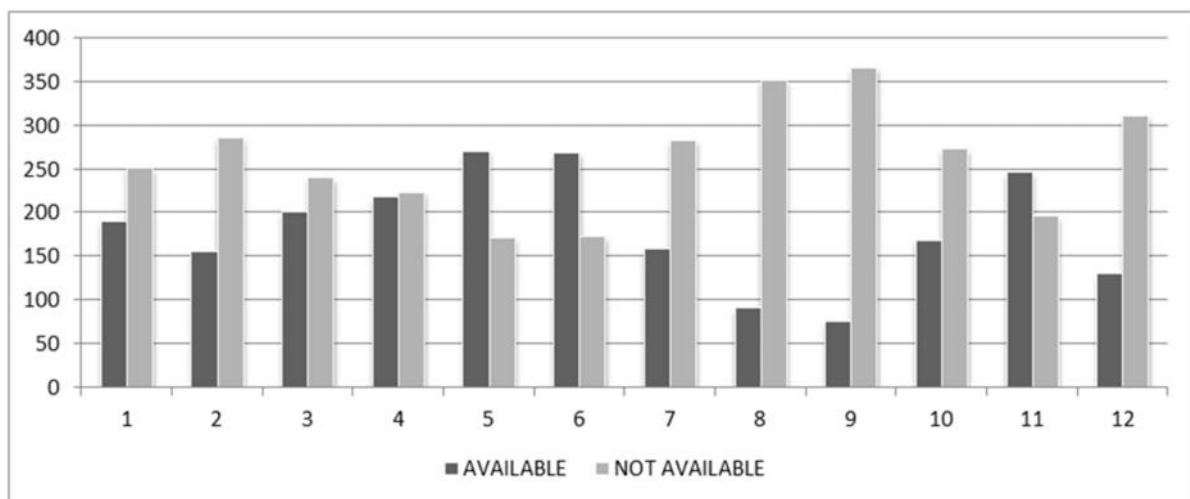
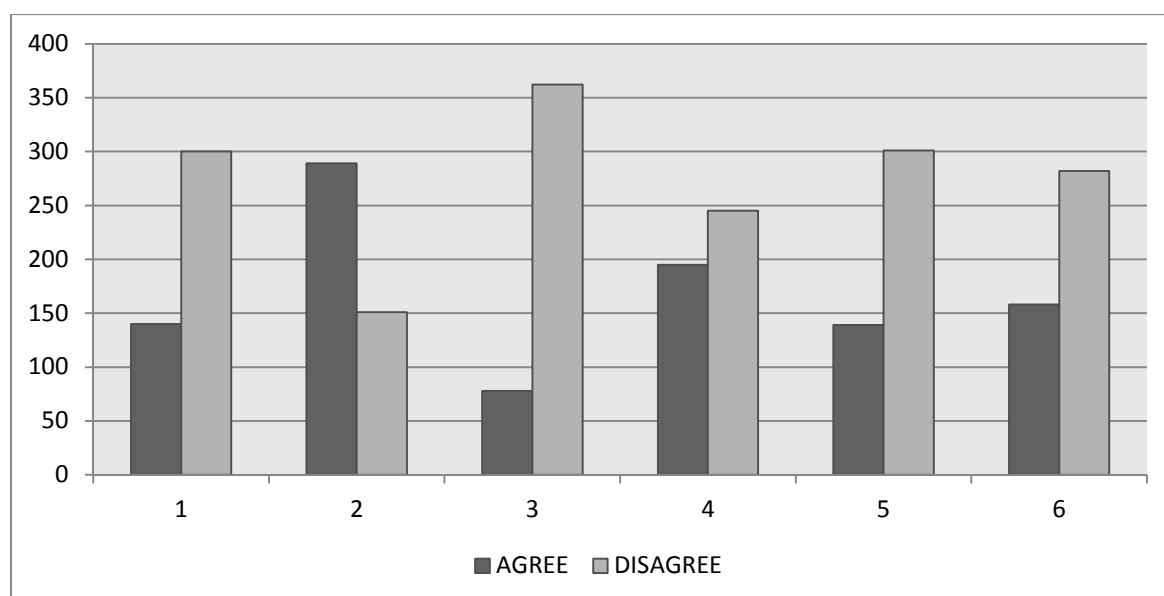


Fig. 1. *Summary of availability of educational technology facilities in secondary schools*

Table 2. Attitude of teachers toward educational technology

S/N	ITEMS	AGREE	%	DISAGREE	%
1	Teachers are exposed to the use of educational technology in teaching	140	31.9	300	68.2
2	No enough time to plan the use of instructional materials	289	65.7	151	34.3
3	There are enough instructional materials to teach the student	78	17.7	362	82.7
4	Periodic training is organized for teachers on the use of educational technology in schools.	195	44.3	245	55.7
5	Teachers are knowledgeable in the use of educational technology	139	31.6	301	68.4
6	Educational technology is too difficult to apply in the classroom	158	35.9	282	64.1
	MEAN		48.8		51.2

Table 2 revealed that teachers were not exposed to the use of educational technology in teaching and learning (31.9%). 65.7% agreed that no enough time to plan the use of instructional materials in the schools while 82.7% disagreed that there are enough instructional materials to teach their students. Of the respondents, 44.3% agreed that periodic training is organized for teachers on the use of educational technology in schools; 31.6% agreed that Teachers are knowledgeable in the use of educational technology and 64.1% disagreed that educational technology is too difficult to apply in the classroom. This means that teachers' attitude toward educational technology is not encouraging.

**Fig. 2. Summary of attitude of teachers toward educational technology****Table 3. Perceived Benefits of Educational Technology**

S/N	ITEMS	AGREE	%	DISAGREE	%
1	Educational technology makes teaching efficient and effective.	342	77.7	98	21.8
2	Instructional materials attract and sustain the attention of learners.	299	68	141	32
3	Educational technology provide for individual differences.	247	56.1	193	43.9
4	Educational technology helps in making teaching and learning more interesting.	317	72	123	28
5	It helps in distance learning programme.	273	62	167	38
6	Instructional materials provide students with realistic experience.	264	60	176	40
	MEAN		66		34

Results in Table 3 showed the perceived benefits of educational technology in the secondary schools. These include making teaching and learning efficient and effective (77.7%); Instructional materials attract and sustain the attention of learners (68%); provide for individual differences (56.1%) and making teaching-learning more interesting (72%). Other perceived benefits include helping distance learning programme (62%) and instructional materials provide students with realistic experience (60%). This finding is in agreement with [2].

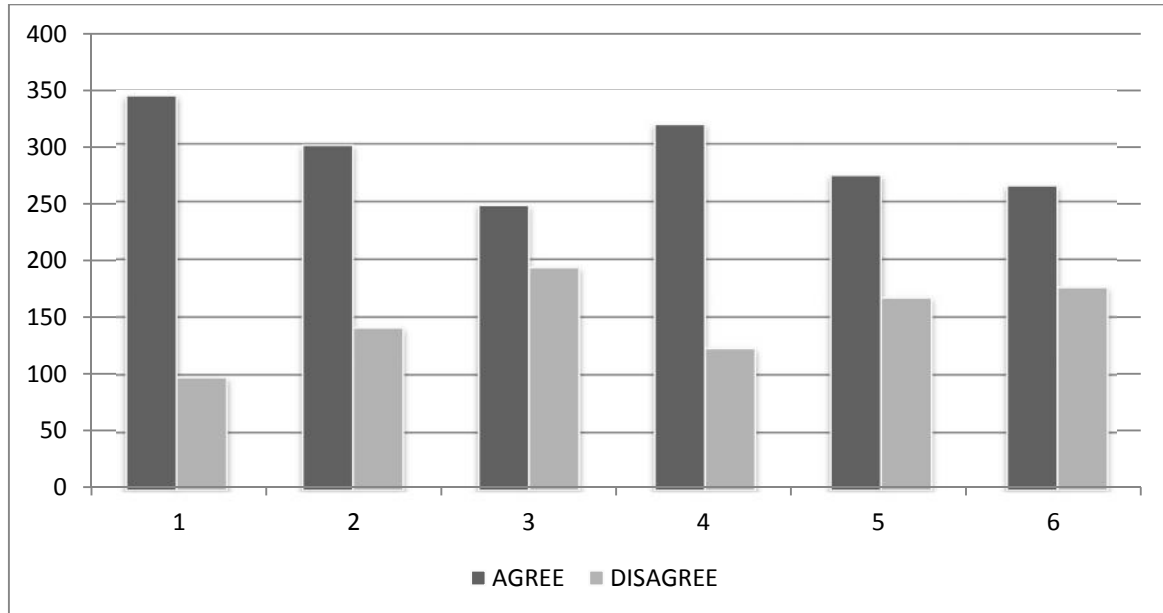


Fig. 3. Summary of Perceived Benefits of Educational Technology

Table 4. Challenges facing the adoption of educational technology in secondary schools.

S/N	ITEMS	AGREE	%	DISAGREE	%
1	Misconception of right concept of educational technology	321	72.9	119	27.1
2	Shortage of relevant books	280	63.6	160	36.4
3	Shortage of specialist in educational technology	310	70.5	130	29.5
4	Inadequate funding	275	62.5	165	37.5
5	Epileptic supply of electricity	250	56.8	190	43.2
6	Teacher resistance to change	309	70.2	131	29.7
7.	Shortage of instructional materials and equipment	245	55.7	195	44.3
8.	Low staff morale	278	63.2	162	36.8
	MEAN		64.4		35.6

From Table 4, it revealed that the major challenge facing the adoption of educational technology in Nigerian secondary schools is the misconception of right concept of educational technology (72.9%). Another challenge facing the adoption of educational technology is shortage of specialist in educational technology (70.5%). Other major challenges are inadequate funding in schools (62.5%); epileptic supply of electricity (56.8%); shortage of relevant books (63.6%); teachers resistance to change (70.2%); shortage of instructional materials and equipment (55.7%) and the low staff morale (63.2%). This finding is in agreement with [7].

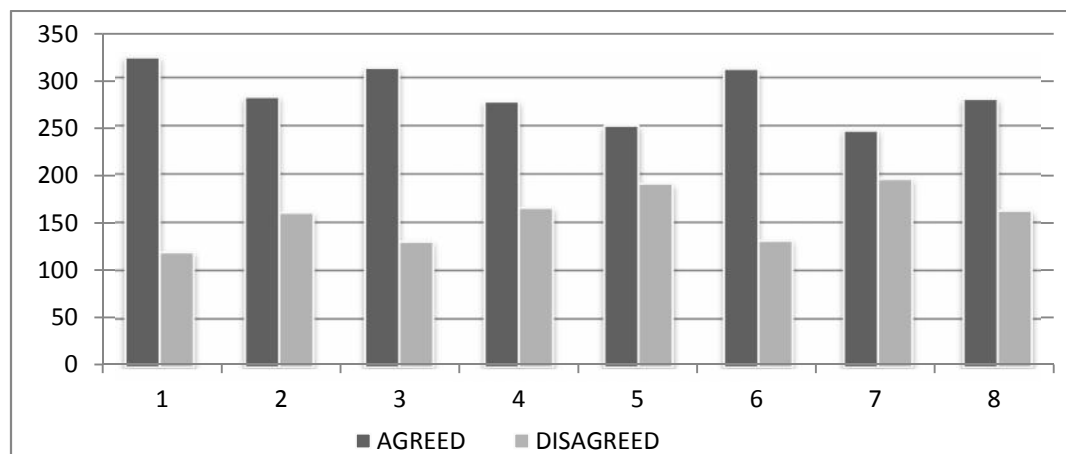


Fig. 4. Summary of challenges facing the adoption of educational technology in secondary schools

Table 5. Application of Educational Technology in secondary schools by teachers

S/N	ITEMS	AGREE	%	DISAGREE	%
1	I use instructional materials in every teaching process	123	28	317	72
2	I do use radio and television programmes to teach my students	142	32.3	298	67.7
3	I use computer to teach my students	154	35	286	65
4	I do produce educational media for my lessons	200	45.5	240	54.5
5	I use projector to teach large in my school	130	29.5	310	70.5
6	It is not necessary that instruction in schools involve instructional materials.	287	65.2	153	37.7
	MEAN		39		61

Table 5 showed the extent to which teachers apply educational technology facilities in secondary schools. Only 28% of the respondents agreed that they use instructional materials in every teaching process in the schools, while 32.3% of them agreed that teachers were using radio and television programs to teach their students. 35% of the respondents also agreed that their use computer to teach their students. Of all the respondents, 45.5 % agreed that they produce educational media for their lessons. 29.5% agreed used projector to teach large in the schools and 65.2% agreed that It is not necessary that instruction in schools involve instructional materials. This means that majority of teachers do not apply educational technology in their various schools.

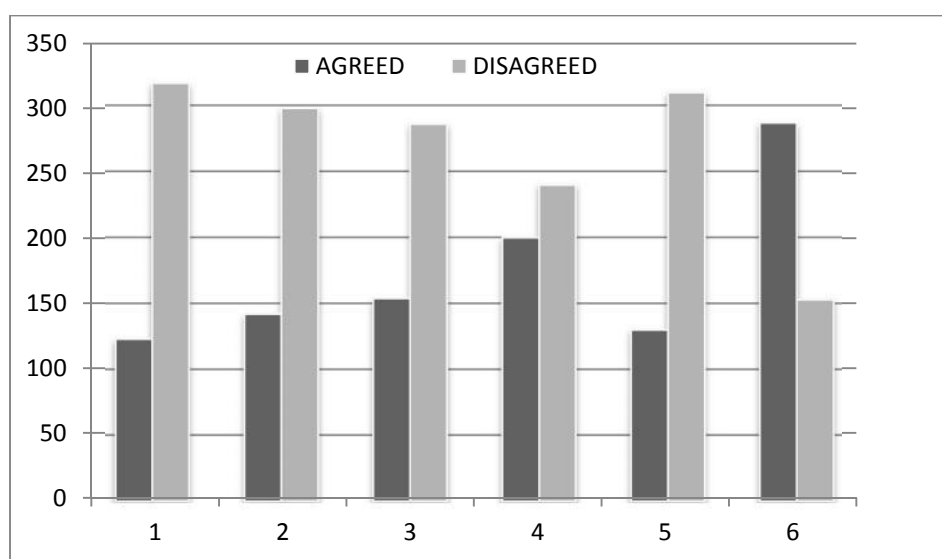


Fig. 5. Summary of application of educational Technology in secondary schools by teachers

CONCLUSION AND RECOMMENDATIONS

The finding of this study has shown that Nigeria secondary schools are lagging behind in the level of application of educational technology in the teaching-learning process. The educational technology facilities are lacking in schools, the capacity for using educational technology by both teachers and students is also very low. Despite the perceived benefits in the use of educational technology in school, there are a lot of factors inhibiting the successful application of educational technology in secondary schools. In order to fit into the new scientific order, it is necessary for Nigerian institutions and individuals alike to develop a society and culture that places a high value on educational technology. The following recommendations are therefore made. The government should increase funding for the entire educational sector with emphasis on educational technology this will help improve the level of educational technology facilities in the schools. There should also be continuous and periodic training of teacher son educational technology skills acquisition. This will help provide them with practical and functional knowledge educational technology with the hope of integrating it with instructional methods of teaching and leaning.

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Mathematical Expressions for Estimation of Errors in the Formulas which are used to obtaining intermediate values of Biological Activity in QSAR

Nizam Uddin

M. B. Khalsa College,
 Indore, Madhya Pradesh, India

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ABSTRACT: Quantitative structure-activity relationships (QSAR) attempts to find consistent relationships between the variations in the values of molecular properties and the biological activity for a series of compounds. These physicochemical descriptors, which include parameters to account for hydrophobicity, topology, electronic properties, and steric effects, are determined empirically or, more recently, by computational methods. Quantitative structure-activity relationships (QSAR) generally take the form of a linear equation where the biological activity is dependent variable. Biological activity is depended on the parameters and the coefficients. Parameters are computed for each molecule in the series. Coefficients are calculated by fitting variations in the parameters. Intermediate values of the biological activity are obtained by some formulas. These formulas are worked in tabulated values of biological activity in Quantitative structure-activity relationships. These formulas are worked in the conditions and all conditions are based on the position of the point lies in the table. Derived formulas using Newton's method for interpolation are worked in conditions which are depending on the point lies. If the point lies in the upper half then used Newton's forward interpolation formula. If the point lies in the lower half then we used Newton's backward interpolation formula. And when the interval is not equally spaced then used Newton's divide difference interpolation formula. When the tabulated values of the function are not equidistant then used Lagrangian polynomial. Mathematical expressions are derived for estimation of errors using intermediate values and formulas.

KEYWORDS: Biological activity, Estimation of Errors, Intermediate values, Mathematical Expressions, QSAR.

1 INTRODUCTION

Quantitative structure-activity relationships (QSAR) represent an attempt to correlate structural or property descriptors of compounds with activities. These physicochemical descriptors, which include parameters to account for hydrophobicity, topology, electronic properties, and steric effects, are determined empirically or, more recently, by computational methods. Activities used in QSAR include chemical measurements and biological assays [1]-[5].

A QSAR generally takes the form of a linear equation

$$\text{Biological Activity} = \text{Constant} + (C_1 \bullet P_1) + (C_2 \bullet P_2) + (C_3 \bullet P_3) + \dots \quad (1)$$

Where the parameters P_1 through P_n are computed for each molecule in the series and the coefficients C_1 through C_n are calculated by fitting variations in the parameters and the biological activity [1].

If
$$f(CP) = \text{Constant} + (C_1 \bullet P_1) + (C_2 \bullet P_2) + (C_3 \bullet P_3) + \dots$$

From equation (1), we got:

$$BA = f(CP)$$

Suppose $CP = X$ then we can write more simple form: $BA = f(X)$

Where BA is biological activity and X is variable from above function [1]. Some formulas are derived on the basis of this function using Newton's method for interpolation and Lagrangian polynomial. These formulas are used to obtaining intermediate values of the biological activity. Derived formulas using Newton's method for interpolation are worked in conditions which are depending on the point lies. If the point lies in the upper half then used Newton's forward interpolation formula. If the point lies in the lower half then we used Newton's backward interpolation formula. And when the interval is not equally spaced then used Newton's divide difference interpolation formula. When the tabulated values of the function are not equidistant then used Lagrangian polynomial [6]-[22].

2 IF THE POINT LIES IN THE UPPER HALF

Let $BA = f(X)$ be a function defined by n points $(BA_0, X_0), (BA_1, X_1), \dots, (BA_n, X_n)$. Where BA is biological activity and X is the variable. When $X_1, X_2, X_3, \dots, X_n$ are equally spaced with interval h . And If the point lies in the upper half then we used following formula [1] [7]-[9]:

$$BA(X) = BA_0 + \Delta BA_0(q) + \frac{\Delta^2 BA_0}{2!}(q)[(q-1)] + \dots + \frac{\Delta^n BA_0}{n!}[(q)(q-1)\dots(q-n)]$$

[Where Δ is forward difference operator and $\frac{X - X_0}{h} = q$]

2.1 ESTIMATION OF ERROR

Let $BA = f(X)$ be a function defined by $(n+1)$ points $(BA_0, X_0), (BA_1, X_1), \dots, (BA_n, X_n)$. When $X_1, X_2, X_3, \dots, X_n$ are equally spaced with interval h and this function is continuous and differentiable $(n+1)$ times.

Let $BA = f(X)$ be approximated by a polynomial $P_n(X)$ of degree not exceeding n such that

$$P_n(X_i) = BA_i \quad [\text{Where } i = 1, 2, 3, \dots, n] \quad (2)$$

Since the expression $f(X) - P_n(X)$ vanishes for $X_1, X_2, X_3, \dots, X_n$,

$$\text{We put } f(X) - P_n(X) = K\phi(X) \quad (3)$$

$$\text{Where } \phi(X) = (X - X_0)(X - X_1)\dots(X - X_n) \quad (4)$$

And K is to be determined in such a way that equation (3) holds for any intermediate values of X , say $X - X'$ [where $X_0 \leq X' \leq X_n$].

$$\text{Therefore from (3): } K = \frac{f(X') - P(X')}{\phi(X')} \quad (5)$$

Now we construct a function $f(X)$ such that: $f(X_0) = f(X_1) = P_n(X) - K\phi(X)$

Where K is given by equation (5).

$$\text{It is clear that: } f(X_0) = f(X_1) = f(X_2) = f(X_3) = \dots = f(X_n) = f(X') = 0 \quad (6)$$

Let $f(X)$ vanishes $(n+2)$ times in the interval $X_0 \leq X \leq X_n$; consequently, by the repeated application of Rolle's Theorem [23] [24], $f'(X)$ must vanish $(n+1)$ times, $f''(X)$ must vanish n times etc in the interval $X_0 \leq X \leq X_n$.

Particularly, $f^{(n+1)}(X)$ must vanish once in the interval $X_0 \leq X \leq X_n$. Let this point be $X = U$, $X_0 < U < X_n$.

Now differentiating equation (6) $(n+1)$ times with respect to X and putting $X = U$, we got:

$$f^{(n+1)}(U) - K(n+1)! = 0$$

Or
$$K = \frac{f^{(n+1)}(U)}{(n+1)!} \quad (7)$$

Putting this value of K in equation (5), we got:
$$\frac{f^{(n+1)}(U)}{(n+1)!} = \frac{f(X') - P_n(X')}{\varphi(X')}$$

Or
$$f(X') - P_n(X') = \frac{f^{(n+1)}(U)}{(n+1)!} \varphi(X'), \quad X_0 < U < X_n$$

Since X' is arbitrary therefore on dropping the prime on X' we got:

$$f(X) - P_n(X) = \frac{f^{(n+1)}(U)}{(n+1)!} \varphi(X), \quad X_0 < U < X_n \quad (8)$$

Now we use Taylor's theorem [25] [26]:
$$f(X+h) = f(U) + hf'(U) + \frac{h^2}{2!} f''(U) + \dots + \frac{h^n}{n!} f^n(U) + \dots \quad (9)$$

Neglecting the terms containing second and higher powers of h in equation (9), we got:

$$f(U+h) = f(U) + hf'(U)$$

Or
$$f'(U) = \frac{f(U+h) - f(U)}{h} \quad (10)$$

Or
$$f'(U) = \frac{1}{h} \Delta f(U) \quad [\because \Delta f(X+h) = f(X) - f(U)]$$

$$Df(U) = \frac{1}{h} \Delta f(U) \quad [\because D = \frac{d}{dU}]$$

$$D = \frac{1}{h} \Delta \quad [\text{Because } f(U) \text{ is arbitrary}]$$

$$\therefore D^{n+1} = \frac{1}{h^{n+1}} \Delta^{n+1}$$

From equation (10), we got:
$$f^{(n+1)}(U) = \frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(U)$$

Putting the values of $f^{(n+1)}(U)$ in equation (8), we got:

$$f(X) - P_n(X) = \left[\frac{\varphi(X)}{(n+1)!} \right] \left[\frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(U) \right]$$

$$f(X) - P_n(X) = \left[\frac{(X-X_0)(X-X_1)(X-X_2)\dots(X-X_n)}{(n+1)!} \right] \left[\frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(U) \right] \quad (11)$$

If $\frac{X-X_0}{h} = q$ Then: $X-X_0 = hq$
 $X-X_1 = X - (X_0 + h) = (X-X_0) - h = (hq - h) = h(q-1)$

Similarly $X-X_2 = h(q-2)$

:

:

:

Similarly $X-X_n = h(q-n)$

Putting these values in equation (11), we got:

$$f(X) - P_n(X) = \left[\frac{(hq)\{h(q-1)\}\{h(q-2)\}\{h(q-3)\}\dots\{(q-n)\}}{(n+1)!} \right] \left[\frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(U) \right]$$

$$f(X) - P_n(X) = \left[\frac{q(q-1)(q-2)(q-3)\dots(q-n)}{(n+1)!} \right] \left[\Delta^{(n+1)} f(U) \right]$$

This is mathematical expression for estimation of error, if the point lies in the upper half.

3 IF THE POINT LIES IN THE LOWER HALF

Let $BA = f(X)$ be a function defined by n points $(BA_0, X_0), (BA_1, X_1), \dots, (BA_n, X_n)$. Where BA is biological activity and X is the variable. When $X_1, X_2, X_3, \dots, X_n$ are equally spaced with interval h . And If the point lies in the lower half then we used following formula [1] [7]-[9]

$$BA(X) = BA_n = \nabla BA_n(r) + \frac{\nabla^2 BA_n}{2!} [r(r+1)] + \dots + \frac{\nabla^n BA_n}{n!} [r\{r+1\}..r+(n-1)]$$

[Where ∇ is backward difference operator and $\frac{X - X_n}{h} = r$]

3.1 ESTIMATION OF ERROR

Let $BA = f(X)$ be a function defined by $(n+1)$ points $(BA_0, X_0), (BA_1, X_1), \dots, (BA_n, X_n)$. When $X_1, X_2, X_3, \dots, X_n$ are equally spaced with interval h and this function is continuous and differentiable $(n+1)$ times.

Let $BA = f(X)$ be approximated by a polynomial $P_n(X)$ of degree not exceeding n such that

$$P_n(X_i) = BA_i \quad [\text{Where } i = 1, 2, 3, \dots, n] \quad (12)$$

Since the expression $f(X) - P_n(X)$ vanishes for $X_1, X_2, X_3, \dots, X_n$,

$$\text{We put we put } f(X) - P_n(X) = K\phi(X) \quad (13)$$

$$\text{Where } \phi(X) = (X - X_n)(X - X_{n-1})\dots(X - X_0) \quad (14)$$

And K is to be determined in such a way that equation (13) holds for any intermediate values of X , say $X - X'$ [where $X_0 \leq X' \leq X_n$].

Therefore from equation (13),

$$K = \frac{f(X') - P(X')}{\phi_1(X')} \quad (15)$$

Now we construct a function $f(X)$ such that: $f(X_0) = f(X_1) - P_n(X) - K\phi_1(X)$

Where K is given by equation (15).

$$\text{It is clear that: } f(X_0) = f(X_1) = f(X_2) = f(X_3) = \dots = f(X_n) = f(X') = 0 \quad (16)$$

Let $f(X)$ vanishes $(n+2)$ times in the interval $X_0 \leq X \leq X_n$; consequently, by the repeated application of Rolle's Theorem [23] [24], $f'(X)$ must vanish $(n+1)$ times, $f''(X)$ must vanish n times etc in the interval $X_0 \leq X \leq X_n$.

Particularly, $f^{(n+1)}(X)$ must vanish once in the interval $X_0 \leq X \leq X_n$. Let this point be $X = Z$, $X_0 < Z < X_n$.

$$f^{(n+1)}(Z) - K(n+1)! = 0$$

$$\text{Or:} \quad K = \frac{f^{(n+1)}(Z)}{(n+1)!} \quad (17)$$

Putting this value of K in equation (15), we got: $\frac{f^{(n+1)}(Z)}{(n+1)!} = \frac{f(X') - P_n(X')}{\varphi_1(X')}$

$$\text{Or} \quad f(X') - P_n(X') = \frac{f^{(n+1)}(Z)}{(n+1)!} \varphi_1(X'), \quad X_0 < Z < X_n$$

Since X' is arbitrary therefore on dropping the prime on X' we got:

$$f(X) - P_n(X) = \frac{f^{(n+1)}(Z)}{(n+1)!} \varphi_1(X), \quad X_0 < Z < X_n \quad (18)$$

Now we use Taylor's theorem [25] [26]:

$$f(X+h) = f(Z) + hf'(Z) + \frac{h^2}{2!} f''(Z) + \dots + \frac{h^n}{n!} f^n(Z) + \dots \quad (19)$$

Neglecting the terms containing second and higher powers of h in equation (19), we got:

$$f(Z+h) = f(Z) + hf'(Z)$$

$$\text{Or:} \quad f'(Z) = \frac{f(Z+h) - f(Z)}{h} \quad (20)$$

$$\text{Or:} \quad f'(Z) = \frac{1}{h} \Delta f(Z) \quad [\because \Delta f(X+h) = f(X)]$$

$$Df(Z) = \frac{1}{h} \Delta f(Z) \quad [\because D = \frac{d}{dZ}]$$

$$D = \frac{1}{h} \Delta \quad [\text{Because } f(Z) \text{ is arbitrary}]$$

$$\therefore D^{n+1} = \frac{1}{h^{n+1}} \Delta^{n+1}$$

$$\text{From equation (20), we got:} \quad f^{(n+1)}(Z) = \frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(Z)$$

Putting the values of $f^{(n+1)}(Z)$ in equation (18), we got:

$$f(X) - P_n(X) = \left[\frac{\varphi_1(X)}{(n+1)!} \right] \left[\frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(Z) \right]$$

$$f(X) - P_n(X) = \left[\frac{(X-X_0)(X-X_1)(X-X_2)\dots(X-X_n)}{(n+1)!} \right] \left[\frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(Z) \right] \quad (21)$$

$$\text{If } \frac{X-X_0}{h} = r \quad \text{Then} \quad \begin{aligned} X-X_0 &= hr \\ X-X_1 &= X-(X_0+h) = (X-X_0)-h = (hr-h) = h(r-1) \end{aligned}$$

$$\text{Similarly } X-X_2 = h(r-2)$$

:

:

:

$$\text{Similarly } X-X_n = h(r-n)$$

Putting these values in equation (21), we got:

$$f(T) - P_n(T) = \left[\frac{(hr)\{h(r-1)\}\{h(r-2)\}\{h(r-3)\} \dots \{h(r-n)\}}{(n+1)!} \right] \left[\frac{1}{h^{(n+1)}} \Delta^{(n+1)} f(Z) \right]$$

$$f(X) - P_n(X) = \left[\frac{r(r-1)(r-2)(r-3) \dots (r-n)}{(n+1)!} \right] \left[\Delta^{(n+1)} f(Z) \right]$$

This is mathematical expression for estimation of error, if the point lies in the lower half.

4 IF INTERVALS ARE NOT BE EQUALLY SPACED

Let $BA = f(X)$ be a function defined by n points $(BA_0, X_0), (BA_1, X_1), \dots, (BA_n, X_n)$. Where BA is biological activity and X is the variable. When $X_1, X_2, X_3, \dots, X_n$ are equally spaced with interval h . And If Intervals are not be equally spaced then we used following formula we used following formula [1] [7]-[9]:

$$BA(X) = BA_i + \Delta_d BA_i (X - X_i) + \Delta_d^2 BA_i (X - X_i)(X - X_j) + \dots + \Delta_d^n BA_i [(X - X_i)(X - X_j) \dots (X - X_n)]$$

[Where Δ_d is divide difference operator]

4.1 ESTIMATION OF ERROR

Let $f(X)$ be a real-valued function define n interval and $(n+1)$ times differentiable on (a, b) . If $P_n(X)$ is the polynomial. Which interpolates $f(X)$ at the $(n+1)$ distinct points $X_0, X_1, \dots, X_n \in (a, b)$, then for all $\bar{X} \in [a, b]$, there exists $\xi = \xi(\bar{X}) \in (a, b)$

$$e_n(\bar{X}) = f(\bar{X}) - P_n(\bar{X})$$

$$= \frac{f^{(n+1)}(\xi)}{(n+1)!} \prod_{j=0}^n (\bar{X} - X_j) \quad (22)$$

This is mathematical expression for estimation of error, if intervals are not be equally spaced.

5 WHEN THE TABULATED VALUES OF THE FUNCTION ARE NOT EQUIDISTANT

Let $BA = f(X)$ be a function defined by n points $(BA_0, X_0), (BA_1, X_1), \dots, (BA_n, X_n)$. Where BA is biological activity and X is the variable. When the tabulated values of the function are not equidistant then we used following formula [1] [7]-[9]:

$$BA(X) = \sum_{i=1}^n BA_i \prod_{\substack{j=1 \\ j \neq i}}^n \frac{(X - X_j)}{(X_i - X_j)}$$

5.1 ESTIMATION OF ERROR

Since the approximating polynomial $f(X)$ given by Lagrangian formula has the same values $f(X_0) f(X_1) f(X_2) f(X_3) f(X_4) \dots f(X_n)$ as does $BA = f(X)$ for the arguments $X_0, X_1, X_2, X_3, X_4, \dots, X_n$ the error term must have zeros at these $(n+1)$ points.

Therefore $(X - X_0) (X - X_1) (X - X_2) (X - X_3) \dots (X - X_n)$ must be factors of the error and we can write:

$$F(X) = f(X) + \frac{(X - X_0)(X - X_1)(X - X_2)(X - X_3) \dots (X - X_n)}{(n+1)!} K(X) \quad (23)$$

Let X to be fixed in value and consider the function

$$W(x) = F(x) - f(x) \frac{(x - X_0)(x - X_1)(x - X_2)(x - X_3) \dots (x - X_n)}{(n+1)!} K(X) \quad (24)$$

Then $W(x)$ has zero $x = X_0, X_1, X_2, X_3, \dots, X_n$ and X .

Since the $(n+1)^{th}$ derivative of the n^{th} degree polynomial $f(X)$ is zero.

$$W^{(n+1)}(x) = F^{(n+1)}(x) - K(X) \quad (25)$$

As a consequence of Rolle's Theorem [23] [24], the $(n+1)^{th}$ derivative of $W(x)$ has at least one real zero $x = \xi$ in the range $X_0 < \xi < X_n$

Therefore substituting $x = \xi$ in equation (25)

$$W^{(n+1)}(\xi) = F^{(n+1)}(\xi) - K(X)$$

$$\begin{aligned} \text{Or } K(X) &= F^{(n+1)}(\xi) - W^{(n+1)}(\xi) \\ &= F^{(n+1)}(\xi) \end{aligned}$$

Using this expression for $K(X)$ and writing out $f(X)$

$$\begin{aligned} f(X) &= \frac{(X - X_1)(X - X_2) \dots (X - X_n)}{(X_0 - X_1)(X_0 - X_2) \dots (X_0 - X_n)} f(X_0) + \frac{(X - X_0)(X - X_2) \dots (X - X_n)}{(X_1 - X_0)(X_1 - X_2) \dots (X_1 - X_n)} f(X_1) + \dots \\ &\dots + \frac{(X - X_0)(X - X_1) \dots (X - X_{n-1})}{(X_n - X_0)(X_n - X_1) \dots (X_n - X_{n-1})} f(X_n) + \frac{(X - X_0)(X - X_1) \dots (X - X_n)}{(n+1)!} f^{(n+1)}(\xi) \end{aligned}$$

Where $T_0 < \xi < T_n$

This is mathematical expression for estimation of error, if the tabulated values of the function are not equidistant.

6 CONCLUSION

Derived mathematical expressions are useful to estimation of the errors in the formulas for obtaining intermediate values of the biological activity in Quantitative structure-activity relationships (QSAR). All expressions are worked in n limit which is the last value in the table. When we obtain the intermediate values of the biological activity in Quantitative structure-activity relationships then these mathematical expressions are useful to estimate the errors in interpolated values of the biological activity.

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Stability of Impulsive Differential Equation with any Time Delay

Sanjay K. Srivastava¹ and Kanwalpreet Kaur²

¹Department of Applied Sciences,
Beant College of Engineering and Technology,
Gurdaspur-143521, Punjab, India

²Department of Applied Sciences,
C.T. Institute of Technology,
Jalandhar-144020, Punjab, India

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ABSTRACT: In this paper, the stability of general impulsive retarded functional differential equations with any time delay has been considered. Many evolution processes are characterized by the fact that at certain moments of time they experience a change of state abruptly. Consequently, it is natural to assume that these perturbations act instantaneously, that is, in the form of impulses. Impulsive differential equations, that is, differential equations involving impulse effects, are a natural description of observed evolution phenomena of several real world problems. Impulsive control which based on impulsive differential equations has attracted the interest of many researchers recently. The method of Lyapunov functions and Razumikhin technique have been widely applied to stability analysis of various delay differential equation. When Lyapunov functions are used, it becomes necessary to choose an appropriate minimal class of functionals relative to which the derivative of the Lyapunov function is estimated. This approach is known as the Lyapunov–Razumikhin technique. When Lyapunov functionals are used the corresponding derivative can be estimated without demanding minimal classes of functional. By using Lyapunov functions and analysis technique along with Razumikhin technique, some results for the uniform stability of such impulsive differential equations have been derived. The obtained results extend and generalize some results existing in the literature.

KEYWORDS: Impulsive delay systems, Lyapunov function, Razumikhin technique, Uniform stability, Time delays.

1 INTRODUCTION

A Impulsive differential equations have attracted many researchers' attention due to their wide applications in many fields such as control technology, drug administration and threshold theory in biology, industrial robotics, sociology, chemistry and so on. Many classical results have been extended to impulsive systems [1], [10], [11]. By Lyapunov's direct method, various stability problems have been discussed for impulsive delay differential equations[9]. On the other hand, there have been many papers and monographs recently on stability analysis of delay differential equations [4], [8]. The method of Lyapunov functions and Razumikhin technique have been widely applied to stability analysis of various delay differential equations, and they have also proved to be a powerful tool in the investigation of asymptotical properties of impulsive delay differential equations [3]. There are several research works appeared in the literature on impulsive delayed linear differential equations. In this paper we will study the stability of impulsive differential equation for any time delays. As a result criteria on uniform stability can be derived.

This paper is organized as follows. In Section II, we introduce some basic definitions and notations. In Section III, we get some criteria for stability of impulsive differential equations with any time delay. Finally, concluding remarks are given in Section IV.

2 PRELIMINARIES

Consider the following impulsive differential:

$$\left\{ \begin{array}{l} x'(t) = f(t, x_t), t \neq t_k, t \geq t_0 \\ \Delta x(t_k) = I_k(t_k, x_{t_k^-}), k \in N \\ x_{t_0} = \eta \end{array} \right. \quad (i)$$

We assume that function $f, I_k: R_+ \times PC([- \tau, 0], R^n) \rightarrow R^n$ and $\eta \in PC([- \tau, 0], R^n)$ satisfy all required conditions for existence and uniqueness of the solutions for all $t \geq t_0$.

The time sequence $[t_k]_{k=1}^{+\infty}$ satisfies $0=t_0 < t_1 < \dots < t_k < \dots, \lim_{k \rightarrow \infty} t_k = \infty$,

$\Delta x(t_k) = x(t_k) - x(t_k^-)$ and $x_t, x_{t^-} \in PC([- \tau, 0], R^n)$ are defined by $x_t(r) = x(t+r)$ and

$x_{t^-}(r) = x(t^-+r)$ for $-\tau \leq r \leq 0$ respectively. We shall assume that $f(t, 0) = I_k(t, 0) = 0$ for all $t \in R_+$ and $k \in N$, so that system (i) admits the trivial solution.

Given a constant $\tau > 0$, we equip the linear space $PC([- \tau, 0], R^n)$ with the norm $\|\cdot\|_\tau = \sup_{-\tau \leq r \leq 0} \|\psi(s)\|$. Denote $x(t) = x(t, \sigma, \eta)$, for $\sigma \geq t_0$ be the solution of (i) s.t.

$$x(\sigma + r) = \eta(s), s \in [- \tau, 0].$$

We further assume that all the solutions $x(t)$ of (i) are continuous except at $t_k, k \in N$ at which $x(t)$ is right continuous.

Definition 1: The function $V: R_+ \times R^n \rightarrow R_+$ is said to belong to the class v_0 if we have the following.

1) V is continuous in each of the sets $[t_{k-1}, t_k) \times R^n$, and for each $x \in R^n, t \in [t_{k-1}, t_k), k \in N$,

$$\lim_{(t,w) \rightarrow (t_k^-, x)} V(t, w) = V(t_k^-, x) \text{ exists.}$$

2) $V(t, x)$ is locally Lipschitzian in all $x \in R^n$, and for all $t \geq t_0, V(t, 0) \equiv 0$.

Definition 2: Given a function $V: R_+ \times R^n \rightarrow R_+$, the upper right-hand derivative of V with respect to system (i) is defined by $D^+V(t, x(t)) = \limsup_{\delta \rightarrow 0^+} \frac{1}{\delta} [V(t+\delta, x(t+\delta)) - V(t, x(t))]$.

3 MAIN RESULTS

In the following, we shall establish criteria on impulsive differential equation with any time delay for uniform stability. We have the followings results.

Theorem 1: Assume that there exist a function $V \in v_0$ and some positive constants $p, c, c_1, c_2, c_3, c_4, c_5$ such that $0 < c_5 < 1$.

(a) $c_1 \|x\|^p \leq V(t, x) \leq c_2 \|x\|^p$, for any $t \in R_+$ and $x \in R^n$

(b) $D^+V(t, \psi(0)) \leq cV(t, \psi(0))$, for all $t \in [t_{k-1}, t_k), k \in N$

Whenever $sV(t, \psi(0)) \geq V(t+r, \psi(r))$ for $r \in [- \tau, 0]$, where $s \geq \alpha e^{\beta \tau}$ is a constant, where $\alpha \geq 1, \beta > 0$.

(c) There exist a positive constant ξ_k , where $0 < \xi_{k-1} \leq 1, \forall k \in N$

$$s.t. V(t_k, \psi(0) + I(t_k, \psi)) \leq \xi_k V(t_k^-, \psi(0)), \frac{1}{\alpha} \leq \xi_{k-1}.$$

(d) $-(c_3 + \frac{c_4}{c_5})(t_k - t_{k-1}) > \ln c_5, \forall k \in N$ the zero solution of (i) is uniformly stable.

Proof: Let $x(t)=x(t, t_0, \eta)$ be any solution of the impulsive system (i) with the initial condition $x_{t_0} = \eta$ and $v(t)=V(t,x)$.

We have:

$$c_1 \|x\|^p \leq v(t) \leq c_2 \|x\|^p, \text{ when } t \neq \tau_k, k = 1, 2, 3 \dots \quad (\text{ii})$$

$$v'(t) \leq c_3 v(t) + c_4 v(t - \tau), \text{ for any } \sigma \geq t_0, \eta \in PC(\Omega)$$

Let $x(t)=x(t, \sigma, \eta)$ be the solution of (i) through (σ, η) . Let $\sigma \in [\tau_{m-1}, \tau_m)$ for some $m \in N$.

First of all we will prove that

$$v(t) \leq \frac{c_2}{c_5} \Omega^2 \quad (\text{iii})$$

Where $\Omega^2 < \left(\frac{c_1 c_5}{c_2}\right) \gamma^p$, for any $\gamma > 0$

Observably, we know that for any $t \in ([\sigma - \tau, \sigma])$, there a $a \in [-\tau, 0]$ such that $t = \sigma + a$

So, we have

$$v(t) = v(\sigma + a) \leq c_2 \|x\|^p \leq c_2 \Omega^2 < \frac{c_2}{c_5} \Omega^2, \sigma - \tau \leq t < \sigma$$

So if inequality (iii) does not hold, then there is a $r' \in (\sigma, \tau_m)$ such that

$$v(r') > \frac{c_2}{c_5} \Omega^2 > c_2 \Omega^2 > v(\sigma)$$

Then from the continuity of $v(t)$ in $[\sigma, \tau_m)$, there exist a $r_1 \in (\sigma, r')$ such that

$$v(r_1) = \frac{c_2}{c_5} \Omega^2$$

$$v(t) \leq \frac{c_2}{c_5} \Omega^2, \sigma - \tau \leq t < r_1$$

$$v'(r_1) \geq 0 \quad (\text{iv})$$

From inequalities (iv), $\frac{c_2}{c_5} \Omega^2 > c_2 \Omega^2, v(t) \leq c_2 \Omega^2$

For $t \in ([\sigma - \tau, \sigma])$, it follows that there exist $r_2 \in [\sigma, r_1)$ such that $v(r_2) = c_2 \Omega^2$

$$v(t) \geq c_2 \Omega^2, r_2 \leq t \leq r_1$$

$$v'(r_2) \geq 0 \quad (\text{v})$$

From the inequalities (iv), $v(t) \leq \frac{c_2}{c_5} \Omega^2, \sigma - \tau \leq t < r_1$

From the inequalities (v), $v(t) \geq c_2 \Omega^2, t \in [r_2, r_1]$

for $t \in [r_2, r_1]$

$$v(t + r) \leq \frac{c_2}{c_5} \Omega^2 \leq \frac{1}{c_5} \Omega^2, r \in [-\tau, 0]$$

So, $v(t - \tau) \leq \frac{1}{c_5} \Omega^2, t \in [r_2, r_1]$

$$v'(t) \leq \left(c_3 + \frac{c_4}{c_5}\right) v(t)$$

$$\frac{v'(t)}{v(t)} \leq \left(c_3 + \frac{c_4}{c_5}\right)$$

$$\int_{r_2}^{r_1} \frac{v'(t)}{v(t)} dt \leq \int_{r_2}^{r_1} \left(c_3 + \frac{c_4}{c_5}\right) dt \leq \int_{\tau_{m-1}}^{\tau_m} \left(c_3 + \frac{c_4}{c_5}\right) dt = \left(c_3 + \frac{c_4}{c_5}\right)(\tau_m - \tau_{m-1}) < -\ln c_5$$

At the same time

$$\int_{r_2}^{r_1} \frac{v'(t)}{v(t)} dt = \int_{v(r_2)}^{v(r_1)} \frac{dy}{y} = \int_{c_2\Omega^2}^{\frac{c_2\Omega^2}{c_5}} \frac{dy}{y} = \ln\left(\frac{c_2}{c_5}\Omega^2\right) - \ln(c_2\Omega^2) = -\ln c_5$$

Which is a contradiction, so (iii) holds

From inequality (iii) & given conditions, we obtain

$$v(\tau_m) \leq c_5 v(\tau_m^-) \leq c_2\Omega^2 \quad (\text{vi})$$

Next, we prove that

$$v(t) \leq \frac{c_2}{c_5}\Omega^2, \tau_m \leq t \leq \tau_{m+1} \quad (\text{vii})$$

If this does not hold, then there is $\hat{u} \in (\tau_m, \tau_{m+1})$

$$\text{Such that } v(\hat{u}) > \frac{c_2}{c_5}\Omega^2 > c_2\Omega^2 \geq v(\tau_m)$$

From the continuity of $V(t, x(t))$ in (τ_m, τ_{m+1}) , there exist a $u_1 \in (\tau_m, \hat{u})$ such that

$$v(u_1) = \frac{c_2}{c_5}\Omega^2$$

$$v(t) \leq \frac{c_2}{c_5}\Omega^2, \sigma - \tau \leq t < u_1$$

$$v'(u_1) \geq 0 \quad (\text{viii})$$

From the inequalities $\frac{c_2}{c_5}\Omega^2 > c_2\Omega^2, v(\tau_m) \leq c_2\Omega^2$

It follows that there exist a $u_2 \in (\tau_m, u_1)$ such that $v(u_2) = \frac{c_2}{c_5}\Omega^2$

$$v(t) \geq c_2\Omega^2, u_2 \leq t \leq u_1$$

Therefore, for $t \in [u_2, u_1]$

$$v(t+r) \leq \frac{c_2}{c_5}\Omega^2 \leq \frac{1}{c_5}v(t)$$

So $v(t-\tau) \leq \frac{1}{c_5}v(t)$, then for $t \in [u_2, u_1]$

$$v'(t) \leq \left(c_3 + \frac{c_4}{c_5}\right)v(t)$$

$$\frac{v'(t)}{v(t)} \leq \left(c_3 + \frac{c_4}{c_5}\right) \quad (\text{ix})$$

So, integrating (ix) in $t \in [u_2, u_1]$, we get

$$\int_{u_2}^{u_1} \frac{v'(t)}{v(t)} dt \leq \int_{u_2}^{u_1} \left(c_3 + \frac{c_4}{c_5}\right) dt \leq \int_{\tau_m}^{\tau_{m+1}} \left(c_3 + \frac{c_4}{c_5}\right) dt = \left(c_3 + \frac{c_4}{c_5}\right)(\tau_{m+1} - \tau_m) < -\ln c_5$$

At the same time

$$\int_{u_2}^{u_1} \frac{v'(t)}{v(t)} dt = \int_{v(u_2)}^{v(u_1)} \frac{dy}{y} = \int_{c_2 \Omega^2}^{\frac{c_2 \Omega^2}{c_5}} \frac{dy}{y} = \ln \left(\frac{c_2}{c_5} \Omega^2 \right) - \ln(c_2 \Omega^2) = -\ln c_5$$

Which is a contradiction. So (vii) holds.

From inequality (vii) and given conditions, we have

$$v(\tau_{m+1}) \leq c_5 v(\tau_{m+1}^-) \leq c_2 \Omega^2$$

By mathematical induction, we can prove that in general for $k=0,1,2,\dots$

$$v(t) \leq c_2 \Omega^2$$

$$v(t) \leq \frac{c_2}{c_5} \Omega^2, \tau_{m+k} \leq t \leq \tau_{m+k+1}$$

$$v(\tau_{m+k+1}) \leq c_2 \Omega^2$$

which together with inequality (iii) and the inequality $\frac{c_2}{c_5} \Omega^2 \geq c_2 \Omega^2$

$$\text{provides } v(t) \leq \frac{c_2}{c_5} \Omega^2, t \geq \sigma$$

$$\text{So, } c_1 \|x\|^p \leq v(t) \leq \frac{c_2}{c_5} \Omega^2, t \geq \sigma$$

$$\|x\|^p \leq \frac{c_2}{c_1 c_5} \Omega^2$$

$$\|x\| \leq \left(\frac{c_2}{c_1 c_5} \right)^{\frac{1}{p}} \Omega^{\frac{2}{p}} < \gamma, t \geq \sigma$$

Therefore, the zero solution of (i) is uniformly stable

Theorem 2: If c_3, c_5, c_6 be any constants and $c_7 = \max(c_5, c_6)$ then zero solution of (i) is uniformly stable

if $c_3(\tau_k - \tau_{k-1}) < -\ln c_7$, for $k \in N$.

Proof: Let $c_1 > 0, c_2 > 0, c_4 > 0$ be any constants. Let us consider that for $\gamma > 0$, there exist $\Omega > 0$ such that

$$\text{Where } \Omega^2 < \left(\frac{c_1 c_7}{c_2 + \tau c_4} \right) \gamma^p$$

Construct a Lyapunov function $v(t) \in v_0$ and let

$$c_1 \|x(t)\|^p \leq v(t) \leq c_2 \|x(t)\|^p + \tau c_4 \sup_{-\tau \leq r \leq 0} \|x(t+r)\|^p$$

When $t \neq \tau_k, k=1,2,\dots$ we have $v'(t) \leq c_3 v(t)$

For any $\sigma \geq t_0$ and $\eta \in PC(\Omega)$, let $x(t) = x(t, \sigma, \eta)$ be the solution of (i) through (σ, η) . Let $\sigma \in [\tau_{m-1}, \tau_m)$ for some $m \in N$. We first prove that

$$v(t) \leq \frac{c_2 + \tau c_4}{c_7} \Omega^2, \sigma \leq t \leq \tau_m \tag{x}$$

$$\text{When } t = \sigma, v(t) = v(\sigma) \leq (c_2 + \tau c_4) \eta^2 \leq (c_2 + \tau c_4) \Omega^2 \leq \frac{c_2 + \tau c_4}{c_7} \Omega^2$$

So if inequality (x) does not hold, then there is $\hat{r} \in (\sigma, \tau_m)$ such that

$$v(\hat{r}) > \frac{c_2 + \tau c_4}{c_7} \Omega^2 > (c_2 + \tau c_4) \Omega^2 \geq v(\sigma)$$

Then from the continuity of $v(t)$ in $[\sigma, \tau_m)$, there exist a $r_1 \in (\sigma, \hat{r})$ such that

$$v(r_1) = \frac{c_2 + \tau c_4}{c_7} \Omega^2$$

$$v(t) = \frac{c_2 + \tau c_4}{c_7} \Omega^2, \sigma \leq t \leq r_1$$

$$v'(r_1) \geq 0$$

From the inequalities $\frac{c_2 + \tau c_4}{c_7} \Omega^2 > (c_2 + \tau c_4) \Omega^2$, $v(\sigma) \leq (c_2 + \tau c_4) \Omega^2$, it follows that there exist a $r_2 \in (\sigma, r_1)$, such that: $v(r_2) = (c_2 + \tau c_4) \Omega^2$

$$v(t) \geq (c_2 + \tau c_4) \Omega^2, r_2 \leq t \leq r_1$$

$$v'(r_2) \geq 0$$

Therefore integrate the inequality $v'(t) \leq c_3 v(t)$ in $t \in [r_2, r_1]$, we have

$$\int_{r_2}^{r_1} \frac{v'(t)}{v(t)} dt \leq \int_{r_2}^{r_1} c_3 dt \leq \int_{\tau_{m-1}}^{\tau_m} c_3 dt = c_3(\tau_m - \tau_{m-1}) < -\ln c_7$$

At the same time :

$$\int_{r_2}^{r_1} \frac{v'(t)}{v(t)} dt = \int_{v(r_2)}^{v(r_1)} \frac{du}{u} = \int_{(c_2 + \tau c_4) \Omega^2}^{\frac{c_2 + \tau c_4}{c_7} \Omega^2} \frac{du}{u} = \ln \left(\frac{c_2 + \tau c_4}{c_7} \Omega^2 \right) - \ln((c_2 + \tau c_4) \Omega^2) = -\ln c_7$$

A contradiction, So (x) holds and from the given conditions we have

$$v(\tau_m) \leq c_7 v(\tau_m^-) \leq (c_2 + \tau c_4) \Omega^2$$

Similar to the proof before, we can easily get the following inequality

$$v(t) \leq \frac{c_2 + \tau c_4}{c_7} \Omega^2, \tau_m \leq t \leq \tau_{m+1}$$

By mathematical induction, we can prove that in general for $k=0,1,2,\dots$

$$v(t) \leq \frac{c_2 + \tau c_4}{c_7} \Omega^2, \tau_{m+k} \leq t \leq \tau_{m+k+1}$$

$$v(\tau_{m+k+1}) \leq (c_2 + \tau c_4) \Omega^2$$

Which together with equation (x) and the inequality $\frac{c_2 + \tau c_4}{c_7} \Omega^2 \geq (c_2 + \tau c_4) \Omega^2$ provides

$$v(t) \leq \frac{c_2 + \tau c_4}{c_7} \Omega^2, t \geq \sigma$$

$$\text{So } c_1 \|x(t)\|^p \leq v(t) \leq \frac{c_2 + \tau c_4}{c_7} \Omega^2, t \geq \sigma$$

$$\|x\| \leq \left(\frac{c_2 + \tau c_4}{c_7 c_1} \right)^{\frac{1}{p}} \Omega^{\frac{2}{p}} < \gamma, t \geq \sigma$$

Therefore the zero solution of (i) is uniformly stable and the proof of the Theorem is complete.

4 CONCLUSION

In this paper, we have considered the stability of impulsive differential equations with any time delay. By using Lyapunov functions and techniques along with Razumikhin technique, we have gotten some results for the uniform stability of impulsive differential equations with any time delay.

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Variabilité spatio-temporelle des paramètres climatiques et son incidence sur le tarissement dans les bassins versant de Bô et Débo (département de Soubré au Sud-Ouest de la Côte d'Ivoire)

[Spatial and temporal variability of climatic parameters and its effect on drying up in Débo and Bô catchments (Department of Soubré, south-western of Ivory Coast)]

Vano Mathunaise Sorokoby, Mahaman Bachir Saley, Koffi Fernand Kouame, Eric M'moi Valère Djagoua, Kouadio Affian, and Jean Biemi

Centre Universitaire de Recherche et d'Application en Télédétection (CURAT),
UFR STRM, Université Félix Houphouët-Boigny (UFHB),
22 BP 801 Abidjan 22, Côte d'Ivoire

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ABSTRACT: The present study deals with the spatial and temporal variability of the climatic parameters and their consequence on the drying up of streams Bô and Débo and on the refill of the ground-water sheet in Soubré area. Methodology used is articulated around the study of the hydrological assessment according to Thornthwaite in the two catchments, the study of the seasonal and interannual variability of the climatic variables and the study of drying up by the determination of the coefficients of drying up and the mobilized volumes as well as their evolution. The hydrological assessment reveals that evapotranspiration is very active in the area of Soubré and has particularly contributed to reduce water resources of the area. Indeed, on the totality of rainfall, only 5.24% joined the underground network to refill the groundwater. The evolution of the curves of drying up reveals that, in Débo and Bô catchments, drying up lasts in general between 30 and 160 days. The coefficients of drying up in the both watersheds knew a rise of 1983 to 1991. Since 1991 there has been a relative decline in these coefficients. Thus, the coefficients of drying up continued to increase in recent years inversely with volumes participating in the reduction of water resources in the area and affecting in a pejorative way the groundwater refill.

KEYWORDS: Climatic variability, drying up, mobilized volumes, catchment, Soubré.

RESUME: La présente étude traite de la variabilité spatio-temporelle des paramètres climatiques et leur conséquence sur le tarissement des cours d'eau Bô et Débo et sur la recharge de la nappe souterraine dans la région de Soubré. La méthodologie utilisée s'articule autour de l'étude du bilan hydrologique selon Thornthwaite dans les deux bassins versants, l'étude de la variabilité saisonnière et interannuelle des variables climatiques et l'étude du tarissement. Il ressort que l'évapotranspiration est très active dans la région de Soubré. Seulement 5,24 % des précipitations a rejoint le réseau souterrain pour réalimenter la nappe. Le tarissement dans les bassins versants de Débo et de Bô, dure en général entre 30 et 160 jours. Les coefficients de tarissement ont connu une hausse de 1983 à 1991. A partir de 1991 on a constaté une relative baisse de ces coefficients. Les volumes mobilisés ont diminués participant à la réduction des ressources en eau de la région et affectant de façon péjorative la recharge souterraine.

MOTS-CLEFS: Variabilité climatique, tarissement, volumes mobilisés, bassin versant, Soubré.

1 INTRODUCTION

La variabilité climatique dans le monde a fait l'objet de nombreuses études dont celles de [4] en Grande-Bretagne, [7] en France, [18] au Canada, [19] aux Etats-Unis et [21] en Australie occidentale. En Afrique, en Afrique de l'Ouest et en Côte d'Ivoire, les travaux de [1], [2], [3], [5], [6], [8], [9], [10], [11], [12], [13], [14], [16], [17], [20], [23] et [24] sont dédiés à la problématique de la variabilité et du changement climatiques et de leurs impacts sur les ressources en eau. La référence [5] a insisté sur la variabilité des paramètres climatiques et leurs influences sur les ressources naturelles. Dans la présente étude il s'agit d'étudier la variabilité des paramètres climatiques et leurs incidences sur le tarissement et par ricochet sur la recharge souterraine et les ressources en eau de surface dans les bassins versants de Débo et Bô dans le département de Soubré.

2 LOCALISATION DE LA ZONE D'ETUDE

Les bassins versants à l'étude sont situés dans la région de Soubré. Le bassin versant de Débo est compris entre les longitudes 6°07' W et 6°26' W et les latitudes 5°30' N et 6° N. Le bassin de Bô est compris entre les longitudes 6°19' W et 6°37' W et les latitudes 5°39' N et 6°01' N. Ces bassins occupent des superficies respectives de 822.5 km² et 1011 km². La figure 1 présente la zone d'étude.

Dans le bassin versant de Bô l'altitude minimale est de 79 m et l'altitude maximale est de 449 m et se situe à l'extrême Est (à l'Est d'Okrouyo). Ces hautes altitudes appartiennent à une série de collines appelées les Monts Trokoua. Ces collines se prolongent dans le bassin versant voisin celui de Débo à l'Est. Les altitudes dans ce bassin versant varient entre 55 m et 413 m (Mont Trokoua à l'Ouest). On note une prédominance de pentes faibles dans ces bassins. En effet, plus de 93 % de la superficie des bassins a une pente inférieure à 4°. La végétation de ces bassins épouse celle de l'ensemble de la région. C'est une forêt sempervirente avec quelques galeries. Le réseau hydrographique est relativement très dense. Le climat est de type baouléen dans le bassin versant de Bô et de type attien dans celui de Débo. La population y est très forte avec une densité de 103 habitants au kilomètre carré. L'activité économique tourne autour de la vente du cacao, du café et des produits vivriers tels que la banane plantain et le riz.

3 MATERIELS ET METHODES

3.1 DONNEES

Les données climatiques ont été obtenues auprès de la Société de Développement et d'Exploitation Aéroportuaire, Aéronautique et Météorologique (SODEXAM). Les données de température, de durée d'insolation et d'humidité relative (chronique 1975-2001) sont celles enregistrées à la station de Gagnoa (6°8'N ; 5°57'W ; Altitude 214 m) alors que les données pluviométriques sont celles enregistrées à la station de Soubré (chronique 1950-2008). L'utilisation des données de la station de Gagnoa pour combler celles de Soubré s'explique par l'absence de station climatique à Soubré et trouve sa justification dans le fait que les deux régions appartiennent à la même zone climatique. Les données hydrologiques obtenues sont des données de débits des cours d'eau Débo et Bao. Ces données proviennent de la Direction de l'Hydraulique Humaine (DHH) précisément de la Sous- direction de l'Hydrologie. Les données cartographiques concernent une carte topographique à l'échelle 1/500000 (feuillé Sud-Ouest) acquise au CCT (Centre de Cartographie et de Télédétection) et qui date de 1996 et une carte topographique de 1966 à l'échelle 1/200000 acquise également au CCT.

3.2 METHODOLOGIE

3.2.1 CALCUL DU BILAN HYDROLOGIQUE

3.2.1.1 CALCUL DE L'EVAPOTRANSPIRATION POTENTIELLE (ETP)

L'évapotranspiration potentielle a été calculée selon Thornthwaite par l'équation 1 :

$$ETP(mm / mois) = 16 \left(\frac{10t}{I} \right)^a \times F(\lambda) \quad (1)$$

Où t est la température moyenne mensuelle en °C, a une fonction complexe de l'indice thermique I avec, $a = 6,75 \cdot 10^{-7} I^3 - 7,71 \cdot 10^{-5} I^2 + 1,79 \cdot 10^{-2} I + 0,49239$, I l'indice thermique annuel somme des douze indices thermiques mensuels (i) et $i = \left(\frac{t}{5}\right)^{1,514}$, $F(\lambda)$ le facteur correctif fonction de la latitude du lieu considéré. Une relation linéaire entre $F(\lambda)$ et la latitude a été établie selon l'équation 2 :

$$F(\lambda) = Cst + a * \lambda \quad (2)$$

Avec Cst une constante et λ la latitude en °.

3.2.1.2 CALCUL DE L'ÉVAPOTRANSPIRATION REELLE (ETR) ET DE L'INFILTRATION

La démarche de calcul du bilan hydrologique selon Thornthwaite comporte deux cas de figure :

- Si $P \geq ETP$, l'évapotranspiration réelle est égale à l'évapotranspiration potentielle ($ETR = ETP$), et il restera une quantité d'eau ($P - ETR$) qui servira à la reconstitution des réserves d'eau du sol ;
- Si $P < ETP$, l'évapotranspiration va se réaliser non seulement sur la totalité des pluies, mais encore sur les réserves du sol : $ETR = P + RFU$.

Le volume d'eau infiltrée est alors donné par l'équation 3 :

$$V = I \times S \quad (3)$$

Avec V : Volume d'eau infiltrée en m^3 , I : Infiltration en mm, S : Surface de la zone en m^2 .

3.2.2 ETUDE DE LA VARIABILITE DES PARAMETRES CLIMATIQUES

L'étude de la variation de la température, de la durée de l'insolation, de l'humidité relative, de l'évapotranspiration potentielle en relation avec la pluviométrie contribue à la compréhension des processus complexes liés au fonctionnement d'un hydrosystème. Ces paramètres ont été étudiés dans la région de Soubré pour comprendre l'impact de la variabilité climatique sur les ressources des hydrosystèmes constitués par les bassins versants de Débo et Bô.

3.2.2.1 ETUDE DE LA VARIABILITE MENSUELLE DES PARAMETRES CLIMATIQUES

Les données étudiées concernent la chronique 1975-2001. Pour chaque paramètre et pour le mois considéré, le calcul de la moyenne mensuelle est basé sur la formule de l'équation 4 suivante :

$$M_{mensuelle} = \frac{1}{N} \sum_{i=1}^n M_{ij} \quad (4)$$

Avec M_{ij} valeur moyenne du paramètre climatique concerné de l'année i et du mois j ;

i varie de 1 à n années et j varie de 1 à 12 mois ;

N le nombre total d'année de la chronique concernée.

3.2.2.2 ETUDE DE LA VARIABILITE INTERANNUELLE DES PARAMETRES CLIMATIQUES

Le calcul de la moyenne interannuelle des paramètres climatiques est basé sur le calcul des valeurs moyennes de chaque paramètre pour toute l'année. La formule utilisée pour ce faire est matérialisée par l'équation 5 suivante :

$$M_{interannuelle} = \frac{1}{12} \sum_{i=1}^{12} M_i \quad (5)$$

$M_{interannuelle}$, Moyenne interannuelle du paramètre climatique considéré ; M_i , moyenne mensuelle du paramètre climatique du mois i .

3.2.3 ETUDE DU PHENOMENE DE TARISSEMENT PAR LA LOI DE MAILLET

3.2.3.1 EVALUATION DU TARISSEMENT DANS LES BASSINS VERSANTS DE DEBO ET BO

Pour évaluer les tarissements sur les différents bassins, l'application de la loi de la décroissance exponentielle de Maillet est requise. Cette loi est donnée par l'équation 6 :

$$Q_t = Q_0 e^{-kt} \quad (6)$$

Avec Q_t et Q_0 , les débits aux instants t et t_0 (début du tarissement) exprimés en jours, et k le coefficient de tarissement de Maillet dépendant des caractéristiques physiques et géométriques de l'aquifère qui a la dimension k . La valeur de k est l'inverse du temps et s'exprime en jours⁻¹ et $k = \frac{1}{T}$. Il est généralement constant pour un même aquifère.

Le coefficient de tarissement k se déduit dans ce cas du logarithme de l'expression de l'équation 6 précédente comme suit (équation 7) :

$$k = \frac{\log Q_0 - \log Q_t}{0,4343t} \quad (7)$$

La courbe de tarissement se construit à partir des débits caractéristiques de la période sèche. Ces débits sont portés sur un graphique logarithmique de sorte que le temps est porté en abscisses et les débits en ordonnées. Le débit initial Q_0 doit correspondre au débit journalier le plus élevé de la période sèche proche des hautes eaux. Le pas de temps utilisé ici est de 10 jours. Le volume mobilisé, $V_{mobilisé}$ de la réserve hydrogéologique susceptible d'alimenter l'écoulement superficiel est déterminé par approche graphique à partir de la courbe de tarissement. Dans le cas contraire le calcul du volume d'eau mobilisé se fait à l'aide de l'équation 8 suivante :

$$V_{mobilisé} = \int_0^{\infty} Q_0 e^{-kt} dt = \frac{Q_{0(m^3/s)}}{k} \times 86400(s.j^{-1}) \quad (8)$$

Ainsi les courbes d'évolution des coefficients de tarissement et des volumes mobilisés des bassins versants de Débo et de Bô ont été représentées sur un même graphique pour permettre une étude comparée de leurs évolutions dans ces deux bassins et évaluer leur impact sur les ressources en eau.

4 RESULTATS ET DISCUSSION

4.1 ANALYSE DU BILAN HYDROLOGIQUE DE SOUBRE

4.1.1 PARAMETRES DU BILAN HYDROLOGIQUE DE SOUBRE

Les paramètres du bilan hydrologique calculés sont consignés dans le tableau 3 :

Le bilan hydrologique de Soubré enregistre un déficit d'écoulement estimé à 1258.89 mm. Le déficit hydrique est estimé à 252,09 mm. Sur les 1447 mm précipitées, 1238,9 mm retourne à l'atmosphère sous forme d'ETP soit 85,62 % et seulement 75,79 mm soit 5,24 % s'infiltre dans le sol pour participer à la recharge de la nappe souterraine. La persistance du phénomène de l'évapotranspiration dans la région de Soubré trouve son origine dans la variabilité climatique qui contribue à réduire de façon drastique les ressources en eau de la région et affecte par ricochet la recharge de la nappe souterraine.

4.1.2 EVOLUTION SAISONNIERE DES PARAMETRES CLIMATIQUES DE SOUBRE

La figure 2 montre le graphique d'évolution saisonnière des paramètres climatiques et du bilan hydrologique de la région de Soubré.

L'analyse de cette figure montre que l'humidité relative reste supérieure à 70 % dans la région en période de saison sèche. Cette humidité relative augmente à partir du début de la grande saison des pluies pour atteindre des valeurs très élevées pendant la seconde saison des pluies (98,9 % en septembre).

Il ressort de cette analyse que la région de Soubré est une zone relativement humide du fait des caractéristiques du climat de la région. L'insolation connaît des valeurs élevées d'octobre à avril couvrant presque toute la grande saison sèche avec une valeur moyenne mensuelle qui se situe autour de 160 heures. A partir du mois de mai, les valeurs des heures d'insolation connaissent une baisse importante pour atteindre une valeur de 93,5 heures en août. La période de mai à septembre enregistre des valeurs d'insolation faibles. Au niveau de la température, les faibles valeurs s'observent pendant les mois de mai, juin, juillet, août et septembre alors que les autres mois enregistrent des valeurs relativement élevées. La température moyenne annuelle est relativement faible et oscille autour de 25,8 °C. Les valeurs de l'ETP sont faibles d'avril à octobre et élevées de novembre à mars. C'est dire que le processus d'évapotranspiration est très actif pendant toute la grande saison sèche du fait de l'action conjuguée des fortes valeurs de température, d'insolation et des faibles valeurs de pluviométrie, d'humidité relative. Pendant la période couvrant la petite saison sèche, le processus d'évapotranspiration est moins intense à cause de l'humidité relative élevée, des durées d'insolation courtes et de la température basse.

4.1.3 EVOLUTION INTERANNUELLE DES PARAMETRES CLIMATIQUES DE SOUBRE

L'évolution interannuelle des paramètres climatiques de la région de Soubré pour la période de 1975 à 2001 est présentée à la figure 3.

Cette évolution révèle que les valeurs de températures moyennes interannuelles oscillent entre 24,9 °C et 26,4 °C avec une faible tendance à la hausse (24,9 °C en 1975, 25,7 °C en 1988 et 26,1 °C en 2001). L'humidité relative très forte en 1975 (120,7 %) a connu une baisse à partir de 1976 pour osciller entre 83 % et 75 %. Toutefois on note une faible diminution de cette humidité relative jusqu'en 2001. Les durées d'insolation connaissent des fortunes diverses avec des valeurs faibles en 1977, 1983, 1992 et 1997. Cependant les heures d'insolation dans la région de Soubré restent supérieures à 1600 heures avec une moyenne de 1921,2 heures.

4.2 ANALYSE DES COURBES DE TARISSEMENT

4.2.1 COURBES DE TARISSEMENT DU DEBO

Les courbes de tarissement du Débo sont présentées à la figure 4.

Pour le fleuve Débo, les courbes de tarissement durent entre 50 et 160 jours. Ce sont les années 1995 et 1999 qui enregistrent des tarissements de 50 et 60 jours alors que les années 1983, 1986, 1994 et 2004 enregistrent respectivement 100, 160, 90 et 100 jours. Le bassin versant du Débo étant affecté par un seul type de climat en occurrence le climat attien, caractérisé par deux saisons sèches dont une très longue, le phénomène de tarissement s'étend un peu plus dans le temps. Le tarissement lent du Débo est lié à la faible perméabilité des aquifères car les formations rocheuses qui caractérisent le bassin versant sont surtout de type granitique.

4.2.2 COURBES DE TARISSEMENT DU BAO

La figure 5 montre quelques courbes de tarissement pour des années sélectionnées, de la rivière Bao.

Cette figure montre que les années 1991 et 1999 enregistrent des tarissements de 30 jours. Les années 1983 et 1994 présentent des tarissements de 80 jours alors que les années 1984 et 2004 enregistrent des tarissements de 90 et 120 jours. Dans le bassin versant de Bô, les années 1991 et 1999 ont connu un tarissement rapide à cause de la pluviométrie relativement faible survenue au cours de ces années. Le tarissement des années 1983 et 1994 est dû respectivement à la sécheresse et la rupture hydrologique survenues au cours de ces années. Les années 1984 et 2004 ont enregistré une pluviométrie relativement forte supérieure à la moyenne. Ceci a contribué au ralentissement du tarissement observé pendant ces deux années.

En définitive les bassins versant de Débo et de Bô réagissent de façon générale lentement au tarissement. Ce qui indique une grande perméabilité des aquifères des bassins versants et leur capacité à accumuler les eaux souterraines. Les tarissements rapides sont par contre dus à la pluviométrie relativement importante enregistrée pendant ces années de tarissement rapide.

4.2.3 VARIATION DES COEFFICIENTS DE TARISSEMENT ET DES VOLUMES MOBILISÉS DANS LES BASSINS VERSANTS DE SOUBRE

Les coefficients de tarissement des différents cours d'eau ont été représentés sur le même graphique pour permettre une analyse comparée de ces coefficients. La figure 6 montre le graphique d'évolution des coefficients de tarissement dans les bassins versants de Débo et de Bô.

L'analyse comparative de l'évolution des coefficients de tarissement montre que les coefficients de tarissement du Débo un affluent d'ordre 1 du Sassandra, sont inférieurs à ceux du Bao affluent d'ordre 2. Ces coefficients de tarissement varient respectivement entre $2,7 \cdot 10^{-2} \text{ j}^{-1}$ et $7,2 \cdot 10^{-2} \text{ j}^{-1}$ pour le Débo et entre $2,3 \cdot 10^{-2} \text{ j}^{-1}$ à $1,2 \cdot 10^{-1} \text{ j}^{-1}$ pour le Bô. On remarque que ces coefficients sont relativement élevés. Les valeurs relativement élevées des coefficients de tarissement du Débo et du Bao indiquent que ces cours d'eau sont plus sensibles aux conditions climatiques environnantes et réagissent mieux au phénomène de tarissement. On remarque en général que les valeurs des coefficients de tarissement ont augmentés au niveau des cours d'eau de Soubré ces dernières années.

Les coefficients de tarissement ont été couplés aux volumes mobilisés pour permettre une analyse comparée de leurs évolutions. Ces paramètres sont présentés aux figures 7 et 8.

Au niveau du Débo, les années 1985, 1991 connaissent des faibles valeurs de coefficients de tarissement ($0,0287 \text{ j}^{-1}$ et $0,02206 \text{ j}^{-1}$) et des volumes mobilisés importants ($1,35 \cdot 10^8 \text{ m}^3$).

L'évolution des coefficients de tarissement et des volumes mobilisés au niveau du Débo est en général irrégulière avec par endroit des valeurs plus ou moins élevées ou faibles des coefficients et des volumes mobilisés. Le volume moyen mobilisé pour cette période au niveau du Débo est estimé à $6,52 \cdot 10^7 \text{ m}^3$.

Ce même constat est fait au niveau du Bô mais à la différence qu'on observe une tendance timide à la hausse des coefficients de tarissement de 1983 à 1991 et une relative baisse à partir de cette date. Toutefois on note une forte valeur du coefficient de tarissement en 1999 ($0,1131 \text{ j}^{-1}$) correspondant à un volume mobilisé de $2,15 \cdot 10^7 \text{ m}^3$. L'année 1985 enregistre pour un coefficient de tarissement de $0,0233 \text{ j}^{-1}$, un volume mobilisé élevé de $1,85 \cdot 10^8 \text{ m}^3$. Le volume moyen annuel mobilisé au niveau du Bô est de $6,82 \cdot 10^7 \text{ m}^3$.

4.2.4 ANALYSE COMPAREE DES VOLUMES MOBILISÉS DANS LES BASSINS VERSANTS DE SOUBRE

Les volumes mobilisés des deux cours d'eau ont été représentés sur le même graphique à la figure 9 :

L'analyse comparée des volumes mobilisés (figure 9) révèle que les volumes mobilisés du Débo et du Bô évoluent sensiblement dans le même ordre. En 1985 les volumes mobilisés au niveau des deux cours d'eau ont connu une hausse relative témoignant d'une hausse particulière de la pluviométrie ayant affecté toute la région de Soubré. On note toutefois que le volume mobilisé du Bô ($1,85 \cdot 10^8 \text{ m}^3$) est supérieur à celui du Débo ($1,35 \cdot 10^8 \text{ m}^3$) pour cette même année. Les années 1985 et 1991 se présentent comme celles ayant enregistré des volumes mobilisés importants pour le Débo avec un volume de $1,35 \cdot 10^8 \text{ m}^3$.

4.3 DISCUSSION

Le bilan hydrologique a montré que le phénomène d'évapotranspiration est très actif dans la région de Soubré et a particulièrement contribué à la raréfaction des ressources en eau de la région. En effet, sur la totalité des précipitations tombées dans la région, seulement 5,24 % a rejoint le réseau souterrain pour participer au processus de réalimentation des nappes. La proximité de la grande forêt de la réserve de Taï a sans doute joué un rôle prépondérant dans ce processus d'évapotranspiration. L'évolution des paramètres climatiques reste tributaire de la variabilité et du changement climatique qui a eu un impact réel sur ces paramètres. Les régions tropicales forestières caractérisées par des forêts très étendues sont très sensibles aux variations des états de surface selon [10]. Ainsi, l'augmentation des surfaces sèches provoque une hausse des températures de l'air par transfert de chaleur sensible [10]. Par ailleurs, la diminution de la couverture forestière, qui absorbe naturellement du gaz carbonique contenu dans l'atmosphère, contribue à augmenter la teneur atmosphérique de ce gaz à effet de serre [23].

L'évolution des courbes de tarissement révèle que le tarissement, dans les bassins versants de Débo et de Bô, dure en général entre 30 et 160 jours, les valeurs extrêmes correspondant aux années ayant enregistré respectivement une pluviométrie faible et une pluviométrie abondante. La lente réaction de ces bassins versants au tarissement met en évidence la très grande perméabilité de ces aquifères et leur aptitude à restituer les eaux souterraines accumulées au cours des saisons pluvieuses. En effet, les travaux de [22] dans la région de Soubré ont révélé qu'en période de saison sèche, se sont les

nappes souterraines qui alimentent les cours d'eau en surface.

L'analyse de l'évolution des coefficients de tarissement a montré que les coefficients de tarissement du Débo et du Bô ont connu une hausse de 1983 à 1991. A partir de 1991 on a constaté une relative baisse de ces coefficients. En effet dans la région l'année 1993 se présente comme l'année de la rupture pluviométrique secondaire caractérisée par la reprise de la pluviométrie et une augmentation progressive des coefficients de tarissement après cette année. En général, les valeurs des coefficients de tarissement ont augmenté au niveau des cours d'eau de Soubré ces dernières années. La référence [10] signale aussi cette tendance des coefficients de tarissement à la hausse à partir de la rupture de 1970 dans le bassin versant du N'zo à l'Ouest de la Côte d'Ivoire. Les volumes mobilisés ont évolués inversement aux coefficients de tarissement. On note que ces volumes ont régulièrement baissés depuis l'année 1986 qui est caractérisée par une très faible pluviométrie. En effet l'année 1986 est l'année qui a été marquée par une sécheresse particulièrement intense dans la région de Soubré. Cette sécheresse a contribué à réduire les réserves d'eau de la région et a même affecté la recharge souterraine ce qui a contribué à rendre les volumes mobilisés dans les différents bassins versants de la région. Les références [12] ont également observé une augmentation des coefficients de tarissement dès 1969 sur cinq sous-bassins du fleuve Niger. Ces constatations ont également été faites par [14] qui a signalé ce phénomène sur les bassins versants du Tchad. La référence [24] a fait ce même constat dans le bassin béninois du fleuve Niger.

5 TABLEAUX ET FIGURES

5.1 TABLEAUX

Tableau 1. Paramètres du bilan hydrologique de la région de Soubré

Paramètres	Quantité
Précipitations	1447 mm
ETP	1491 mm
ETR	1238,9 mm
Excédent (E+I)	263,9 mm
Ecoulement	188,11 mm
Infiltration	75,79 mm
Déficit	252,09 mm
Volume d'eau infiltrée	$6,47.10^8 \text{ m}^3$

5.2 FIGURES

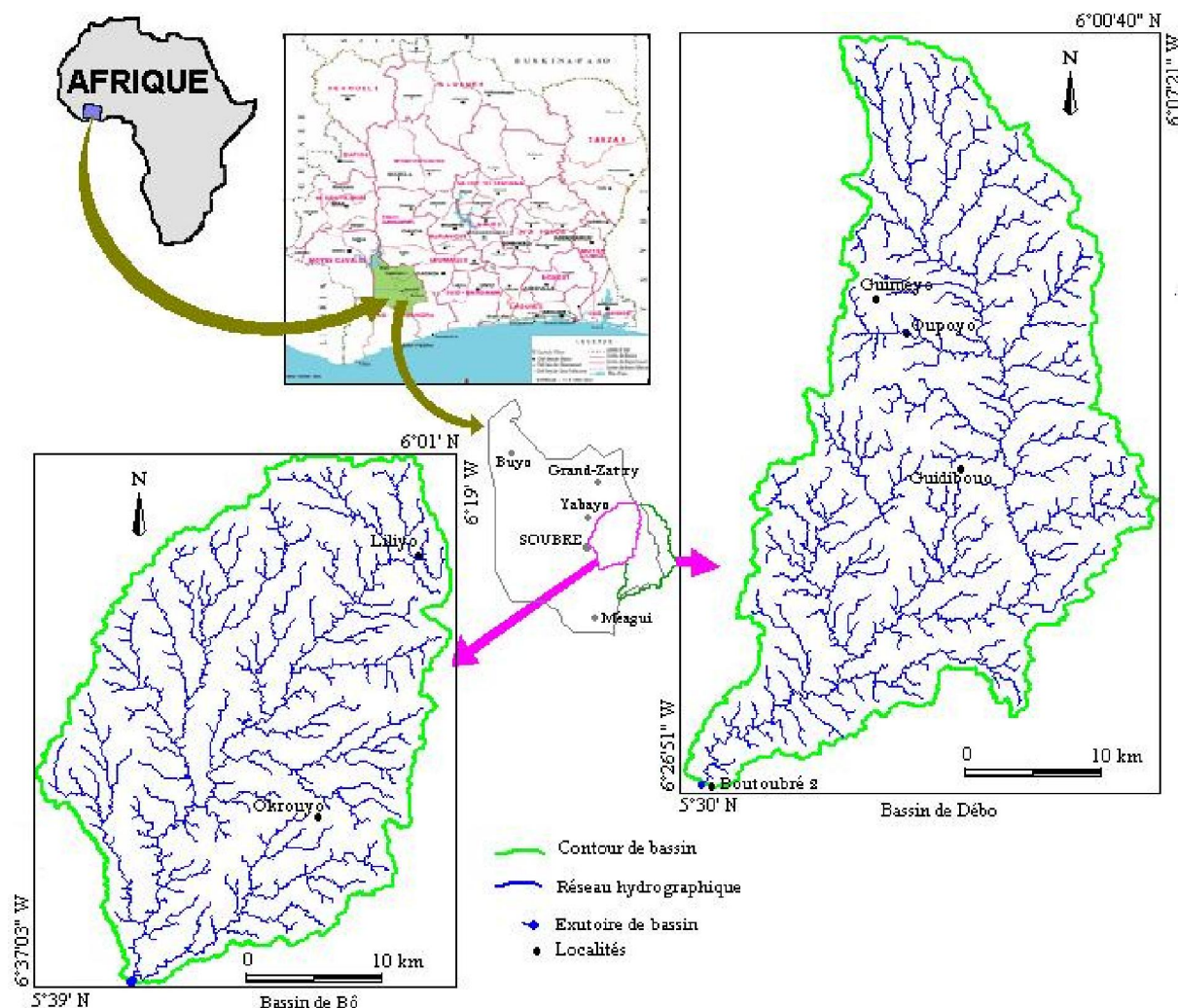


Fig. 1. Présentation et localisation de la zone d'étude

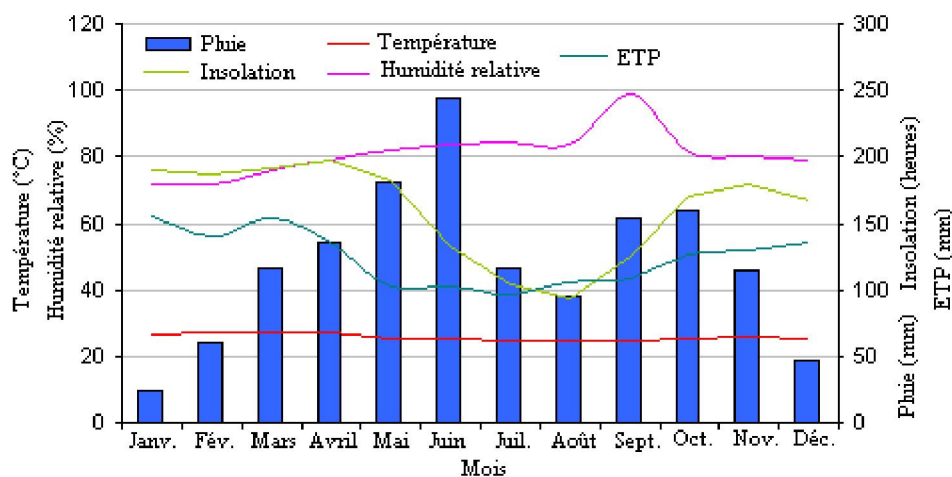


Fig. 2. Evolution saisonnière des paramètres climatiques et de Soubré

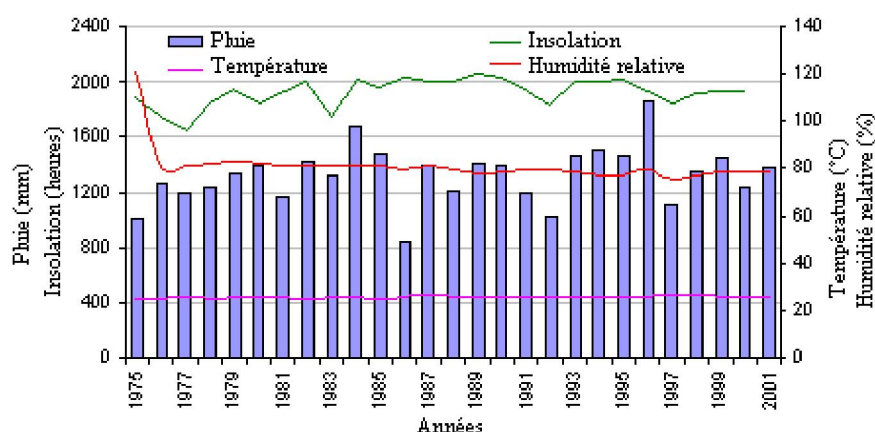


Fig. 3. Figure 3 : Variation interannuelle des paramètres climatiques de Soubré sur la période (1975-2001)

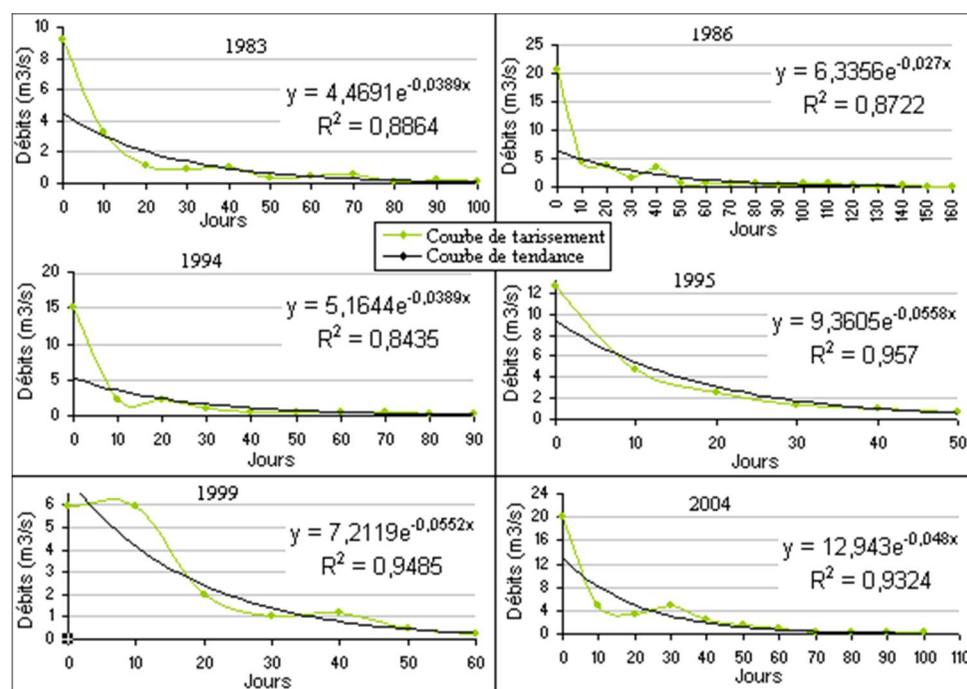


Fig. 4. Courbe de tarissement du Débo pour les années sélectionnées (1983, 1986, 1994, 1995, 1999 et 2004)

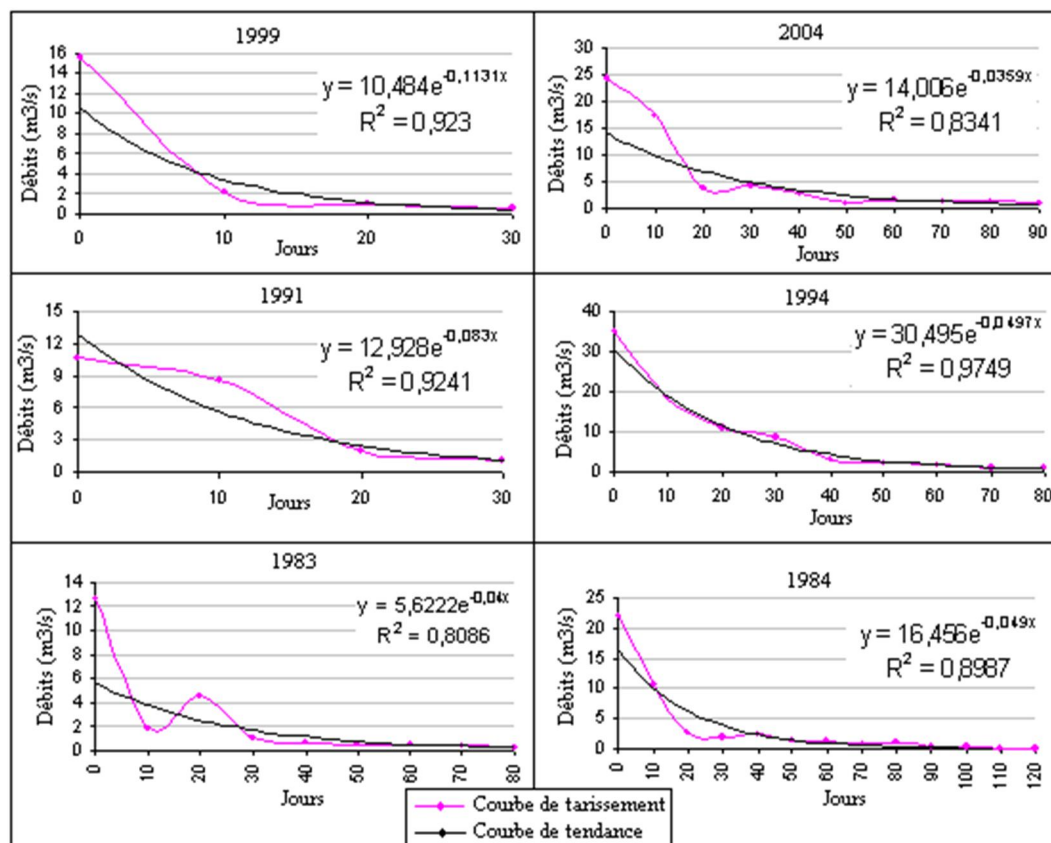


Fig. 5. Courbe tarissement de la rivière Bao (bassin versant de Bô) pour les années sélectionnées (1983, 1984, 1991, 1994, 1999 et 2004)

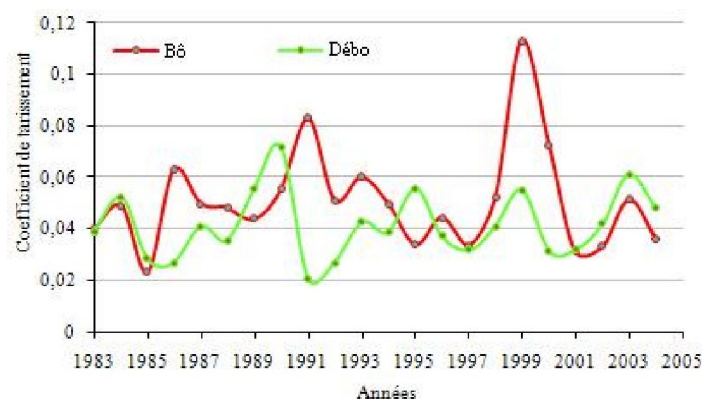


Fig. 6. Evolution des coefficients de tarissement des cours d'eau de Soubré

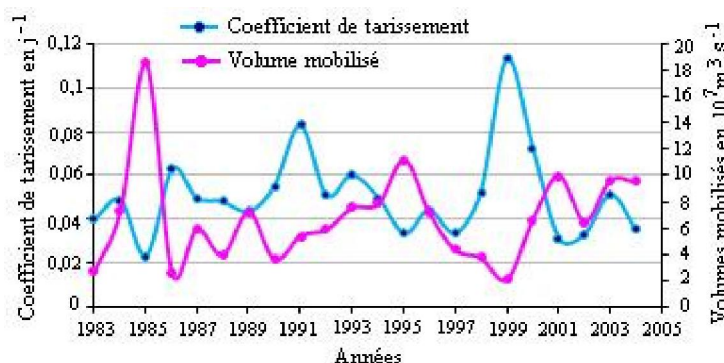


Fig. 7. Variation des coefficients de tarissement et des volumes mobilisés du Débo de 1983 à 2004

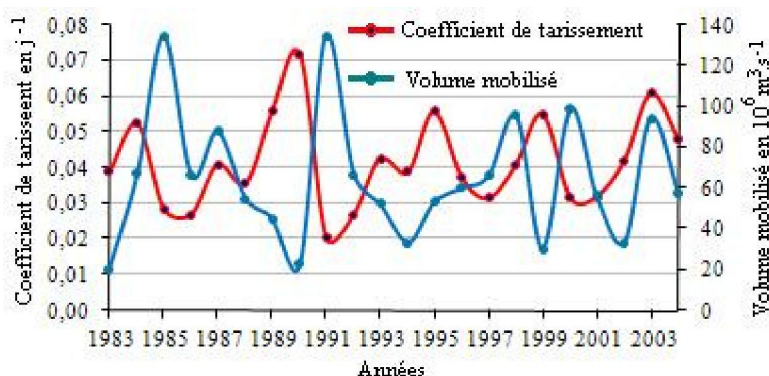


Fig. 8. Variation des coefficients de tarissement et des volumes mobilisés du Bô de 1983 à 2004

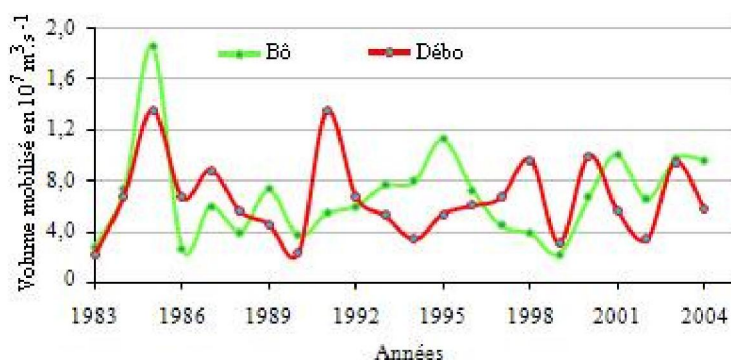


Fig. 9. Variation des volumes mobilisés des cours d'eau de Soubré

6 CONCLUSION

La variabilité des paramètres climatiques dans la région de Soubré a contribué réduire les ressources en eau disponibles. Cette variabilité a eu des conséquences néfastes sur le bilan hydrologique et a affecté la recharge souterraine réduisant ainsi les disponibilités en eau des réserves de la région. Ainsi, les coefficients de tarissement ont continué d'augmenter ces dernières années inversement aux volumes mobilisés dans les bassins versants de la région.

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The Determinants of Foreign Direct Investment and Their Impact on Growth: Panel Data Analysis for AMU Countries

ZENASNI Soumia¹ and BENHABIB Abderrezak²

¹Department of Economics,
University of Tlemcen,
Tlemcen, Algeria

²Department of Economics and Management,
Tlemcen School of Economics,
Tlemcen, Algeria

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ABSTRACT: The purpose of this paper is to study the determinants of foreign direct investment (FDI) and empirically examine their effects on the growth of the Arab Maghreb Union (AMU) countries. This relationship has largely been analyzed in the economic literature. The results are mixed, some of the theoretical and empirical studies have shown that there is no positive relationship between FDI and economic growth, while others have found that FDI affect positively and significantly the long-run economic growth. Indeed, AMU countries have developed in recent years, an economic policy aimed at promoting the development of their economy. In these economies, FDI is considered as a key factor towards progress in economic sectors. This type of external funding has shown an increasing trend over time; however, the achievements of AMU countries in attracting FDI are still low compared to their potential and their performance to attract more foreign investments. In this paper, we use a dynamic panel system GMM estimator to study the determinants and the growth effects of FDI in three Maghreb countries (Algeria, Morocco, and Tunisia) during the period 1980-2010. Our empirical investigation suggests that, under particular economic and financial conditions, such as the adoption of an export promotion trade regime, restoring international competitiveness and diversification of exports, foreign direct investment affects positively the growth rate in the long run and improves the economic situation in AMU countries.

KEYWORDS: Foreign direct investment, economic growth, Determinants and effects, AMU countries, Panel data analysis.

1 INTRODUCTION

Since the late 1990s, the literature on economic development has been renewed by focusing on the quality of foreign investment as a key explanation of cross-country differences in both growth rates and income per capita. In fact, there has been a growing interest in the determinants of foreign direct investment (FDI) in developing countries, as FDI is considered one of the most stable components of capital flows to developing countries and can also be a vehicle for technological progress through the use and dissemination of improved production techniques. Like other developing economies, Maghreb countries have developed in recent times, an economic policy aimed at promoting the development of its economy through FDI. However, the flows of these attracted investments remain relatively low and their impact on growth is ambiguous.

Along with the rapid growth of FDI flows, abundant theoretical and empirical literature has been developed in recent years to determine the theoretical advantages of these flows on the economy of each country (*Bornschier and al 1978; Borensztein and al 1992; De Gregorio 1993; Borensztein and al 1998; Choe 2003; Güner and Yilmaz 2007; Massoud 2008; Tiwari and Mutascu 2010; Rogmans 2011*). The results are mixed; some of them have shown that there is no positive relationship between FDI and economic growth (*Bornschier and al 1978; Alfaro and al 2002; Carkovic and Levine 2002; Effendi and al 2003; Massoud 2008*), while others have found that FDI positively and significantly affect the long-term

economic growth (Fry 1993; De Mello 1999; Bengoa and al 2003; Türkcan and al 2008; Agrawal and Khan 2011; Adeniyi and al 2012).

The objective of this article is to estimate the main determinants of FDI in developing countries and examine their effects on the economic growth of AMU economies by addressing the following issue: ***what are the determinants and the potential effects of foreign direct investment on economic growth of AMU countries?*** Using the econometrics of panel data, we estimate a dynamic panel system GMM estimator proposed by *Blundell and Bond (1998)* during the period 1980-2010. The estimation results show that, under particular economic and financial conditions, such as the adoption of an export promotion trade regime, restoring international competitiveness and diversification of exports, foreign direct investment positively affects the level of growth in the long-run and improves the economic situation in the studied countries.

This paper is structured as follows. In Section 1, we provide a review of the theoretical literature dealing with the determinants of direct foreign investment. The relationship between FDI and economic growth will be analyzed in section 2. Then the characteristics of FDI in the three studied countries will be highlighted in the third section that will be followed by the description of the data, the estimation methods and the specification of the regression model in section 4. Finally, section 5 presents the estimation results.

2 THEORETICAL AND EMPIRICAL LITERATURE REVIEW ON THE DETERMINANTS OF FDI IN HOST COUNTRIES

2.1 LITERATURE REVIEW

Foreign Direct Investment (FDI) is perceived as an important source of investment particularly in developing countries. Research has shown that the amount of FDI depends on a number of determining factors. One of the most important determinants of foreign direct investment is the population from which we can determine the market size as well as the growth prospect of the host economy. It is normally assumed that if the country has a big market, it can grow quickly from an economic point of view and it is concluded that the investors would be able to make the most of their investments in that country.

To explain the differences between the inflows of FDI in developing countries, many authors (*Bisat 1996; Alessandrini and Resmini 1999; Bennett 2003; El-Naggar 1990; Batra and al. 2000; Onyeiwu 2003; Végonzons-Varoudakis 2004; Habash 2006*) have asserted that the failure of North African economies may be attributed to a combination of factors that include lack of democracy, lack of transparency, and lack of good governance as well as macroeconomic instability. *Tsai (1994)* analyzed the decades of 1970 and 1980 and addressed the endogeneity problem between FDI and growth by using a simultaneous equation model. The estimation results suggest that domestic market size and trade balance are two key determinants of FDI, though economic growth and labour costs are also important. On the other hand, results indicate that the impact of FDI on economic growth is quite limited [1]. In the same perspective, *Loree and Guisinger (1995)* studied the determinants of foreign direct investment in the U.S. using 1977 and 1982 Benchmark data. They concluded that variables related to host country policy are significant in developed countries only when infrastructure is an important determinant in all regions [2]. A number of studies suggest that investments in developing countries are also positively affected by the degree of openness of the host economy. This implies that foreign investors prefer countries with relatively liberal trade regimes, possibly within region with free trade agreements [3]. In addition, existing business linkages and knowledge of local markets may help foreign firms, especially small and medium-sized ones, to take advantages of the opportunities presented by a rapidly evolving market structure.

Asked on the factors that influence the location and the choice of the host country, most transnational enterprises are interested firstly by the “*economic and political stability*” followed by the “*dimension of the market*”. The political and economic stability has a dimension that should inspire the legal and institutional framework: it must be stable, transparent and reliable. These conditions are important and their absence induces the enterprises to suspend their investment decisions or limits their financial commitments. Therefore, the availability of “*skilled labour*”, rather than low labour costs, is the third variable that affects investors’ attractiveness and it should be connected to the type of investment as well as the introduction of more complex technologies and the tendency to externalize an increasing number of production phases. “*Structural conditions*” within Mediterranean countries reinforce the risk of marginalization of the area, if the adoption of corrective measures aimed at modernizing the domestic production and labour market continues to be postponed. Such a risk is real also in those countries that succeed in attracting foreign investors in the sixties and the seventies. It seems that the current competitive model driven the globalization contrasts with the old logic of tariff protectionism. Of growing importance is also the need for “*communications and infrastructure*” that allow the transfer of information and goods [4].

Alessandrini and Resmini (1999) analyze the determinants of FDI in the Mediterranean region and compare the recent experience of the Mediterranean (MED) countries with that of the Central and Eastern European countries (CEECs). The

authors use a panel data study in eight Central European countries¹ and 11 Mediterranean countries² for the years 1990-1997. Results suggest that the natural resource endowment still represents an important factor of attraction of FDI, relative to CEECs. Moreover, foreign investors have been attracted in the MED region by market considerations, concerning not only the single national markets, but also the regional one. This effect is stronger than in the CEECs, suggesting that a deeper regional integration may sound attractive to foreign enterprises. *Benacek and al. (2000)* have studied the determinants and effects of FDI in CEECs. They suggest that market seeking has been the primary motive of investors, and that the presence of foreign firms has increased productivity levels in Central Europe, but only to a limited degree [5].

Based on a dynamic panel estimation of 26 transition economies over the period 1991-1999, *Garibaldi and al. (2001)* analyzed a large set of variables divided into macroeconomic factors, structural reforms, institutional and legal frameworks, initial conditions, and risk analyses. Results indicated that macroeconomic variables, such as market size, fiscal deficit, inflation and exchange regime, risk analysis, economic reforms, trade openness, availability of natural resources, barriers to investment and bureaucracy all had the expected signs and were significant [6]. Among the several studies that examined FDI flows in developing countries, *Nunnenkamp and Spatz (2002)* studied a sample of 28 developing countries during the period 1987-2000. They find significant correlations between FDI flows and per capita GNP, risk factors, years of schooling, foreign trade restrictions, complementary production factors, administrative bottlenecks, and cost factors³. Population, GNP growth, firm entry restrictions, and technology regulation all proved to be non-significant. However, when regressions were performed separately for the non-traditional factors, in which traditional factors were controls (population and per capita GNP), only factor costs produced significant results and, even so, only for the 1997-2000 period [7].

The neo-classical theory of the determinants of FDI suggests that host countries' labour supply influences foreign investors' location decisions through the labour cost and the quality of the skills of the labour force. Locations with low labour costs and/or highly skilled labour force are expected to be more attractive for foreign investors, particularly for firms producing labour intensive goods. Studying the case of Middle East and North Africa (MENA) countries, *Onyeiwu (2003)* indicates that the MENA region is different from other developing countries with regard to FDI flows (i.e., some of determinants factors⁴ of FDI flows in developing countries are not relevant for FDI flows to MENA countries). This author concludes that there are two significant factors explaining why FDI flows to MENA countries are less than other developing countries: corruption and limited trade openness [8]. This goes along the analysis presented by *Batra and al. (2003)* argue that MENA countries are faced with two major obstacles impeding FDI flows: political instability and corruption [9].

Campos and Kinoshita (2003) use panel data to analyze 25 transition economies between 1990 and 1998. They reached the conclusion that for the studied countries, FDI is influenced by economy clusters, market size, the low cost of labor, and abundant natural resources. Besides all these factors, the following variables presented significant results: sound institutions, trade openness, and lower restrictions to FDI inflows [10]. *Bennett (2003)* affirms that many of the MENA countries are grappling with the failed legacies of central planning, including unviable state companies, bloated bureaucracies, a narrow tax base, and expensive subsidies. He suggests that public sector reform is one of the keys to reinvigorating these stagnating economies that have been missing out on the benefits of globalization and world economic integration [11]. Along the same lines of studies undertaken by Bisat and al. (2000) and Onyeiwu (2003), *Chan and Gemayel (2004)* find that instability associated with investment risk is critical in explaining the level of foreign direct investment for the MENA countries, which generally have higher investment risk than developed countries [12]. According to *Ben-Taher and Giorgioni (2009)*, during the last two decades, the amount of FDI inwards to North African countries (including Algeria, Morocco, and Tunisia) was small both in absolute and relative terms in comparison with other developing countries [13].

In sum, the main variables normally used are the size of the market, the rate of GDP growth, economic stability, the degree of openness of the economy, as well as several other institutional variables. However, the relation between FDI and economic growth deserves special attention. If, on one hand, economic growth is a powerful stimulant to the inflow of FDI, on the other, an increase in foreign investment (an increase in the existing capital stock) would also be one of the factors responsible for economic growth, meaning the existence of an endogeneity problem. Thereafter, the main determinants of FDI in developing countries will be presented.

¹ The Visegrad group countries, Bulgaria, Estonia, Romania, and Slovenia.

² Algeria, Cyprus, Egypt, Israel, Jordan, Lebanon, Malta, Morocco, Syria, Tunisia, and Turkey.

³ Costs related to taxation, employment conditions, labor market regulation, and the power of labor unions.

⁴ These factors include the rate of return on investment, infrastructures, and macroeconomic fundamentals such as GDP growth and inflation.

2.2 DETERMINANTS OF FDI IN DEVELOPING COUNTRIES

Based on the existing literature, it can be argued that FDI depend on a number of factors. Some of the main determinants are the followings (*Anwar and Nguyen, 2010*):

2.2.1 MARKET SIZE

The market size which is one of the most important determinants of FDI is usually measured by GDP per capita. Several empirical studies have shown that an increase in GDP per capita is associated with increased FDI inflows into host countries. Rising income levels are a signal of an increase in the market size and purchasing power. *Kravis and Lipsey (1980)* found a positive relationship between the market size in host nations and the location decision of US multinationals [14]. *Chakrabarti (2001)* found also a strong positive relationship between the market size of a host country and FDI.

2.2.2 THE QUALITY AND THE DEVELOPMENT OF BASIC INFRASTRUCTURE

Availability of international standard infrastructure (such as road transport, railway transport...) is a major determinant of FDI in host countries. In other words, a good infrastructure developed and evolved is essential to maintaining country's economic growth, because in such conditions the operating cost is low, which can increase the return on investment and therefore promotes FDI.

2.2.3 THE LEVEL OF TRADE OPENNESS

Attracting FDI is also dependent on the degree of integration into the global economy. The openness of an economy is measured by the ratio of imports and exports to GDP, it accounts for the fact that more open economies tend to be more vulnerable to losing access to foreign financing [15]. Indeed, a decrease in the level of restrictions imposed on trade exchanges tends to increase horizontal FDI in host countries. However, vertical FDI that is viewed as a non-market seeking investment may prefer to locate in more open economies (that is, where trade barriers are few). *Balasubramanyam and Salisu (1991)*, *Jackson and Markowski (1995)* have used export volume as a measure of the openness of an economy. They have found a positive relationship between exports and FDI inflow. *Grossman and Helpman (1991)* and *Barro and Sala-i-Martin (2004)* have argued that a more open trade regime leads to a greater ability to absorb technological progress and export goods that stimulates economic growth.

2.2.4 HUMAN CAPITAL

Human capital is long regarded as a determinant of economic growth. Human capital also affects growth through its interaction with FDI.

2.2.5 MACROECONOMIC STABILITY

While early studies, such as the Friedman's (1977) study, have highlighted the role of the inflation rate (measured by the index of consumer prices, CPI), which is an important indicator of a country's macroeconomic stability, recent studies have used the real exchange rate as an indicator of macroeconomic stability. The real exchange rate volatility is regarded as an indicator for poor macroeconomic policies that lead to real exchange rate misalignment thereby hindering economic growth.

Economic stability is often cited by investors as a key factor of their location decisions. From the empirical work on African countries, including North African countries, *Basu and Srinivasan (2002)* emphasize the decisive aspect of the macroeconomic stability for investors in an environment which can reduce the risk and increase return on investment [16]. *Lim (2001)*, *Bloningen (2005)*, *Froot and Stein (1991)* *Stevens (1998)* and *Klein and Rosengren (1994)*, confirms the particular importance of macroeconomic stability the stability of exchange rates. There is a macroeconomic dimension of country risk or the business climate for the particular characteristics of inflation, debt and deficit reduction, which can negatively affect the investment decisions of firms by creating conditions of uncertainty on the value of assets or future taxes.

2.2.6 LEVEL OF FINANCIAL DEVELOPMENT

Barro (1991) has argued that financial development has a significant positive impact on economic growth. King and Levine (1993) have suggested that higher levels of domestic investment are positively related to faster economic growth [17]. *Hermes and Lensink (2003)* have argued that that the development of the financial system of a host country is an important

precondition for FDI to have a positive effect on economic growth. They further argue that a well-developed financial system positively contributes to the process of technological diffusion associated with FDI [18].

2.2.7 RATE OF RETURN ON INVESTMENT

The profitability of investments is of primary interest to foreign investors. The decision to invest in a host economy, therefore, depends on the risk and return on investment in the economy. Portfolio theory contends that capital tends to flow to economies with low risks and high rates of return. In very risky economies, the risk-adjusted rate of return on investment must be reasonably high in order to attract FDI (Onyeiwu 2003).

In addition to these determinants of FDI, several economists (Lim 2001; Bloningen 2005; Benassy and al, 2005) emphasize the importance of **political stability** for investors. In other words, **fiscal and institutional context** can also improve the business climate and the potential attractiveness of a territory by acting as a facilitating factor for investment, particularly by reducing uncertainty and unforeseen costs which associated to foreign investors [19].

3 LITERATURE REVIEW ON THE LINK BETWEEN FDI AND GROWTH

In the economic literature, there is a large body of studies on the impact of foreign direct investment (FDI) on economic growth. This literature explores various aspects of the spillover effects of FDI such as (i) technology transfer (ii) introduction of new processes (iii) productivity gains and (iv) opening of new market opportunities. FDI is usually viewed as a channel through which technology is able to spread from developed to developing countries. According to Chen (1992), the positive developmental role of FDI in general is well documented. He argues that FDI produces a positive effect on economic growth in host countries. Moreover, Blomström and Kokko (1997) reveal that economic theory provides two approaches to studying the effects of FDI on host countries. One is rooted in the standard theory of international trade and dates back to MacDougall (1960). This is a partial equilibrium comparative-static approach intended to examine how marginal increments in investment from abroad are distributed. The main prediction of this model is that inflows of foreign capital -whether in the form of FDI or portfolio capital- will raise the marginal product of labor and reduce the marginal product of capital in the host country. The other approach departs from the theory of industrial organization, and was pioneered by Hymer (1960)⁵. This approach suggests that to be able to invest in production in foreign markets, a firm must possess some asset (for example, product and process technology or management and marketing skills) that can be used profitably in the foreign affiliate. Firms investing abroad therefore represent a distinctive kind of enterprise. In their study, Blomström and Kokko (1997) suggest that foreign direct investment may promote economic development by helping to improve productivity growth and exports.

In their study elaborated on the benefits of FDI for domestic firms, Aitken and Harrison (1999) show that the net effect of FDI on firm level productivity is negligible [20]. Bosworth and al. (1999) used panel regression techniques to evaluate the impact of capital inflows on investment on a group of 58 developing countries for the period 1978-95. They found that FDI flows have a positive (and almost one for one) impact on investment, whereas portfolio flows have no discernible effect [21]. Additionally, Ogutucu (2002) argues that the foreign direct investment is a major catalyst for the development and the integration of developing countries in the global economy [22]. In the same perspective, Alfaro (2003) has made a sectorial panel OLS analysis, using cross-country data over the period 1981-1999. Alfaro affirms that, although it may seem natural to argue that FDI can convey great advantages to host countries, the benefits of FDI vary greatly across sectors by examining the effect of foreign direct investment on growth in the primary, manufacturing, and services sectors. The main results indicate that FDI in the primary sector tend to have a negative effect on growth, while investment in manufacturing a positive one, and the effect of investment on growth in service sector is ambiguous [23].

Balamurali and Bogahawatte (2004) emphasize that a better trade policy reforms (promotion of foreign direct investment and domestic investment) and restoring international competitiveness to expand and diversify the country's exports have the potential of accelerating economic growth in the future [24]. Based on a number of determinants of the linkage between FDI and economic growth (such as human capital, learning by doing, exports, macroeconomic stability, level of financial development, public investment and other determinants), Neuhauser (2006) shows that there are three main channels through which FDI can influence the technological change, improve the capital stocks and generate economic

⁵ Other important contributions have made by Buckley and Casson (1976), Caves (1971), Dunning (1973), Kindleberger (1969), and Vernon (1966).

growth: (a) direct transmission (through "Greenfield Investments"); (b) indirect transmission (through "Ownership Participation") and (c) second-round transmission (through "Technology Spillover") [25].

In turn, based on the Generalized Least Squares models, the study of *Bhandari et al. (2007)* illustrate that an increase in the stock of domestic capital and inflow of foreign direct investment are main factors that positively affect economic growth in East European countries [26]. Besides, *Won et al. (2008)* focused their analysis on the case of Asian newly industrializing economies. Using the panel vector autoregressive models, results show that the openness of the economy, measured by exports and FDI inflows, is the most common economic factor attributed to the rapid growth of the Asian newly industrializing economies [27]. *Tiwari and Mutascu (2010)* have conducted an empirical analysis to examine the effects of FDI on economic growth for 23 Asian countries over the period 1986-2008. Results show that FDI and exports enhance the economic growth of Asian countries [28]. *Agrawal and Khan (2011)* investigated the impact of FDI on economic growth in five Asian countries (China, Japan, India, South Korea, and Indonesia) over the period 1993-2009. This study confirms that FDI promotes economic growth and further provides an estimate that one dollar of FDI adds about 7 dollars to the GDP of each of the five countries [29]. Moreover, *Adeniyi and al (2012)* examines the causal link between FDI and economic growth with financial development in some small open developing economies. Using a trivariate framework which applies Granger causality tests in a vector error correction (VEC) over the period 1970-2005, results suggest that the extent of financial sophistication matters for the benefits of foreign direct investment on economic growth in studied economies [30].

Finally, we can observe that several studies have examined this relationship in particular in the case of developing countries. The major part of them stress that FDI, adjusted to other determinants, have a significant positive effect on economic growth.

4 OVERVIEW OF FDI AND ECONOMIC GROWTH IN AMU COUNTRIES

In recent years, foreign direct investment is considered as a key factor towards progress in Maghreb countries. This type of external funding has shown an increasing trend over time which can reflect, partly, the large-scale privatization programs that were implemented by these economies in recent years (*Reggad 2008*). The sustained efforts at policy reforms in AMU countries (including privatizations by host countries, and intensified search for natural-resource), drove FDI inflows to the North African sub-region to \$24 billion, although this was slightly lower than in 2007. In Algeria, Morocco and Tunisia, there was an increase in FDI inflows, which was driven by investments in their oil and gas industries (in Algeria), and the agriculture, manufacturing and tourism (in Morocco and Tunisia), in addition to privatizations of public companies engaged in the oil industry (*UNCTAD World Investment Report, 2009*).

Table 1 provides some basic data on three North African countries as well as some data that are particularly relevant in the context of our research.

Table 1. Overview of AMU Countries in 2008

Country	Pop'n M	GDP US \$ m	GDP per capita US \$	FDI inflow US \$ m	FDI stock US \$ m	OPEC Y/N	WTO Yr joined
Algeria	34.4	166,545	4,845	2,646	14,458	Yes	No
Morocco	32.1	88,883	2,769	2,388	41,001	No	1995
Tunisia	10.3	40,309	3,903	2,761	29,083	No	1995

Rogmans T. J. (2011), [31]

From the table it can be seen that the region's top economy in terms of overall GDP is Algeria, the member of OPEC (Organization of the Petroleum Exporting Countries). In addition, WTO membership is important for countries in the sense that member states commit to a rules based framework for international trade and investment. In terms of Foreign Direct Investment, as per 2008, the three North African countries (Algeria, Morocco, and Tunisia) account between 2 and 3 US million \$ of the FDI inflows; table shows also that Morocco is the most important country in the region in terms of FDI stock with 41 US million \$. It is true that a substantial increase was recorded in these countries, but it is still insufficient on a global scale [32].

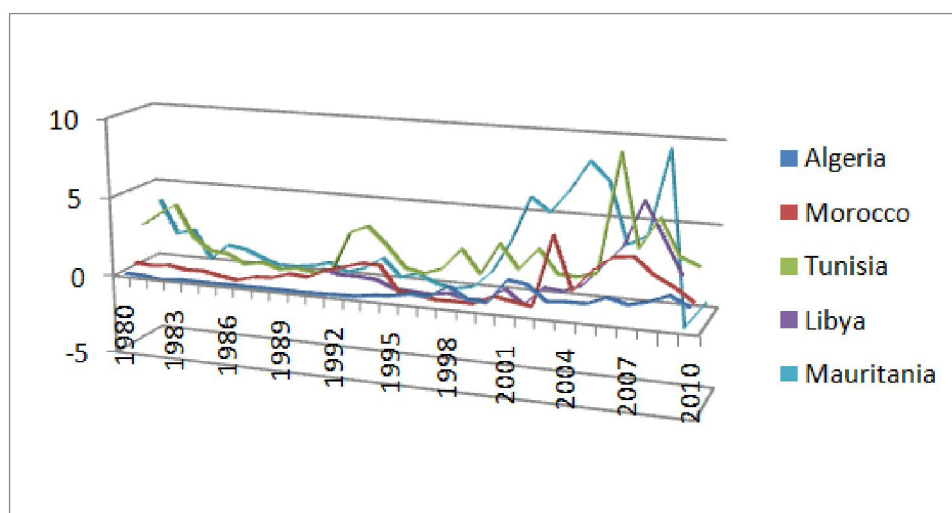


Fig. 1. FDI, A Comparison Among The Five Maghreb Countries (Net Inflows, % of GDP)

Source : *The African Development Indicators, Wolrd Bank, 2012.*

Fig. 1 shows that the achievements of AMU countries in attracting FDI are still low compared to their potentiality and their performance (in the case of Algeria for example, 97.5% of Algerian economic returns are generated by the oil; so there are great potentialities and opportunities (in the entire region) to attract more foreign investments). This lower rate is mainly related to some economic obstacles. Comparing FDI between the five North African countries (Algeria, Morocco, Tunisia, Libya, and Mauritania), we can observe that Algerian economy has the lowest rate in attracting FDI; this situation is caused by the period of significant crisis that faced the country in the 1990s, as well as some other economic and financial barriers.

Moreover, FDI flows to developing countries' sectors increased rapidly in the late 1980s and early 1990s in almost region of the world revitalizing the long and contentious debate about the costs and benefits of FDI inflows. Attracting FDI has been one of the key policy goals of developing countries and today everybody agrees that FDI has been an important vehicle to accelerating enterprise modernization and restructuring by introducing new technologies, management techniques and marketing practices. In contrast to other capital flows, FDI is less volatile and does not show a pro-cyclical behavior. It has therefore become the "favorite capital inflows" for developing countries. Many authors would argue that, given appropriate policies and a basic level of development, FDI can play a key role in the process of creating a better economic environment. On the other hand potential drawbacks do exist, including a deterioration of the balance of payments as profits are repatriated and negative impacts on competition in national markets.

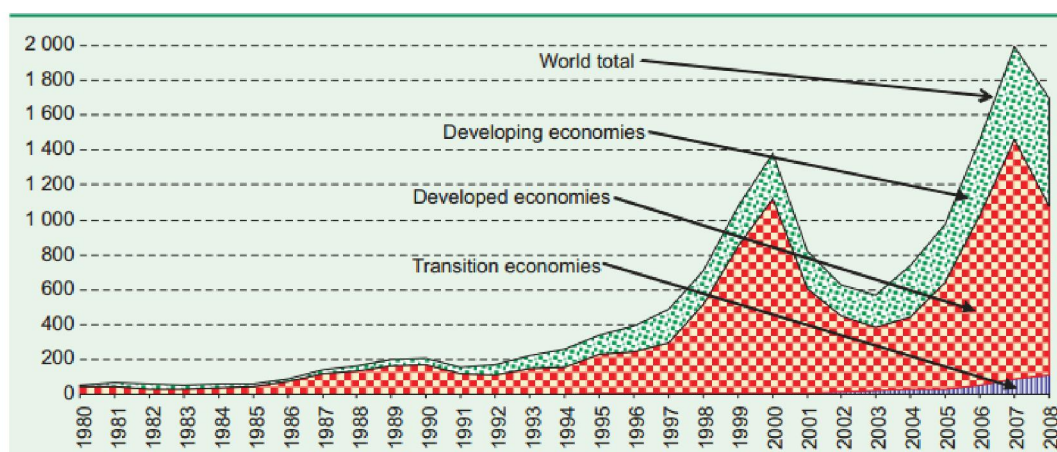


Fig. 2. FDI Inflows, Global and By Groups of Economies, 1980-2008 (In Billions of Dollars)

UNCTAD (2009), [33]

As shown in Fig. 2 and according to the *UNCTAD World Investment Report (2009)*, turmoil in the financial markets and the worldwide economic downturn progressively affected global FDI in 2008 and in the first half of 2009. After uninterrupted growth in FDI activity in the period 2003-2007, global FDI inflows fell by 14% in 2008 to 1,697 billion \$, from a record high of 1,979 billion \$ in 2007. While the 2008 level was the second highest in history, in late 2008 and the first few months of 2009, significant declines were recorded in all three components of FDI inflows: equity investments, other capital (mainly intercompany loans). Such a decline was caused mainly by the financial crisis that developed countries have experienced following the collapse of Lehman Brothers (one of the largest financial institutions in the United States).

Moreover, the pattern of FDI flows has varied by groups of economies. FDI inflows and outflows of developed countries plunged in 2008, with inflows declining by 29%, to 962 billion \$, and outflows by 17%, to 1,507 billion \$ (*UNCTAD World Investment Report, 2009*). In contrast, developing and transition economies saw FDI inflows rise in 2008 to record levels for both, with their shares in global FDI inflows growing significantly between 2003 and 2007. The decline in FDI flows in 2008-2009 in developing countries reflects the impact of the financial crisis of 2007.

However, most developing countries are disappointed about the continuing high levels of protection and subsidies for agricultural goods, mainly in developed countries. These measures hamper developing-country exports of agricultural products, and undermine the effective use of their comparative advantages.

5 EMPIRICAL ANALYSIS

5.1 DESCRIPTIVE DATA

To examine the effects of foreign direct investment on economic growth in the three Maghreb countries (Algeria, Tunisia, and Morocco), we use data from 1980 to 2010. The data utilized for the analysis have been collected from a various international databases: the World Development Indicators (WDI), the CNUCED, the UNCTAD stat, the SESRIC BASEIND (Basic Social and Economic Indicators) Database 2012, the Chinn-Ito index (2010)⁶, and the World Economic Outlook Database (IMF), 2012. The exact source for each variable is presented in Appendix (table A).

5.2 ESTIMATION METHODOLOGY

We use the recent developments in time series econometrics to analyze and determine causal relationships between FDI and economic growth in the three North African countries. We first examine long-run equilibrium (cointegration) relationship among variables. Then, we use the panel data econometrics; we estimate a dynamic panel system GMM estimator proposed by *Blundell and Bond (1998)*. This approach will be applied using three econometric methods with fixed effects, Ordinary Least Squares method (OLS), Two Stages Least Squares method (TSLS), and Generalized Method of Moments (GMM).

5.3 REGRESSION SPECIFICATION

From the examination of theoretical and empirical literature review, aimed to study the effect of FDI on economic growth, we specify the model of our study. The econometric model of this work is based upon studies undertaken by *Alfaro (2003)*, *Balamurali and Bogahawatte (2004)*, *Anwar and Nguyen (2010)*. It is as follows:

$$GROWTH_{i,t} = \theta_0 + \theta_1 FDI_{i,t} + \theta_2 DINV_{i,t} + \theta_3 CONTROLS_{i,t} + \epsilon_{i,t}$$

where $GROWTH_{i,t}$ is a variable representing the logarithmic of growth in real GDP per capita. $FDI_{i,t}$ represents foreign direct investment measuring the inflows of capital accruing to country i in year t . $DINV_{i,t}$ is the nationally owned investments defined as gross fixed capital formation. $CONTROLS_{i,t}$ is a vector of control variable of the determinants of FDI and growth; it contains $Topen_{i,t}$ represents the trade openness measured by the sum of imports and exports in percentage of GDP; $FDev_{i,t}$ is a measure of the development of domestic financial systems; it is calculated by the money supply as a share of per capita GDP; $Inf_{i,t}$ variable measures the inflation rate in the three North African countries and represents the annual rate of change

⁶ The Chinn-Ito index (*KAOPEN*) measures a country's degree of capital account openness. This index is based on the binary dummy variables that codify the tabulation of restrictions on cross-border financial transactions reported in the IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions*.

of the Consumer Price Index; $ExRate_{i,t}$ denotes the real exchange rate variable calculated from nominal exchange rates and CPIs; $Kaopen_{i,t}$ variable that measures the extent of openness in capital account transactions. $\mu_{i,t}$ is the error term.

5.4 ESTIMATION RESULTS

5.4.1 STATIONARITY AND COINTEGRATION TEST RESULTS

Before testing the long-run relationship among variables, it is necessary to check whether series are stationary. We employ the ADF test and the PP test. The PP test corrects, in a non-parametric way, the possible presence of autocorrelation in the standard ADF test. Then, we use the Johansen Cointegration test to examine the long-run equilibrium relationship. Table 2 provides the results of the ADF and PP tests. The results of the unit root tests conducted on the variables reveal that the natural logs of real per capita growth, foreign direct investment, gross domestic investment, trade openness, financial development, inflation, nominal effective exchange rate, and capital account transactions all are stationary in the 1st differences. Given these test results, we can conclude that these time series are integrated of order one, or $I(1)$.

Table 2. Unit Root Test Results

Variables in 1 st Differences	Algeria		Morocco		Tunisia	
	ADF Test	PP Test	ADF Test	PP Test	ADF Test	PP Test
GROWTH	- 3.926*** (0.0055)	- 4.132*** (0.0033)	- 4.599*** (0.0010)	- 6.299*** (0.0001)	- 5.035*** (0.0003)	- 5.022*** (0.0003)
FDI	- 3.473** (0.0209)	- 7.274*** (0.0001)	- 4.612*** (0.0010)	- 9.722*** (0.0000)	- 6.715*** (0.0001)	- 6.644*** (0.0001)
DINV	- 4.837*** (0.0005)	- 4.826*** (0.0006)	- 4.768*** (0.0006)	- 4.769*** (0.0006)	- 3.371** (0.0209)	- 3.486** (0.0158)
TOpen	- 3.196** (0.0317)	- 3.606** (0.0119)	- 7.619*** (0.0000)	- 8.027*** (0.0000)	- 4.536*** (0.0012)	- 4.966*** (0.0004)
FDev	- 4.382*** (0.0018)	- 4.373*** (0.0018)	- 4.875*** (0.0005)	- 5.724*** (0.0001)	- 4.726*** (0.0008)	-10.365*** (0.0000)
Inf	- 5.991*** (0.0001)	- 5.981*** (0.0001)	- 3.105** (0.0409)	- 6.857*** (0.0001)	- 2.672* (0.0839)	- 3.944*** (0.0028)
ExRate	- 4.827*** (0.0006)	- 4.817*** (0.0006)	- 3.645** (0.0111)	- 6.666*** (0.0001)	- 4.812*** (0.0007)	- 4.839*** (0.0007)
Kaopen	- 5.385*** (0.0001)	- 5.385*** (0.0001)	- 5.228*** (0.0002)	- 6.354*** (0.0001)	- 5.196*** (0.0002)	- 5.196*** (0.0002)

***: variable stationary at significant levels at 1%, 5%, and 10% (-3.689, -2.971, -2.625 respectively).
Values between brackets are probabilities.

Table 3 presents the results of the Johansen cointegration test. It shows the existence of a cointegration relationship between the variables in all Maghreb countries (Algeria, Morocco, and Tunisia).

Table 3. Johansen Cointegration test results

Hypotheses of cointegration equation	Algeria		Morocco		Tunisia	
	Trace Test	Max. Eigen Test	Trace Test	Max. Eigen Test	Trace Test	Max. Eigen Test
None	49.013* (0.0387)	28.365* (0.0397)	47.153 (0.0581)	31.928* (0.0129)	45.461 (0.0825)	28.548* (0.0375)
At most 1	20.648 (0.3799)	12.614 (0.4883)	15.224 (0.7654)	10.929 (0.6543)	16.912 (0.6465)	11.219 (0.6254)
At most 2	8.034 (0.4618)	6.427 (0.5590)	4.924 (0.8783)	4.284 (0.8282)	5.693 (0.7314)	5.688 (0.6534)
At most 3	1.606 (0.2050)	1.606 (0.2050)	0.010 (0.9186)	0.010 (0.9186)	0.004 (0.9465)	0.004 (0.9465)

* denotes rejection of the hypothesis at the 0.05 level. Values between brackets are probabilities.

This table shows that, in Morocco and Tunisia, there is one cointegration equation at the 0.05 level based on the maximum eigenvalue test. In the case of Algeria, there is one cointegration equation at the 0.05 level based on the trace test, as well as the maximum eigenvalue test. Moreover, the stationarity test as well as the cointegration test results will allow us to better specify the dynamic panel GMM estimator.

The cointegration tests of the four variables for each country give us the results interpreted in the following equations:

Algeria: $GROWTH = 0.288 FDI + 9.086 DINV - 0.311 CONTROLS$

(0.069) (1.260) (0.084)

Morocco: $GROWTH = 0.069 FDI + 1.046 DINV + 0.119 CONTROLS$

(0.019) (0.235) (0.026)

Tunisia: $GROWTH = 0.381 FDI + 2.402 DINV + 0.163 CONTROLS$

(0.051) (0.775) (0.067)

5.4.2 DYNAMIC PANEL GMM TEST RESULTS

The empirical analysis using the dynamic panel GMM method gives the results reported in Tables 4, 5 and 6.

Table 4. FDI and economic growth: Least Squares method (LS)

Variables	Algeria	Morocco	Tunisia
FDI	1.716 (0.067)	3.017** (0.027)	6.062*** (0.066)
DINV	19.130*** (0.110)	17.457*** (0.103)	11.569*** (0.134)
CONTROLS	0.994 (0.038)	2.782* (0.035)	0.271 (0.077)

*Dependant variable: growth rate of real per capita GDP. (***), (**) and (*) indicate statistical significance at the 1%, 5% and 10% level, respectively. Values between brackets are Standard Error.*

Table 5. FDI and economic growth: Two-Stage Least Squares method (TSLS)

Variables	Algeria	Morocco	Tunisia
FDI	1.599 (0.111)	1.625 (0.049)	3.375** (0.119)
DINV	6.799*** (0.368)	4.427*** (0.296)	3.241** (0.387)
CONTROLS	- 0.753 (0.136)	2.262 (0.113)	0.635 (0.326)

*Dependant variable: growth rate of real per capita GDP. (***), (**) and (*) indicate statistical significance at the 1%, 5% and 10% level, respectively. Values between brackets are Standard Error.*

Table 6. FDI and economic growth: Generalized Method of Moments (GMM)

Variables	Algeria	Morocco	Tunisia
FDI	1.031 (0.172)	2.181 (0.038)	3.428** (0.114)
DINV	4.990*** (0.500)	9.833*** (0.158)	6.358*** (0.241)
CONTROLS	- 0.526 (0.191)	2.566 (0.066)	0.260 (0.242)

*Dependant variable: growth rate of real per capita GDP. (***), (**) and (*) indicate statistical significance at the 1%, 5% and 10% level, respectively. Values between brackets are Standard Error.*

Interestingly, the effect of foreign direct investment (FDI) is positive and statistically significant at the 99% level of confidence in the three countries and in all specifications (LS, TSLS, and GMM), suggesting that FDI is beneficial for economic growth in the three studied countries. Nevertheless, its effect is relatively small; this can be justified by the existence of many obstacles to attracting foreign investment projects. In addition, the effect of domestic investment is positive and statistically significant at the significance level of 99% in the three countries and in all specifications (LS, TSLS, and GMM); this can confirm that this type of investment is an important determinant which can foster the economic growth in the studied countries. As shown in Table 6, the estimation using GMM method gives more relevant results than the OLS and the TSLS methods; this is due to the specificity of estimators in this method. We can check also the observation that the macroeconomic fundamental such as exchange rate, trade openness, financial system development, capital account transactions..., have, in sum, a positive impact in Moroccan and Tunisian economic growth; whilst, it negatively affects economic growth in Algeria, that may contribute to the explanation as to why Moroccan and Tunisian economies exhibit better macroeconomic stability.

In sum, results show that Foreign Direct Investment (FDI) is an important factor which contributes to increase economic growth of AMU countries. Finally, we can assert that these countries should adopt some economic and financial conditions, such as, adopting a better trade policy reforms⁷, restoring international competitiveness, and diversifying the country's exports, to significantly improve their financial and economic situations.

6 CONCLUSION

After reviewing the theoretical and the empirical literature over the link between foreign direct investment and economic growth, this article examines empirically this relationship for the case of three AMU countries using the dynamic panel system GMM estimator proposed by *Blundell and Bond (1998)* over the period 1980-2010. This study emphasizes that FDI plays a positive role in boosting the economic growth of Maghreb countries. It also emphasizes that these countries has been relatively successful over the last decade in attracting FDI inflows that have not shown a significant performance.

FDI inflow could bring important benefits to Algeria, Morocco and Tunisia in the form of capital inflows, technology spillovers, human capital formation, international trade integration, job creation, the enhancement of enterprise development, and so forth. However, government policies are needed to enhance benefits and minimize negative effects on the local community. The role of political stability as a key factor in attracting and maintaining investors cannot be overemphasized, and maximizing a country's potential for attracting FDI inflows need to include policies improving the legal framework, adequate infrastructure, good governance, an effective judicial system and respect for the rule of law among others.

Finally, we can say that, although, the economy of each North African country has achieved, these recent years, significant steps leading them to achieving higher level of economic and financial developments, it remains nevertheless that these countries should firstly elaborate structural economic policies especially on the commercial, banking and financial plans, secondly improve the investment climate, and thirdly, create the conditions for an attractive and sound economic environment for foreign investments. Besides, these some obstacles should be removed in order to facilitate free movements of capital that may lead to the establishment of a common currency and a free trade area. This can allow them to increase the degree of financial integration, improve economic growth rates in each country, and, thereby, make them less vulnerable to different external shocks.

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⁷ Such as the promotion of the foreign direct investment as well as the domestic investment.

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APPENDIX

Table A. Definition and sources of variables

Variable	Definition	Source
GDP growth	This variable represents the growth of the real per capita gross domestic product.	• IFS; • SESRIC Database.
FDI	Direct Foreign Investment flow as % of GDP. This variable measures the inflows of capital in countries. It is the sum of equity capital, reinvestment of earnings, other long-term capital and short-term capital.	• CNUCED • UNCTADstat
DINV	It is the nationally owned investments defined as "gross fixed capital formation".	African Development Indicators, World Bank.
Topen	Trade Openness (Export and import volume of goods and services) as a share of GDP. This variable measure the openness degree of domestic banking and financial system.	• The SESRIC BASEIND (Basic Social and Economic Indicators) Database 2012.
FDev	Financial Development measured by money and quasi money (M2) as share of GDP: comprises the sum of currency outside banks, demand deposits other than those of the central government, and the time, savings, and foreign currency deposits of resident sectors other than the central government. This variable measures financial market development.	• International Financial Statistics (IFS). • The SESRIC BASEIND (Basic Social and Economic Indicators) Database 2012.
Inf	This variable measures the inflation rate in the three Maghreb Countries. It represents the annual rate of change of the Consumer Price Index.	• International Monetary Fund, World Economic Outlook Database, April 2012.
ExRate	Exrate denotes the exchange rate variable; it is calculated from nominal exchange rates and CPIs.	• IFS, Global Insight, Oxford Economic Forecasting and ERS Baseline Regional Aggregations.
Kaopen	This variable measures the extent of openness in capital account transactions.	• The Chinn-Ito index (2010 Update Version).

Table B. Overview of studies on the impact of FDI on economic growth

Studies	Countries	Period	Estimation Methods	Main results
Bornschiefer, Chase-Dunn and Robinson (1978)	76 less developed countries	1960-1975	OLS	FDI has negative impact on economic growth in developing countries. Also, this impact increases when income level increases.
Fry (1993)	16 developing countries	1975-1991	OLS	In 11 developing countries, FDI negatively affects growth. But in Pacific Basin countries FDI affects positively growth.
Borensztein, Gregorio and Lee (1998)	69 developing Countries	1979-1989	Seemingly Unrelated Regressions Technique	FDI is an important tool for technology transfer. Also, it makes more contributions to economic growth than domestic investment.
Aitken et Harrison (1999)	Venezuela	1975-1989	Panel Data	The net effect of FDI on firm level productivity is negligible.
Berthelemy and Demurger (2000)	24 Chinese provinces	1985-1996	GMM	FDI plays an important role in the economic growth of Chinese provinces.
Duttaray (2001)	66 developing Countries	1970-1996	Granger Causality Test	FDI positively affects growth in less than 50% of selected countries.
Carkovic and Levine (2002)	72 developed and developing Countries	1960-1995	GMM	The exogenous component of FDI does not exert a robust, independent influence on growth.
Mencinger (2003)	8 EU countries	1994-2001	Granger Causality Test	FDI affects economic growth but economic growth doesn't affect FDI.
Bengoa and Sanchez-Roblesu (2003)	18 Latin American countries	1970-1999	Hausman Test ; OLS	Foreign direct investment is positively correlated with economic growth in the host countries.
Balamurali and Bogahawatte (2004)	Sri Lanka	1977-2003	VAR model	The promotion of foreign direct investment can accelerate the long-run economic growth.
Hansen and Rand (2006)	31 developing countries	1970-2000	Panel VAR Model	FDI has an impact on GDP via knowledge transfers and adoption of new technology.
Basu and Guariglia (2007)	119 developing Countries	1970-1999	GMM	FDI enhances economic growth in developing countries.
Massoud (2008)	Egypt	1974-2005	Two Stage Least Squares	The main argument of the paper is that FDI is not an aggregate phenomenon. FDI has an ambiguous effect on growth.
Tiwari and Mutascu (2010)	23 developing Asian countries	1986-2008	Dynamic Panel Model ; OLS	Both foreign direct investment and exports enhance growth process in Asian countries.
Agrawal and Khan (2011)	5 Asian economies	1993-2009	Panel data Regression	FDI promotes economic growth and further provides an estimate that one dollar of FDI adds about 7 dollars to the GDP of each of the five countries.
Adeniyi and al (2012)	5 Small Developing African Countries	1970-2005	Vector Error Correction (VEC) model	The extent of financial sophistication matters for the benefits of foreign direct investment on economic growth in small open developing countries.

A wealth of Wildlife Endangered in northern Nimba County, Liberia

Jean-Claude Koffi Bene^{1,2}, Joel Gamys³, and Sylvain Dufour⁴

¹Unité Pédagogique et de Recherche de Biologie et Physiologie Animale,
Université Jean Lorougnon Guédé,
BP 150 Daloa, Côte d'Ivoire

²Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS),
01 BP 1303 Abidjan 01

³Conservation International – Liberia, Congo town back road,
Monrovia, P.O. Box 2075, Liberia

⁴SYLVATROP : Protection, conservation, gestion durable et participative de la biodiversité en milieu tropical,
Association Loi 1901 -26, route de Vannes 44100 NANTES – SIRET, France

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ABSTRACT: Mount Nimba is one of the most famous sites for biodiversity conservation in West Africa because of its high level of richness. People are concerned about the decline of tropical forest ecosystems and the decrease or disappearance of animal species has been attributed mainly to the destruction of habitat through human activities. In Liberia, the iron ore that constitutes the mountain body on Mount Nimba is now exploited by Arcelor Mittal Company. In the framework of its impact assessment process, Arcelor Mittal asked for a bushmeat study in its mining concession. We conducted a hunter's survey to better understand the motivations of the town communities and the human – wildlife relationship. Then, the hunter's activities have been monitored to identify the animal species encountered in the game and to evaluate their local conservation status. The study reveals that all kinds of wild animals in the area are considered to be potential prey and several species have been recorded in the hunting game. Through this study, it seems that many species are probably being driven or facing extinction in the area due mainly to agriculture and hunting activity; whereas in addition to hunting pressure, there are new threats to animals with mining activities and their direct and indirect consequences.

KEYWORDS: Biodiversity, ecosystem, wildlife, hunting activity, animal species.

INTRODUCTION

Liberia lies at the southwest corner of West Africa, bordered by Sierra Leone to the northwest, Guinea to the northeast, and Côte d'Ivoire to the east. The landscape is dominated by generally flat coastal plains, rising to rolling plateaus and low mountains in the northeast, highest of which is the Nimba range in North Nimba County. This country is the only West African country thought to have been totally covered in tropical rainforest before the influence of human settlement [1]. Actually, this forest is estimated to cover about 49% of the total landmass of the country. The importance of these forests is such that the Guinean Forests of West Africa (GFWA) ecosystem was designated as one of the world's 35 Hotspots, areas of highest biodiversity richness under the greatest threat. Liberia's forests are considered the top priority for conservation in West Africa; Liberia holding the most intact remaining forest in the Hotspot [2].

The Nimba range and its surroundings which are part of the forest block of Upper Guinea are listed by international organizations (IUCN, CEPF, FFI, CI, etc.) among the most important zones for the conservation of the biodiversity of moist forests of the sub-region. In western Africa 8,500 plant species have been listed and 403 species of orchids recorded. The

pygmy hippopotamus, the giant forest hog, and a number of insectivores, rodents and bats, tree frogs, bird species inhabit the area. Liberia, being one of the countries whose forest makes up the West African Rain Forest, includes many of the species of plants and animals found through the West African Rain forest.

Unfortunately, the Upper Guinea Ecoregion is highly threatened and is one of the most critically fragmented regions on the planet. Increased rates of forest loss, particularly in biodiversity rich areas, have reached crisis proportions [3], [4]. Humankind's economic activities are undoubtedly responsible for the erosion of biodiversity, in particular, the extinction of species, populations, and their habitats. The danger is particularly acute in the tropics where conservation resources are scarcest, where habitat conversion is more rapid and where the threat to biodiversity is greatest [5]. Extinction risk is considered highest in the case of taxa that have received little attention and live in parts of the world that are not a major focus of biologists and conservationists [6]. This seems to be the case for the entire Nimba County, Liberia and its Mammals species including monkeys, chimpanzees, leopard, pygmy hippopotamus, zebra duiker and jentink duiker...

Nimba County is located in the north-central portion of Liberia. Much of the remaining forest of this region is exploited for timber or threatened by hunting and does not represent intact habitat [7]. Large-scale mining for iron ore, diamonds, gold, and bauxite, particularly in mountain areas, and small-scale mining for gold and diamonds also pose a major threat to the forests and biodiversity. Furthermore, in many areas, loggers, miners and other introduced populations further stress the forest resources through hunting of wild animals. Several animal species have been extirpated from many forests in all the countries of Upper Guinea as a direct result of forest loss and overhunting [8]-[10]. Despite of the recognized importance ecosystem roles (prey species, fruit eaters and seeds dispersers), economic importance for Humans (used for food, pets, and in medical research) and cultural importance, large mammals are facing several direct and indirect threats in Nimba County.

The area allocated to AML by the Liberian authorities, in the northern Nimba County cover, for the most part, the hunting territories of the communities where they find animal protein consisted of large and medium mammals such as rodents, ungulates, primates and carnivores [11]-[13]. Among these animals, some such as chimpanzees, diana monkey, mangabey, leopard and others that live in this region are species of conservation concerned. The greater part of these species occurring in the area operated by the mining company, the aim of this paper is to pull the alarm on to involve all organization that care about the preservation of biodiversity in general and its wildlife component in particular, in a joint action to save these animals from local extinction. This disappearance will also have repercussion on the communities that depend on this fauna as part of food security.

OBJECTIVES

The main goal of this study is to pull on the alarm bell by making the Scientists, policy makers and conservation NGOs, know the wealth of wildlife in northern Nimba County and the threats that they are facing. This should bring all these agencies to find solutions for long-term conservation of the wildlife whose habitat is threatened with extinction in the coming years.

METHODOLOGY

STUDY AREA

Nimba County is located in the northeastern region of Liberia. The Nimba Mountain Range is located at the border between Guinea, Côte d'Ivoire and Liberia and is part of the Guinea Highlands, a series of discontinued mountains rising over a large plateau of an altitude of 500 to 600 m and extending northwest to southeast from Fouta-Djalon in Guinea to the Man region in Côte d'Ivoire. The main mountain range reaches an altitude of 1,752 m (Mount Richard-Molard) and extends about 40 kilometers northeast to southwest. The lower southern part reaches Liberia. The northwestern side is closely bordered by several peaks and smaller ranges while the opposite side plunges abruptly to the foothills.

SAMPLING

- Hunter's survey: To better understand the motivations of the town communities and the human – wildlife relationship we conducted a hunters surveys by sending hunters' questionnaire in the four study towns.
- Hunter activity monitoring: we followed regularly hunting activities of some hunters. It was then possible to determine the time spent to hunt and all animals killed were registered, weighed and measured.
- Identification of animal species: We have not experienced any problems in the specific determination of the dominant species, particularly in regards to ungulates, primates and large rodents. Personal knowledge, practical guides, English and French versions of Kingdon 1997 were used for this purpose.

- Evaluation of conservation status: We used the national (Liberia) conservation status of the new “an act adopting the national wildlife conservation and protected area management law of Liberia” and the IUCN Red List of Threatened Species 2008 and 2011 to determine each species' conservation status.

RESULTS

ANIMAL SPECIES ENCOUNTERED IN THE HUNTING TAKE OFF

The results of this chapter concern both the interview of the hunters and the regular monitoring of hunting activities. According to the hunters interviewed, about 3065 animals were killed in 2009, averaging 31 animals per hunter. From June to December 2010, approximately 1626 animals have been killed with an average of 16 animals per hunter for the first six months of the year. From January 2011 to August 2011 a total of 4982 animals have been killed by 147 hunters giving an average of 34 animals per hunter (table 1). These animals are mainly composed of rodents (46% of yes) and ungulates (43% of yes). Then, at a low rate, we have primates and carnivores with respectively 11% (of yes) and 20% (of yes) of the animals killed by hunting with shotgun.

Table 1. Data on animals killed in 2009, midyear 2010 and 2011, according to respondents

	Number of hunters	2009	Animal / hunter	2010	Animal / hunter	Number of hunters	2011	Animal / hunter
Bonlah	24	1073	47	547	24	52	992	19
Gbapa	23	605	26	378	16	24	813	34
Zolowee	23	899	39	425	18	36	2029	56
Zortapa	21	488	23	276	13	35	1148	33
Total	91	3065	34	1626	18	147	4982	34

Regular monitoring of the hunting activity of some hunters identified the game that they catch per trap or killed with guns. According to these data, hunting with gun killed 58% of the total game against 41% for trap and around 1% for other means. At the genus level, these animals are mainly constituted of Rodents (57.45%), Ungulates (20.41%), Carnivores (12.97%), Primates (5.27%) and Pholidota (3.38%). At specific level, the analysis shows that at least 25 mammal species have been recorded in the game (see table 2).

CONSERVATION STATUS

Among these mammal species, the Brush-tailed porcupine (*Atherurus africanus*) is the most encountered in the game, but is not listed in Liberian's protected animals and is Least Concern (LC) by IUCN. At the second place, the striped ground squirrel (*Euxerus erythropus*) is not in liberian's list and is Low Risk and Least Concern (LR/lc) on IUCN red list. The Giant pouched rats (*Cricetomys gambianus*) and the marsh cane rate (*Trynomys swinderianus*), are at the third and fourth places and are not listed by Liberia and are Least Concern by IUCN. The first Ungulate in the list is the Bay duiker (*Cephalophus dorsalis*), then the Maxwell duiker (*C. maxwelli*). All of them are absent in Liberian's protected animals and are listed as Low Risk and Near threaten (LR/nt). Among the Carnivores, the most encountered is the Cusimanse (*Crossarchus obscurus*), not listed in Liberia and Least Concern by IUCN. The bushbuck (*Tragelaphus scriptus*), not listed in Liberia is Low Risk and Least Concern (LR/lc) in IUCN red list. Some species are encountered at low rate : the Red-legged sun squirrel (*Heliosciurus rufobrachium*) not listed in Liberia and LC by IUCN , the Potto (*Perodicticus potto*) not listed in Liberia and LC (IUCN), the African palm civet (*Nandini binotata*) partially protected in Liberia and Neat Threaten in IUCN red list, the Long-tailed pangolin (*Uromanis tetradactyla*) fully protected in Liberia and LC in IUCN red list, the Tree pangolin (*Phataginus tricuspis*) fully protected in Liberia and NT in IUCN red list, the Black duiker (*Cephalophus niger*) not listed in Liberia and LR/nt by IUCN, the Slender mongoose (*Herpestes sanguinea*) is not protected in Liberia and is LC in IUCN. The Western tree hyrax (*Dendrohyrax dorsalis*), the lesser spot-nose (*Cercopithecus petaurista buttikofferi*) are fully protected in Liberia and LC (IUCN), Campbell's monkey (*Cercopithecus mona campbelli*) fully protected in Liberia is LC and the African civet (*Civettictis civetta*) partially protected by Liberia law and LR/lc are the less encountered in that list (see table 2).

Table 2. Catches list based on their encounter rate and their conservation status

Order	Scientific name	English name	Number	Encounter rate	National status	IUCN status
Artiodactyla	<i>Cephalophus dorsalis</i>	Bay duiker	60	8,11	Not listed	LR/nt
	<i>Tragelaphus scriptus</i>	Bushbuck	37	5	Not listed	LR/lc
	<i>Cephalophus maxwelli</i>	Maxwell's duiker	42	5,68	Not listed	LR/nt
	<i>Cephalophus niger</i>	Black duiker	12	1,62	Not listed	LR/nt
Carnivora	<i>Crossarchus obscurus</i>	Cusimanse	43	5,81	Not listed	LC
	<i>Herpestes sanguinea</i>	Slender mongoose	14	1,89	Not listed	LR/lc
	<i>Nandinia binotata</i>	African palm civet	24	3,24	Partially protected	LR/lc
	<i>Genetta sp</i>	Genet	8	1,08	Partially protected	?
	<i>Civettictis civetta</i>	African civet	7	0,95	Partially protected	LR/lc
Chiroptera	<i>Hypsignathus monstrosus</i>	Bat	1	0,14	Not listed	LC
Pholidota	<i>Phataginus tricuspis</i>	Tree pangolin	13	1,76	Fully protected	NT
	<i>Uromanis tetradactyla</i>	Long-tailed pangolin	10	1,35	Fully protected	LC
Primates	<i>Perodicticus potto</i>	Potto	26	3,51	Not listed	LC
	<i>Cercopithecus petaurista b.</i>	Lesser spot-nose	6	0,81	Fully protected	LC
	<i>Cercopithecus m. campbelli</i>	Campbell's monkey	7	0,95	Fully protected	LC
Hyracoidae	<i>Dendrohyrax dorsalis</i>	Western tree hyrax	2	0,27	Partially protected	LC
Reptila	<i>Python spp</i>	Python	3	0,41	Fully protected	LC
Rodentia	<i>Anomalurus sp</i>	Anomalure	1	0,14	Fully protected	?
	<i>Artherurus africanus</i>	brush-tailed porcupine	90	12,16	Not listed	LC
	<i>Thryonomys swinderianus</i>	marsh cane rat	74	10	Not listed	LC
	<i>Cricetomys emini</i>	Giant pouched rats	26	3,51	Not listed	LC
	<i>Cricetomys gambianus</i>	Giant pouched rats	77	10,41	Not listed	LC
	<i>Euxerus erythropus</i>	Striped ground squirrel	87	11,76	Not listed	LR/lc
	<i>Protoxerus stangeri</i>	African giant squirrel	40	5,41	Not listed	LC
	<i>Heliosciurus rufobrachium</i>	Red-legged sun Squirrel	29	3,92	Not listed	LC
		Squirrel	1	0,14	Not listed	?
TOTAL			740	100		

MAIN THREATS ON ANIMAL

Beside collection of animals, digging or putting fire in warren in order to bring out their tenants, all the hunters use two main types of tools to hunt in Nimba County: the gun and the trap. Some hunters use both shotguns and traps and constitute the majority (44%). Others use exclusively either shotguns (28%) or traps (28%). Among these hunters (67%) have their own shotguns that they often lend to friends (57%). According to hunters (60%), these shotguns are registered by the authorities. The hunters use an average of 7 cartridges in a week and a hunting period lasts in average 9 hours. And the hunting takes place day and night. Besides the firearms, hunters in Nimba County use the trap for capturing wild animals. Most farmers use trapping as a means to fight against the harmful animal species to their crops, but other traps are set for the sole purpose of harvesting bushmeat. There are several types of traps and none of them is selective.

During the study, a few hunters hunt during all seven days of the week. They represent only 5% of the study group. The most part of these hunters practice their hunting activity three days a week (35%), four times a week (26%) or once a week (15%). Some of them go to hunt two days in the week (14%), five days (4%) or six days a week (1%) (fig. 1). Whatever the number of hunting days in the week, the hunt takes place mainly day and night (46%) or only the day (43%), only at night (11%).

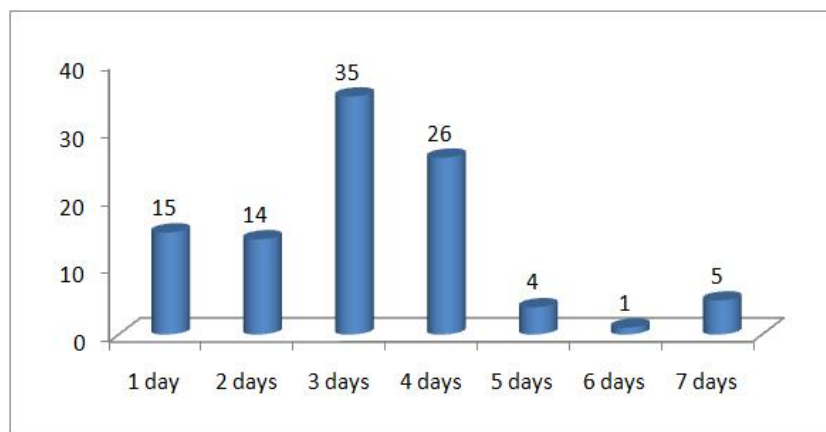


Fig. 1. Number of hunting days in a week in the surveyed towns

During the first monitoring period (August 2010 to November 2010), we identified a total of 242 animals killed by 91 hunters. We notice that more animals were killed by the gun (65%, $N = 157$) during a total of 37 hunting days, compared to traps (35%, $N = 85$) for 3688 traps laid 120 nights. For the second period (May 2011 to August 2011), 146 hunters were involved in the study and 504 animals were killed. The animals killed by shotgun (76 hunters) represent 55% ($N = 279$) during 107 hunting day, against 45% ($N = 225$) for traps (70 trappers) laid 121 nights.

Table 3 below shows the captured biomass, the theoretical biomass and the lost biomass depending on the species caught:

- Average weight = theoretical weight of an adult
- Theoretical biomass (kg) = sum of averages weights x number of caught
- Real biomass (kg) = sum of weight recorded or estimated
- Lost biomass (kg) = theoretical average weight - real biomass
- Percentage of lost biomass (%) = biomass lost x 100 / theoretical biomass

We note that the catch could theoretically yield 6429 kg for the hunters if all the animals captured were represented by adult individuals. The majority of animals killed are represented by young and sub-adults individuals. Indeed, the real biomass captured is about 3616 kg corresponding to a loss of about 2812 kg on all catches, which represents approximately 44% loss in biomass.

The fig. 2 shows the causes of wildlife depletion according to hunters. Most of them (94%) agreed that animals are no longer abundant in the forest. Over half of the hunters (56%) attributed this decline to intensive hunting and recently the increase in number of hunters, then to mining underway in the region (26%) and to some phenomena such as the increase in population (5%), farm (4%) and bushfires (1%). Or the destruction of animal habitats (5%) and the fact that animals are not protected (3%).

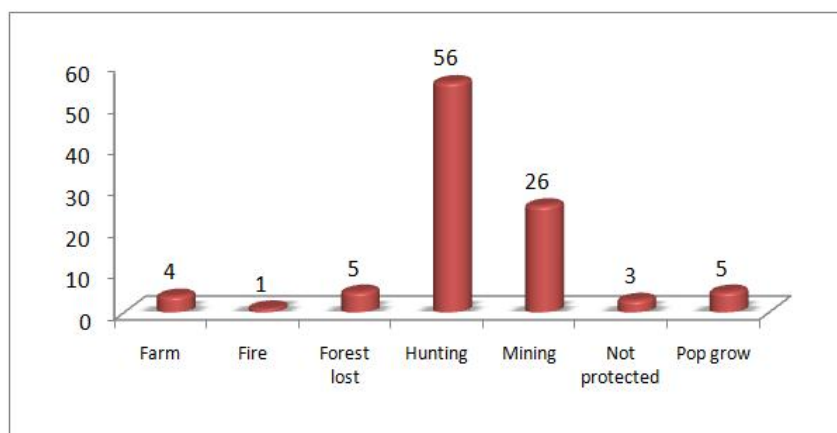


Fig. 2. Causes of wildlife decrease in surveyed area according to hunters

Table 3. Catch presentation based on their weight values

Order	Scientific name	English name	Local name	average weight	Number	theorical biomass (kg)	Real biomass (kg)	Lost biomass (kg)	pourcentage of lost biomass (%)
Artiodactyla	<i>Cephalophus dorsalis</i>	Bay duiker	Belleh	20	60	1200,00	785,25	414,75	34,56
	<i>Tragelaphus scriptus</i>	Bushbuck	Zolo	71,25	37	2636,25	1165,50	1470,75	55,79
	<i>Cephalophus maxwelli</i>	Maxwell's duiker	Velleh	10	42	420,00	343,75	76,25	18,15
	<i>Cephalophus niger</i>	Black duiker	Gba	24	12	288,00	162,00	126,00	43,75
Carnivora	<i>Crossarchus obscurus</i>	Cusimanse	Wehin	1,5	43	64,50	53,44	11,06	17,15
	<i>Herpestes sanguinea</i>	Slender mongoose	Kelin	0,85	14	11,90	10,60	1,30	10,92
	<i>Nandinia binotata</i>	African palm civet	Gouo	15	24	360,00	72,35	287,65	79,90
	<i>Genetta sp</i>	Genet	Blohou	2	8	16,00	15,50	0,50	3,13
	<i>Civettictis civetta</i>	African civet	Goua	3,5	7	24,50	24,00	0,50	2,04
Hyracoidae	<i>Dendrohyrax dorsalis</i>	Western tree hyrax	Weeh	4	2	8,00	4,00	4,00	50,00
Chiroptera		Bat	Laye	0,4	1	0,40	0,20	0,20	50,00
Pholidota	<i>Phataginus tricuspis</i>	Tree pangolin	Balakeleze	3	13	39,00	26,95	12,05	30,90
	<i>Uromanis tetradactyla</i>	Long-tailed pangolin	Balakeleze	3,25	10	32,50	32,05	0,45	1,38
Primates	<i>Perodicticus potto</i>	Potto	Zohon	1,4	26	36,40	32,90	3,50	9,62
	<i>Cercopithecus petaurista b.</i>	Lesser spot-nose	Golo	3,7	6	22,20	13,80	8,40	37,84
	<i>Cercopithecus m. campbelli</i>	Campbell's monkey	Kanh	4	7	28,00	16,40	11,60	41,43
Reptila	<i>Python spp</i>	Python	Bili	8	3	24,00	8,00	16,00	66,67
Rodentia	<i>Anomalurus sp</i>		Kpelleh	0,7	1	0,70	0,50	0,20	28,57
	<i>Artherurus africanus</i>	brush-tailed porcupine	The	4	90	360,00	312,50	47,50	13,19
	<i>Trynomys swinderianus</i>	marsh cane rat	Sobeh	8	74	592,00	298,90	293,10	49,51
	<i>Cricetomys emini</i>	Giant pouched rats	Bonon	1,4	26	36,40	33,60	2,80	7,69
	<i>Cricetomys gambianus</i>	Giant pouched rats	Bonon	1,4	77	107,80	104,25	3,55	3,29
	<i>Euxerus erythropus</i>	Striped ground squirrel	Loo	0,75	87	65,25	64,40	0,85	1,30
	<i>Protoxerus stangeri</i>	African giant squirrel	Wankpo	1	40	40,00	22,60	17,40	43,50
	<i>Heliosciurus rufobrachium</i>	Red-legged sun squirrel	Gben	0,5	29	14,50	12,65	1,85	12,76
			Korokoro	0,7	1	0,70	0,50	0,20	28,57
TOTAL				194,3	740	6429,00	3616,59	2812,41	43,75%

Almost all the hunters (95%) agreed that forest cover has also decreased and that the reasons for forest degradation are mainly agriculture (42%), mining activity (21%), brushfire (12%), sawing activity (12%) and hunting (10%) (Fig. 3). The mining operations indicated by the hunters here is especially in reference to the past activities of LAMCO with the resulting degradation of the vegetation on some mountains and open road.

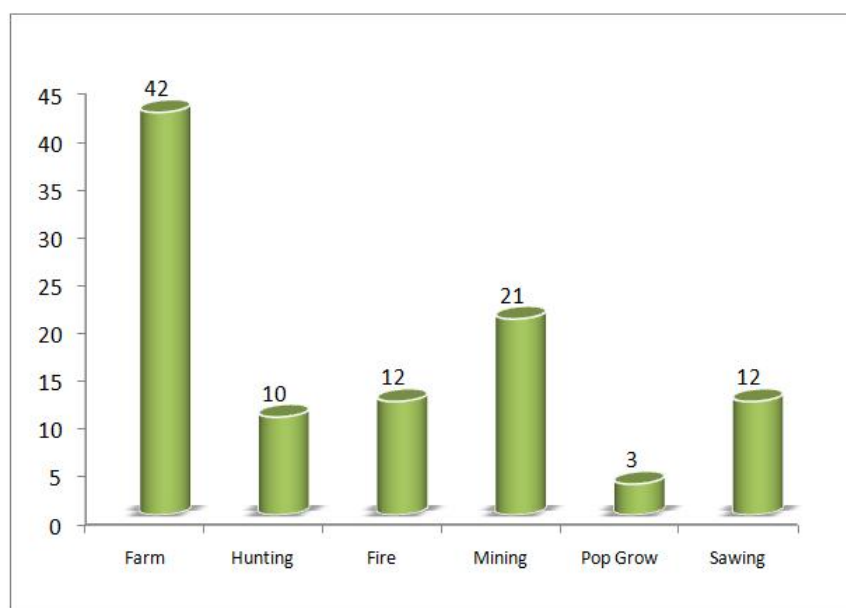


Fig. 3. Causes of forest decrease in Nimba County according to hunters

Even if we did not collect quantitative data, time spent in the bush with hunters to visit the hunting areas showed that one of the ecological impacts of hunting is pollution, especially physical pollution. Indeed, during the hunting party, hunters leave empty bags in which they often carry their food, batteries, the packaging of these batteries, cans. These are all physical elements that animals can swallow on or choke on or cause intoxication. Hunting tools used by hunters from Nimba County are not selective. The cables used for traps catch all animals coming in irrespective of gender, age, conservation status of this animal, nor its state of pregnancy. Also, hunting with firearms is practiced most often at night and hunters do not also distinguish the above parameters.

DISCUSSION

FAUNA RICHNESS

Monitoring of hunting for eight months has recorded 25 different species of mammals in Nimba County, among which we note representative of the main genera (Artiodactyla, Carnivora, Hyracoidea, Chiroptera, Pholidota et Rodentia). Indeed, the Nimba Range has a remarkable fauna population, in terms of variety and specificity due to presence of mountainous landscapes, diversity of plant formations and influence of microclimates. Hundreds of species have been described by scientists from the *Institut Fondamental d'Afrique Noire*, *Fauna and Flora International*, *Afrique Nature International* and *Sylvatrop* [14]-[19]. The Nimba Range is also characterized by its richness in primate species with *Perodicticus potto*, *Galagoides demidovii*, *G. senegalensis*, *Colobus polykomos polykomos*, *C. badius badius*, *Cercopithecus campbelli campbelli*, *C. diana diana*, *C. petaurista buettikoferi*, *Cercocebus atys atys*, and *Pan troglodytes verus* [20]. Among these primate species, only three species (*P. potto*, *C. campbelli campbelli*, *C. petaurista buettikoferi*) were recorded in the game of hunting during the eleven months of study. In addition to these three species should also report chimpanzee bones seen in one of the study town (Gbapa) and a carcass of green monkey seen with a hunter who did not cooperate with our team in one town (Zolowee). As can be seen, this study confirms that several primate species have become locally rare, if they have not completely disappeared.

In addition to the primates species confirmed during this study, the tree pangolin (*Phataginus tricuspis*) and the long-tailed pangolin (*Uromastix tetradactyla*) were encountered. Several species of rodents are also mentioned. Almost twelve species of carnivores are supposed to live in this region [21]. Among them, five have been encountered in the game: the African civet (*Civettictis civetta*), the African palm civet (*Nandinia binotata*), the pardine genet (*Genetta pardina*), the Cusimanse (*Crossarchus obscurus*) and the Slender mongoose (*Herpestes sanguinea*). Artiodactyla are also represented with, the bushbuck (*Tragelaphus scriptus*), the black duiker (*Cephalophus niger*), the bay duiker (*C. dorsalis*) and the Maxwell's duiker (*C. maxwelli*). However, these animals are represented by more than juvenile and sub-adult individuals than adults with more than 44% loss of biomass. For "reference [20]", most big mammals have become rare in Nimba County, due to habitat degradation and uncontrolled hunting.

A part from this mammal species, some 400 bird species are known in the Nimba Mountains, of which 16 are of global conservation concern [22]. There are also 69 species of reptiles including six species of global conservation concern. Amphibians and chiropterans are represented respectively by 66 and 46 species [23], [24].

MAIN THREATS

Despite of the recognized importance, ecosystem roles (prey species, fruit eaters and seeds dispersers), economic importance for Humans (used for food, pets, and in medical research) and cultural importance, large mammals are facing several threats. In the Nimba County, the current direct threats are those that are found throughout sub-Saharan Africa: extension of farmlands, logging, wildfires, bushfires, hunting, impact of past mining and preparation of future mining activities...The future direct threats in the study area are those that will be generated by the implementation of the mining activity and the development of infrastructures (building, opening of roads, noise disturbances...). All large mammal species will be concerned somehow. Large mobile species will probably flee away from the site. Large mammals like ungulates, primates and large carnivores in particular will try to reach safer areas if possible. However, smaller species or species which cannot move quickly might not have that possibility at all.

The current indirect threats are expressed at the population level. Indeed, as stated above, it seems that the populations of large mammals in the region are low especially for some species. It is known that the chance for survival of a species is reduced when the number of individuals in the population decreases, mainly for animal that have their reproductive potential reduced, and their genetic diversity reduced, which increases the risk of extinction [20]. The future indirect threats are almost close to those presented above, but here a particular attention must be paid to the future growth of human population in the region. The ongoing mining activities will increase job opportunities (either directly or indirectly), which will attract peoples and increase human pressure on natural resources, especially hunting pressure [25] for wildlife.

It is also known that one of the reasons of the scarcity of some Primates species in much of West Africa is the result of unregulated forest exploitation, habitat loss and the increasing demand for bushmeat [26]-[29]. Indeed, populations of forest-dependent animals have been reduced to such low levels that a number of them can no longer be considered viable. Large mammals are become the first to be eliminated from forest areas. As in most other countries in West and Central Africa, people in Liberia and in Nimba County have always hunted and relied on bushmeat to provide them with protein [30], [25]. The bushmeat trade is a lucrative business in Liberia, as in other parts of Africa [31]-[33]. The apparent extinction of some species such as the Red Colobus (*Piliocolobus badius badius*), in the study area can be attributed to hunting and the demand for bushmeat as good forest cover steel existing in the region. West African Chimpanzees are the most threatened of the three subspecies mainly due to habitat loss, high hunting pressure and the pet trade [34]. Despite international conservation of this ape, it continues to be the target of hunters in Nimba County.

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Application de méthodes géophysiques à l'étude de la productivité des forages d'eau en milieu cristallin: cas de la région de Toumodi (Centre de la Côte d'Ivoire)

[Application of geophysical methods to the study of the productivity of water drillings in crystalline aquifers: case of the Toumodi region (Central Côte d'Ivoire)]

KOUASSI Amani Michel¹, COULIBALY Drissa¹, KOFFI Yao Blaise², and BIEMI Jean²

¹Institut National Polytechnique Félix Houphouët-Boigny (INP-HB) de Yamoussoukro,
Département des Sciences de la Terre et des Ressources Minières (STeRMi),
Laboratoire du Génie Civil, des Géosciences et des Sciences Géographiques,
Bp: 1093 Yamoussoukro, Côte d'Ivoire

²Université Félix Houphouët-Boigny d'Abidjan-Cocody,
Unité de Formation et de Recherche des Sciences de la Terre et des Ressources Minières (UFR-STRM),
Laboratoire des Sciences et Techniques de l'Eau et de l'Environnement (LSTEE),
22 Bp: 582 Abidjan 22, Côte d'Ivoire

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ABSTRACT: In Ivory Coast, the phenomenon of decline of water drilling is found in rural and urban areas in the crystalline and crystallophyllian basement. The sub-prefecture of the department Angoda Toumodi does not rest (55%). Although several factors such as the condition of equipment, operating conditions, power conditions, the lithological conditions, problems of monitoring of hydraulic and quality parameters, etc., may partly explain this phenomenon, a fundamental question needs to be asked: drilling decline is it not related to a bad implementation of drilling? Thus, this study aims to analyze the productivity of water wells in operation, implemented by the method geomorphic from geophysical measurements. The study area is sub-prefecture of Angoda which lies between longitudes 5°00' and 5°10' West and latitude 6°35' to 6°45' North with an area of 660 Km². It meets the plutonic, volcanic and schistose. The technique chosen is dragged geophysical electrical resistivity of the particular device gradient or rectangle measuring electrical resistivity. The results showed, firstly, poor implementation of some wells on fractures resulting in dieback, and secondly, the proper implementation of further drilling manifested by a specific constant flow. The results show that the method is suitable for the problem. Thus, to overcome the problems of wasting water wells, one must couple the geomorphological and geophysical methods.

KEYWORDS: Geophysical methods, electrical resistivity, gradient or rectangle device, productivity of drilling, Angoda-Toumodi, Ivory Coast.

RESUME: En Côte d'Ivoire, le phénomène de dépérissement des forages d'eau en exploitation est constaté dans les milieux ruraux et urbains au niveau des zones de socle cristallin. Dans le département de Toumodi et particulièrement la sous-préfecture d'Angoda, ce phénomène est observé. L'état des lieux fait ressortir que 55% des forages en exploitation sont concernés par ce problème. Bien que plusieurs éléments tels que l'état des équipements, les conditions d'exploitation, les conditions d'alimentation, les conditions lithologiques, les problèmes de suivi des paramètres hydrauliques et qualitatifs, etc., peuvent expliquer en partie ce phénomène, une question fondamentale mérite d'être posée: le dépérissement des forages n'est-il pas lié à une mauvaise implantation du forage ? En effet, les forages ont été implantés à partir d'études géomorphologiques. Etant en milieu de socle où la recherche d'eau est basée sur les fractures hydrauliquement actives, il se pose le problème de la méthode adaptée pour y parvenir. C'est dans ce cadre que cette étude a été menée avec pour

objectif d'analyser la productivité des forages d'eau en exploitation, implantés par la méthode géomorphologique, à partir de mesures géophysiques. Le site de l'étude est la sous-préfecture d'Angoda qui est comprise entre les longitudes 5° et 5°10 Ouest et les latitudes 6°35 et 6°45 Nord et a une superficie de 660 Km². On y rencontre les formations plutoniques, volcaniques et schisteuses. La technique géophysique choisie est le traîné de résistivité électrique notamment le dispositif gradient ou rectangle mesurant la résistivité électrique. L'appareil utilisé pour les mesures est le résistivimètre Syscal R₁+ d'IRIS Instruments. Les résultats obtenus ont mis en évidence, d'une part, la mauvaise implantation de certains forages sur les fractures se traduisant par des dépérissements, et d'autre part, la bonne implantation d'autres forages se manifestant par une constance du débit spécifique. Les résultats obtenus montrent que la méthode utilisée est adaptée à la problématique. Ainsi, pour pallier aux problèmes de dépérissement des forages d'eau en milieu cristallin, où l'élément primordial est la fracture, l'on doit coupler les méthodes géomorphologiques et géophysiques, ce qui réduirait le taux des forages négatifs et optimiserait l'exploitation des forages positifs.

MOTS-CLEFS: Géophysique, résistivité électrique, dispositif gradient ou rectangle, productivité des forages, Angoda-Toumodi, Côte d'Ivoire.

1 INTRODUCTION

En Côte d'Ivoire, de nombreux efforts ont toujours été consentis par les gouvernements pour desservir toutes les populations (centres urbains, péri-urbains et ruraux) en eau de bonne qualité et en quantité suffisante. L'hydraulique villageoise capte les eaux souterraines au moyen de forages situés soit sur le socle, soit sur le bassin sédimentaire côtier. En effet, la Côte d'Ivoire est partagée entre deux milieux géologiques très différents : le socle qui occupe 97,5% et le bassin sédimentaire, 2,5%. Contrairement au milieu continu (bassin sédimentaire) la recherche des eaux souterraines en milieu de socle repose essentiellement sur le repérage des fractures qui sont les témoins des déformations tectoniques. Ainsi, en milieu de socle, un forage qui ne traverse aucune fracture ne peut produire de l'eau. La sous-préfecture d'Angoda dans le département de Toumodi s'inscrit dans ce contexte hydrogéologique. Dans cette zone, il se pose le problème de dépérissement des forages d'eau réalisés pour l'approvisionnement des populations. Cette localité abrite vingt-neuf (29) forages repartis dans onze (11) villages. Treize (13) forages sont en bon état (45%) tandis que seize (16) ont des problèmes de dépérissement (55%). Les informations obtenues auprès de la Direction de l'Office National de l'Eau Potable (ONEP) montrent que tous ces forages ont été implantés à partir d'études géomorphologiques. Le phénomène de dépérissement constaté se traduit par une diminution progressive ou brusque du débit d'eau dans le forage. Ce dépérissement peut s'expliquer fréquemment par plusieurs éléments tels que l'état des équipements, le sur-pompage, les incrustations, le colmatage par les matériaux fins et solides du terrain (argiles, limons), mauvaise alimentation de la nappe, le manque de suivi périodique des paramètres hydrauliques, insuffisance des paramètres de qualité de l'eau, etc. Les nappes d'eaux souterraines recherchées en milieu de socle sont confinées dans les fractures. Cela pose le problème de choix rationnel des sites d'implantation et de la méthode adaptée pour y parvenir. En effet, si les forages sont mal positionnés sur les fractures, on assiste alors à une mauvaise alimentation du forage en eau qui engendre à long terme le dépérissement du forage. Dans ce contexte, la géophysique qui permet d'imager le sous-sol de manière rapide et non-destructrice, est un choix très approprié pour la résolution des problèmes de cet ordre. En effet, beaucoup de problèmes en hydrogéologie peuvent trouver leurs solutions au moyen de la géophysique [1]-[4]. C'est dans cette optique que nous proposons une étude du fonctionnement des forages en exploitation basée sur les mesures géophysiques dans l'hypothèse que le dépérissement serait dû à une mauvaise implantation du forage (méthode géomorphologique). L'objectif de cette étude est d'analyser la productivité des forages en exploitation, implantés par la méthode géomorphologique, à partir de mesures géophysiques. Cette étude a conduit dans un premier temps à l'interprétation graphique des mesures de terrain (résistivité électrique), préalable à la détermination des minima préparés avant d'envisager une analyse comparative entre ceux-ci et les sites de forage existants.

2 PRESENTATION DE LA ZONE D'ETUDE

La sous-préfecture d'Angoda est située au Nord du département de Toumodi dans la partie méridionale du "V" baoulé (Centre de la Côte d'Ivoire). Elle est comprise entre les longitudes 5° et 5°10 Ouest et les latitudes 6°35 et 6°45 Nord avec une superficie de 660 Km² (Fig. 1). Le climat de la sous-préfecture d'Angoda est de type tropical humide avec une alternance de deux (2) saisons pluvieuses et de deux (2) saisons sèches. La hauteur pluviométrique moyenne annuelle est inférieure à 1200 mm. Sous ce climat, la végétation est constituée pour l'essentiel d'une savane arborée, des îlots forestiers par endroit et des galeries forestières le long des cours d'eau.

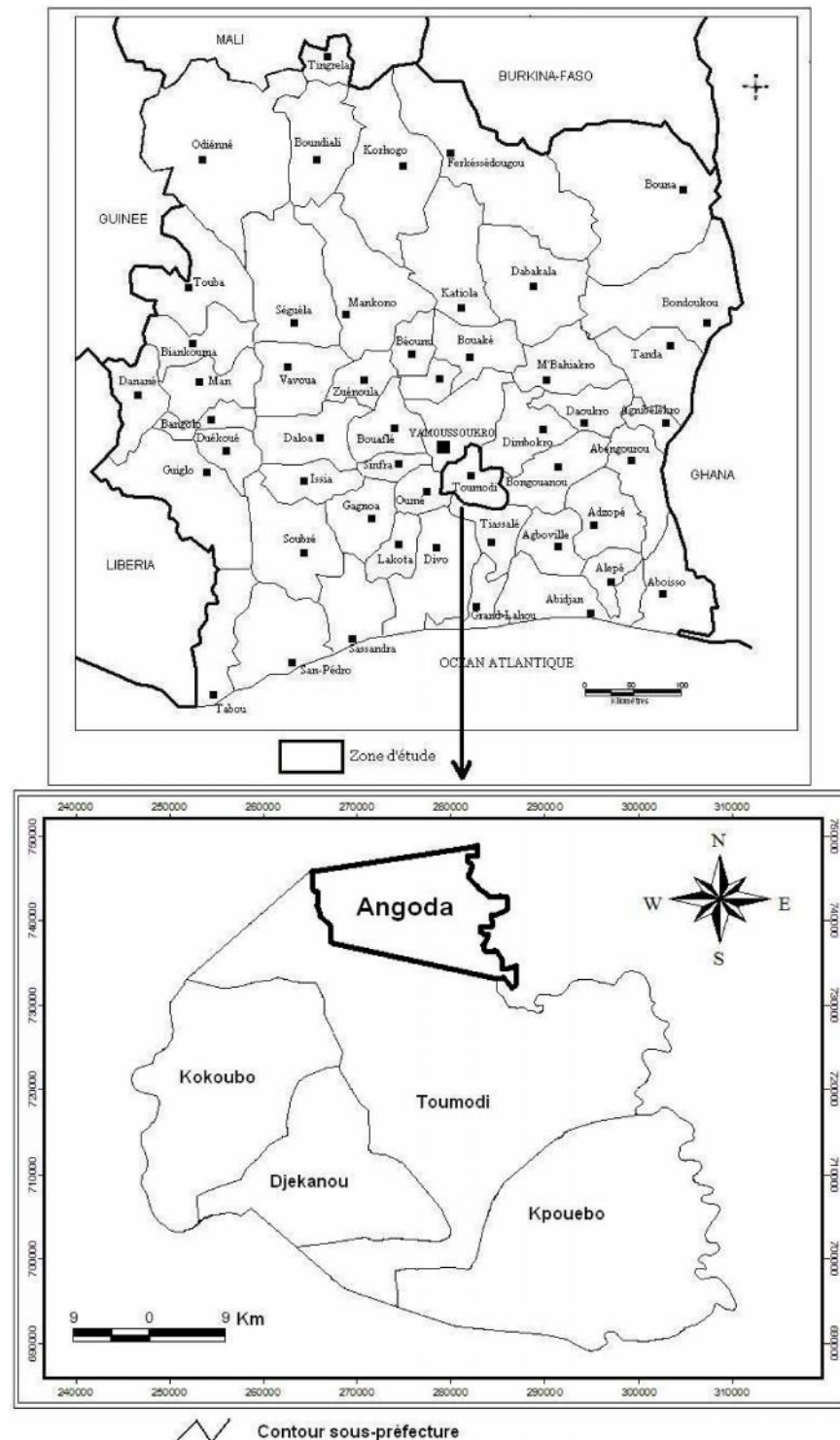


Fig. 1. Présentation de la sous-préfecture d'Angoda (département de Toumodi)

La sous-préfecture d'Angoda est située dans une zone relativement accidentée marquée par la présence de chaînes de collines de structure granitique. Beaucoup de chaînes de montagnes culminent dans cette région dont la plus célèbre est la chaîne baoulé qui affleure dans la sous-préfecture d'Angoda. Une multitude de rivières (Brahiba, Bomba, Bohiro, etc.) qui sont les affluents du fleuve Bandama, arrosent cette zone. Du point de vue géologique, la sous-préfecture d'Angoda appartient au domaine Baoulé-Mossi du craton ouest africain. On y distingue trois (3) groupes de formations géologiques dont certaines sont affectées par un métamorphisme [5]-[6] (Fig. 2). On a les granitoïdes (granites, migmatites, gneiss), les

formations volcaniques (métadolérites, métagabbro, métarhyolites, métadacites, metabasaltes) et le groupe des schistes-grès-quartzites qui forment la majeure partie du substratum de la zone d'étude. Ces formations géologiques sont affectées par des activités tectoniques majeures ayant entraîné une forte fracturation de la zone qui joue un rôle essentiel dans l'hydraulicité du système aquifère [7]. Le modèle d'aquifères rencontré est de type bicouche constitué d'un niveau altéré et d'un niveau fissuré [8].

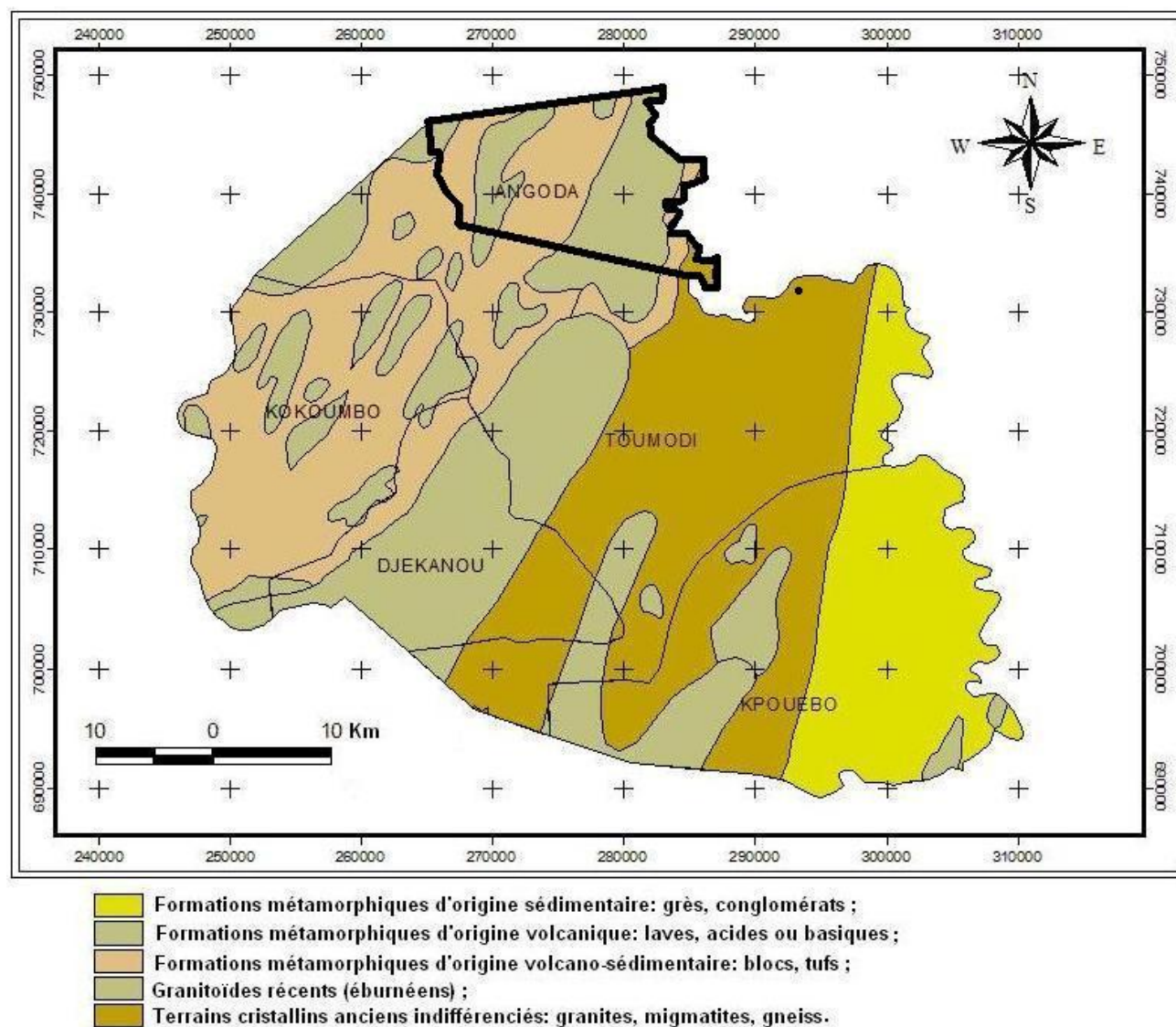


Fig. 2. Carte géologique de la zone d'étude

3 MATERIELS ET METHODES

3.1 DONNEES COLLECTEES

Les données utilisées sont composées de fiches techniques de forages et des mesures de géophysique. Les fiches techniques de forages ont été fournies par la Direction de l'Office National de l'Eau Potable (ONEP) de Yamoussoukro. Les données géophysiques ont été collectées pendant une mission de terrain effectuée au mois de juin 2009 par une équipe de cinq (5) personnes. Ces données ont été collectées sur sept (7) forages repartis dans cinq (5) villages: Akoué Kouadiokro, Afotobo, Angoda, Assafou et Koffidjékro (Tableau 1). La plupart des forages retenus pour cette étude présentent les signes les plus alarmants au regard du dépérissement selon les rapports de suivi des forages de la Direction Territoriale de l'Hydraulique (DTH) de Yamoussoukro.

Tableau 1. Coordonnées géographiques (X et Y) et altitudes (Z) (m) des forages étudiés

Villages	Forages existants	Coordonnées et altitudes des forages
AkouéKouadiokro	Forage A63	X= 6°37'20''
		Y= 5°01'28''
		Z= 122m
AkouéKouadiokro	Forage A54	X= 6°23'37''
		Y= 5°12'43''
		Z= 105m
Assafou	Forage A8	X= 5°03'50''
		Y= 6°44'10''
		Z= 215m
Koffidjékro	Forage A101	X= 5°03'50''
		Y= 6°42'30''
		Z= 220m
Koffidjékro	Forage A99	X= 5°09'45''
		Y= 6°45'36''
		Z= 210m
Afotobo	Forage A50	X= 5°01'50''
		Y= 6°42'28''
		Z= 180m
Angoda	Forage A68	X= 5°01'25''
		Y= 6°40'43''
		Z= 190m

3.2 MATERIELS DE TERRAIN

Le matériel de terrain est constitué du matériel de tracé des layons et de l'appareillage d'acquisition des mesures. Le tracé des layons a nécessité deux (2) machettes pour dégager les herbes en cas d'encombrement, deux (2) ruban-mètres de cent mètres (100 m) chacun pour les mesures des distances, une (1) boussole pour les mesures des directions des layons et un (1) GPS pour les mesures des coordonnées des forages. Les prises des mesures de résistivité ont nécessité un (1) résistivimètre permettant de fournir le courant aux électrodes et d'enregistrer les mesures électriques, quatre (4) bobines (fils électriques) permettant de connecter le résistivimètre aux électrodes, quatre (4) électrodes permettant de communiquer le courant électrique au sous-sol et quatre (4) marteaux pour enfoncer les piquets et les électrodes dans le sol. L'appareil utilisé pour les mesures est le résistivimètre Syscal R₁+ d'IRIS Instruments. Il a été conçu par le Bureau de la Recherche Géologique et Minière (BRGM) et est commercialisé par IRIS Instruments, entreprise française, basée à Orléans. Le résistivimètre Syscal R₁+ est un instrument performant pour les prises de mesures électriques visant à étudier le sous-sol. Sa faible masse permet un déplacement facile le long des layons sur le terrain.

3.3 METHODOLOGIE D'ACQUISITION DES DONNEES GEOPHYSIQUES

Les méthodes de prospection géophysique sont nombreuses et toutes caractérisées par l'étude des variations des paramètres physiques des roches et des sols. Dans le cas de notre étude, le choix d'une méthode géophysique dépendra de ses possibilités à localiser les fractures susceptibles de contenir de l'eau afin de pouvoir justifier le dépérissement lié aux forages existants. Plusieurs méthodes géophysiques sont utilisées dans l'hydrogéologie du milieu fissuré (méthodes électriques, sismique, etc.). Les méthodes électriques qui sont des méthodes de champ sont bien adaptées à la caractérisation des variations de la géologie et sont donc les mieux indiquées pour l'identification des fractures et de la profondeur du socle [9]. Les fondements des méthodes électriques sont développés par plusieurs auteurs [10]-[11]. La

technique géophysique choisie est le traîné de résistivité électrique notamment le dispositif gradient mesurant la résistivité électrique [12]-[13]. Le dispositif gradient ou rectangle consiste à créer un champ «uniforme» entre des électrodes d'injection (AB), et à déplacer dans la zone où le champ électrique est quasi-uniforme (distance d'environ AB/5 centrée) un petit dispositif de mesures (MN).

Les traînés électriques, effectués de façon horizontale, font ressortir les zones plus conductrices qui sont de faible résistivité et les zones moins conductrices de fortes résistivités. Ainsi, les fractures pouvant contenir de l'eau, seront mises en évidence par les traînés électriques à travers des résistivités faibles. L'anomalie qui est la fracture susceptible de contenir de l'eau sera représentée par des minima préparés. Le tracé des layons se fait perpendiculairement aux thalwegs. En cas d'absence de thalweg, il a été réalisé perpendiculairement à la direction générale des structures géologiques (N60°).

La méthode électrique utilisée dans le cadre de cette étude a consisté à injecter du courant continu dans le sol à l'aide d'électrodes A et B et à en mesurer la différence de potentiel en deux points MN compris entre A et B suivant les profils de traînés électriques (Fig. 3). Ces profils de traînés électriques permettent l'investigation latérale [14]. La méthode des traînés électriques s'est effectuée avec un dispositif gradient dont les électrodes d'injection A et B sont distantes de 450 m et restent à position fixée. Les électrodes de mesure de potentiel M et N sont distantes de 20 m. Le dipôle MN est déplacé de 10 m le long des profils. Sept (7) profils de traînés électriques de 450 m de longueur chacun ont été réalisés, soit un total de trois mille cent cinquante mètres (3150 m). Le paramètre mesuré est la résistivité. La valeur de chaque résistivité obtenue est la résistivité apparente (ρ_a) de la partie du terrain comprise entre les deux électrodes M et N. Cette résistivité est inversement proportionnelle à la conductivité de ce terrain, c'est-à-dire que plus la résistivité est faible, plus la conductivité est élevée. Cependant, on distingue deux types de conductivités à savoir la conductivité métallique qui est liée à la présence de métaux ou de sulfures et la conductivité électrolytique qui est liée à la présence d'ions dans la zone (présence d'eau). On émet l'hypothèse que la conductivité mise en évidence est la conductivité électrolytique tout en minimisant la conductivité métallique. On suppose aussi que les variations de résistivité ne sont pas liées aux variations de la géologie, et à la présence d'argile, étant donné que nous sommes dans un milieu cristallin. Ainsi, les zones à forte conductivité électrolytique ou de faibles résistivités sont les zones à forte concentration d'eau. La technique géophysique appliquée consistera donc à identifier les fractures hydrauliquement actives.

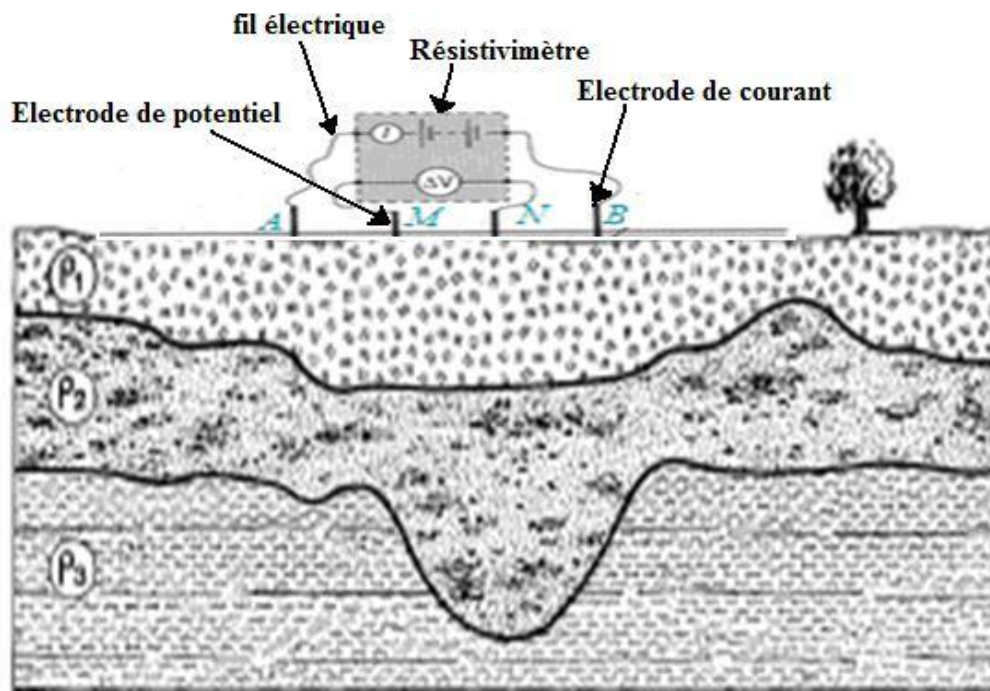


Fig. 3. Principe du dispositif gradient ou rectangle

4 RESULTATS ET DISCUSSION

Les différentes mesures obtenues à partir de la méthode des traînées électriques appliquée aux différents forages ont été représentées sous forme de graphes. En abscisse, on a les différents PK exprimés en mètre (m) qui constituent les points de

mesures et en ordonnée, les différentes valeurs de résistivité apparente exprimées en $\Omega.m$. Les différents résultats obtenus parviennent à deux cas. D'une part, le cas où les forages sont situés hors des zones anormales et d'autre part, le cas où les forages sont situés à l'intérieur des zones anormales. Seul le premier cas a été présenté avec deux sous cas. Le premier sous cas concerne les forages implantés hors des minima préparés et le deuxième sous cas, les forages situés dans la zone de transition des minima préparés.

Ont été retenus pour le premier sous cas, les forages A50 (Afotobo) et A63 (Akoué-Kouadiokro). La courbe de résistivité du forage A50 (Afotobo) montre quatre (4) points de faible résistivité situés aux Pk-80, -50, 0, et 50 mais présente trois (3) zones d'anomalie caractérisées par trois (3) minima préparés (Fig. 4a). Le premier minimum est préparé par trois (3) points situés aux Pk-60, -50 et -40. Le deuxième minimum est préparé également par trois (3) points localisés aux Pk-10, 0 et 10 et enfin le troisième minimum est préparé par les Pk 40, 30 et 60. La courbe d'Afotobo présente donc trois (3) zones favorables à l'implantation de forages d'eau. Ces zones anormales sont représentées sous la forme d'un « V ». Le forage existant est positionné au point Pk 10. Du point de vue géophysique, ce forage est mal implanté. Les points les plus favorables sont au Pk -50 et au Pk 50.

La courbe du forage A63 (Akoué-Kouadiokro) est constituée de cinq (5) parties mettant en évidence trois (3) pics qui se situent à 30 m, 40 m et 80 m du point d'origine (Fig. 4b). Les points de faibles résistivités retenus après analyse de la courbe Fig. 4b sont les Pk30 et Pk75 de valeurs de résistivité égales respectivement à 822,8 $\Omega.m$ et 655 $\Omega.m$. Deux (2) zones anormales ont été mises en évidence. En effet, le premier minimum est préparé par trois points à savoir les Pk 20, 30, et 40 ; tandis que le deuxième est préparé par quatre (4) points à savoir les Pk 60, 70, 80 et 90. Comparativement aux anomalies géophysiques reconnues en Côte d'Ivoire dans la recherche des fractures, la première anomalie a la forme d'un « V » tandis que la deuxième se présente sous forme de « fond de bateau ». Le forage est implanté à 15 m de la zone favorable située au Pk 75. Le forage existant est implanté à près de 90 m du point d'origine c'est-à-dire au sommet de la branche montante de la deuxième zone favorable. Le forage a été donc mal positionné sur la fracture. Si l'on devrait positionner un forage de façon précise, il serait intéressant de l'implanter aux points de faibles résistivités c'est-à-dire aux points d'abscisses $X=30$ m et $X=75$ m.

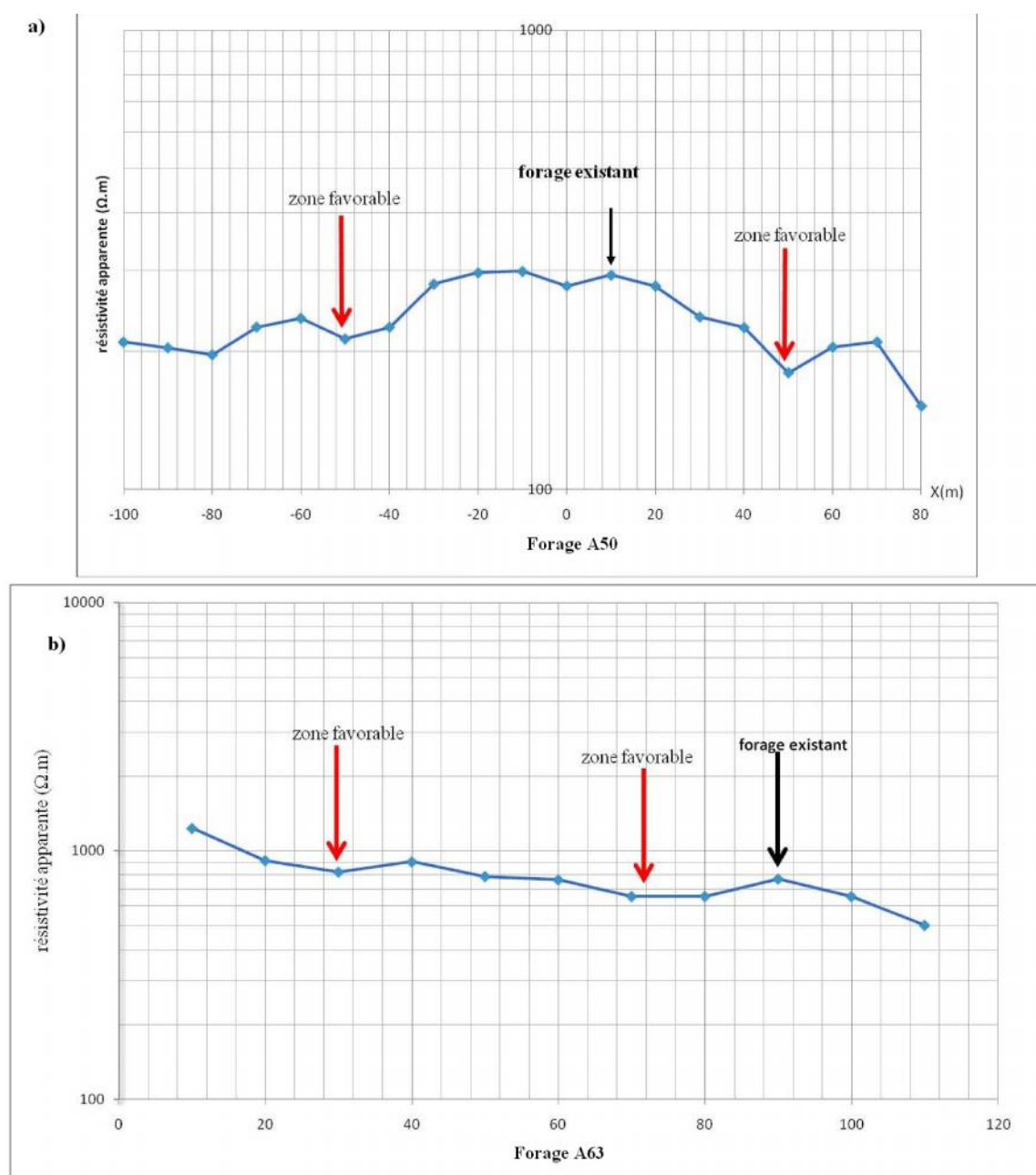


Fig. 4. Courbes de traînés électriques aux environs des forages A50 (a) et A63 de Akoué-Kouadiokro(b)

Les forages A54 (Akoué-Kouadiokro) et A99 (Koffidjèkro) ont été retenus pour le deuxième sous cas. La courbe de résistivité du forage A 54 (Akoué-Kouadiokro) montre une zone anormale qui est mise en évidence par un minimum préparé à partir de trois (3) points à savoir les Pk0, 10 et 20 (Fig. 5a). Cette zone d'anomalie se présente sous la forme d'un « V ». Le point de faible résistivité retenu est le Pk10 dont la valeur est de 543,7 $\Omega.m$. Le forage est implanté à -2 m du point d'origine. Le forage a donc été implanté juste après le minimum préparé qui met en évidence une zone hydrogéologiquement favorable. De façon précise, le forage a été implanté au niveau du complexe résistant, ce qui n'est pas conseillé par la géophysique en matière d'implantation de forage d'eau. Le forage n'a pas été implanté exactement au niveau de l'anomalie (Pk 10). L'anomalie en question a donc été déviée de 12 m.

La courbe de résistivité du forage A 99 (Koffidjèkro) met en exergue la présence d'une zone anormale qui est mise en évidence par une seule zone de faible résistivité définie par un minimum préparé à partir de cinq (5) points à savoir les Pk20, 30, 40, 50 et 60 (Fig. 5b). La plus faible résistivité obtenue au Pk 40 est de 217,7 $\Omega.m$. Cette zone anormale se présente sous

forme de « U » c'est-à-dire sous forme de « fond de bateau ». Le forage existant est positionné au Pk10. Ce forage n'a pas été implanté dans la zone la plus favorable mais sur la pente descendante, moins favorable, traduisant une forte baisse de la résistivité.

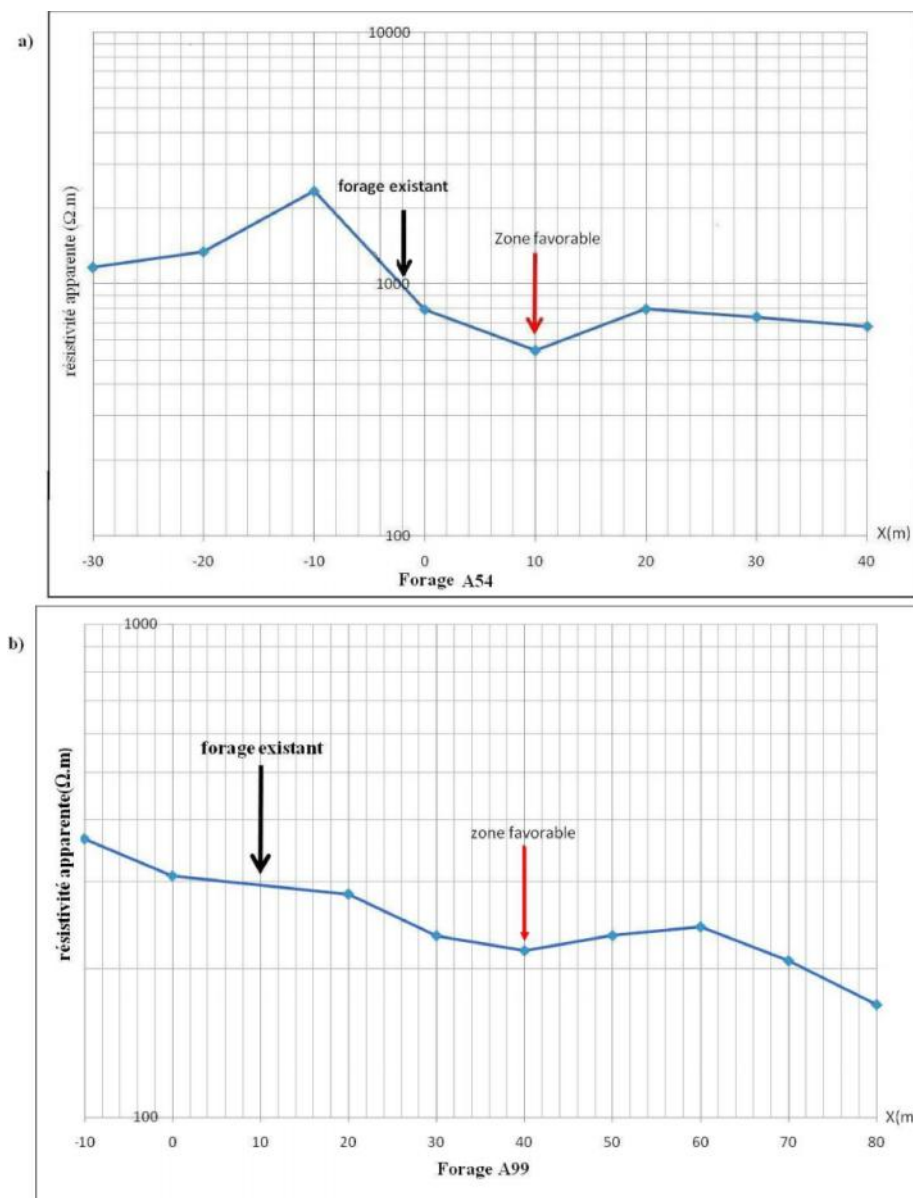


Fig. 5. Courbes de traînée électrique aux environs des forages A54 (a) (Akoué-Kouadiokro) et A99 (b) (Koffidjèkro)

En Côte d'Ivoire, les courbes obtenues à partir des mesures de traînés électriques dans la recherche des eaux mettent en évidence des anomalies se présentant sous formes de "V", "W" et "U" [15]. Dans le cadre de cette étude, ces différentes formes d'anomalie ont été rencontrées. Du point de vue géophysique, ces formes traduisent des zones de faibles résistivités qui peuvent être assignées à des fractures ou des fissures pouvant servir de cadre pour une retenue d'eau dans le socle cristallin [16]-[17]. Ces zones sont favorables à l'implantation des forages d'eau. Dans la prospection d'eaux souterraines en milieu cristallin, lorsque ces anomalies sont déviées, on assiste à de nombreux échecs pendant la phase d'exécution du forage (forage négatif) ou encore à plusieurs problèmes liés au fonctionnement du forage (intermittence, dépérissement et

tarissement). Les études géophysiques entreprises dans la région de Toumodi plus précisément dans la sous-préfecture d'Angoda ont permis de constater trois (3) cas d'implantation des forages existants dans la zone d'investigation :

- i) cas où les forages sont mal implantés ;
- ii) cas où les forages sont bien implantés mais ont un problème de ravitaillement ;
- iii) cas où les forages sont bien implantés et fonctionnent normalement.

La mauvaise implantation d'un forage s'explique par le fait que le forage n'est pas positionné au niveau des zones favorables c'est-à-dire sur les fractures productives. Le cas des forages bien implantés mais qui connaissent un problème de ravitaillement en eau serait dû à un problème d'équipement ou de communication entre les fractures [18]. En ce qui concerne les ouvrages bien implantés et qui fonctionnent normalement, on peut retenir que ceux-ci ont été positionnés sur les fractures les plus productives. Les problèmes de dépérissement et d'intermittence rencontrés au niveau des forages d'Angoda sont dus pour la plupart à la mauvaise implantation des forages (57%). En effet, ces forages avaient été implantés simplement avec la méthode géomorphologie qui se limite aux informations à la surface. Cette étude soulève la problématique de la prospection combinée (géomorphologie-géophysique). Il est donc souhaitable que les implantations commencent par l'approche géomorphologique qui permet de définir la zone la plus favorable (étude globale). La géophysique viendra donc pour préciser les points les plus favorables pour l'implantation du forage (étude détaillée). Nous recommandons donc le couplage géomorphologie-géophysique dans l'implantation des forages en milieu cristallin où l'élément primordial est la fracture, ce qui réduirait le taux des forages négatifs et optimiserait l'exploitation des forages positifs.

5 CONCLUSION

La productivité des forages d'eau en exploitation n'a que très rarement été étudiée par la géophysique en Côte d'Ivoire. La méthodologie mise en œuvre constitue donc une première. Cette étude a permis d'une part, de comprendre la productivité des forages en exploitation affectés par le dépérissement, et d'autre part, de localiser certaines zones favorables en cas de nouvelles implantations de forages. La méthode des traînés électriques basée sur le dispositif gradient utilisé au cours de cette étude, a fourni des résultats satisfaisants. Les résultats de l'étude ont confirmé les différentes formes d'anomalie rencontrées en Côte d'Ivoire à savoir les anomalies sous formes de "V", "W" et "U". Les études géophysiques entreprises ont permis de mettre en évidence trois (3) cas de fonctionnement hydraulique des forages liés à leur implantation. Le premier cas concerne les forages mal implantés qui s'avèrent négatifs à la foration ou qui tarissent très rapidement s'ils ont été positifs. Le deuxième cas concerne les forages bien implantés mais qui ont un problème de ravitaillement, et connaissent les problèmes d'intermittence et de dépérissement. Enfin, le troisième cas est celui des forages bien implantés, c'est-à-dire positionnés sur les fractures hydrauliquement actives, qui fonctionnent normalement, c'est-à-dire qui ont des débits spécifiques plus ou moins constants dans le temps. Pour pallier au problème de dépérissement des forages d'eau en milieu cristallin, où l'élément primordial est la fracture, l'on doit coupler les méthodes géomorphologique et géophysique, ce qui réduirait le taux des forages négatifs et optimiserait l'exploitation des forages positifs.

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Improving anaerobic biodigestion of manioc wastewater with human urine as co-substrate

*Kpata-Konan Nazo Edith¹⁻², Gnagne Théophile¹⁻³, Konan Koffi Félix⁴⁻⁵, Bony Kotchi Yves⁴⁻⁵,
Kouamé Kouamé Martin¹⁻⁵, Kouamé Yao Francis¹⁻², and Tano Kablan⁶*

¹Water and Sanitation for Africa, National Representation of Côte d'Ivoire,
Abidjan, Côte d'Ivoire

²Laboratory of Environmental Sciences, UFR of Sciences and Environment Management,
University Nangui ABROGOUA,
Abidjan, Côte d'Ivoire

³Laboratory of Geosciences and Environment, UFR of Sciences and Environment Management,
University Nangui ABROGOUA,
Abidjan, Côte d'Ivoire

⁴University Jean LOROUGNON GUEDE,
Daloa, Côte d'Ivoire

⁵Laboratory of Aquatic Environment and Biology, UFR of Sciences and Environment Management,
University Nangui ABROGOUA,
Abidjan, Côte d'Ivoire

⁶Laboratory of Tropical Product Food Technology, UFR of Sciences and Food Technology,
University Nangui ABROGOUA,
Abidjan, Côte d'Ivoire

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ABSTRACT: This study investigated anaerobic co-digestion of cassava liquid waste (very acid and poor in nitrogen) and human urine. Three experimental digesters were used: manioc effluent; manioc effluent + urine; manioc effluent + urine + cow dung. All digesters have functioned with mesophilic temperatures between 24.0 and 35.6°C. Digesters without urine have a pH varying between 3 and 4 during experimentation. In reactors containing urine, the pH oscillated between 6.46 and 10.29. The COD/TKN ratios recorded in digesters buffered with human urine are lower than those observed in digester without human urine. Volume of gas produced by the two digesters containing human urine was significantly higher than that of the digester without urine. The additions of human urine and cow dung improve highly the methane potential during anaerobic co-digestion of manioc effluent. The flammability test is positive except for the digester without urine. Using human urine as a co-substrate for anaerobic digestion of cassava wastewater requires a large quantity of urine (40% in terms of proportion) for a best productivity. As well as allowing biogas production as a source of renewable energy, this system of co-digestion could help to resolve the sensitive problem of human excreta management in poor area. Indeed, human urine with an alkaline pH and richness in nitrogen can substitute chemicals commonly used to correct the pH during anaerobic biodigestion, in particular for the treatment of cassava wastewater which is very acid.

KEYWORDS: Anaerobic co-digestion, Manioc wastewater, Human urine, Biogas.

1 INTRODUCTION

Basic food in many tropical countries in Africa, Asia and America, manioc (*Manihot esculenta* Crantz) is now considered as a key element in the fight against nutritional problems afflicting many countries in south of the Sahara ([1]). In Côte d'Ivoire, attiéké (semolina of manioc cooked with the vapor) is the main form of food produced with the tuberous roots of manioc ([2]). Attiéké is obtained after several stages of transformation of manioc: peeling, crushing, fermentation, pressing, granulation, drying, winnowing-sifting and cooking with the vapor ([3]). The production of attiéké starts to be done in the industrial form by numerous small manufacturing units. Indeed, women of native population of Abidjan District (Ebrié) have kept their traditional activities of attiéké production in their different villages sunken by urbanization. However, during the production of attiéké, large quantities of solid (cassava pulp and fiber) and liquid wastes (pressing juice of cassava) are generated ([4]). At present, in areas of high attiéké productions such as in District of Abidjan (Côte d'Ivoire), the most important part of the solid waste generated is valued through a low cost animal feed. Manufacturing wastewater of attiéké, including pressing juice of manioc, is discharged into natural environment, particularly Ebrié lagoon adjacent to site of production, without prior treatment. These effluents constitute an important source of pollution in Abidjan. Indeed, these liquid wastes are rich in organic matter ([5], [6]) and highly toxic due to the high content of cyanide ([7]).

Those effluents must be considered as recyclable waste and must be eliminated in respect of laws and environment. Among solutions to regulate these problems, anaerobic digestion of these organic wastes appears as a viable alternative. Anaerobic digestion is a biologic process widely employed as technology for organic wastes treatment including municipal, industrial and agricultural wastes ([8] - [10]). This biologic process permits to produce combustible biogas, a renewable energy, from organic matter by bacteria in anaerobic conditions. This renewable energy is mainly composed of methane and can reduce half of organic matter ([11]). According to [9], the digestat is stable, deodorized, rided in major part of pathogenic germs and can even be used as a fertilizer for agricultural purposes.

Given the large quantities available and the high biodegradable organic matter content, waste potential as source of energy, instead of a waste stream, has been increasingly realized ([10], [12]). However, the use of manioc effluents as a single substrate for anaerobic digestion has been complicated by problems such as the high acidity of these effluents and their poor C/N ratio ([3], [13], [14]), which inhibits the process of methanization.

Anaerobic co-digestion has emerged as an alternative concept with potentials to overcome these challenges ([10], [15]). Indeed, according to [3] and [16], anaerobic co-digestion has advantage of improving nutrient ratios in mixed substrates and enhancing pH buffering capacity, which could lead to more efficient waste treatment and biogas production.

Many successful studies have been conducted on co-digestion of sewage sludge with several other substrates, such as the source-sorted organic fraction of municipal solid waste ([17], [18]), confectionery waste ([19]), sludges from the pulp and paper industry ([20]), coffee waste ([21]), grease-trap sludge from meat processing plants ([22], [23]), glycerol ([15]), cassava pulp and pig manure ([24]), grease trap waste ([10]), pig manure with spent mushroom compost ([25]).

While anaerobic co-digestion has been studied and practiced for a broad range of organic wastes, few studies have been conducted on the co-digestion of manioc liquid waste derived from attiéké production with human urine as a co-substrate.

In addition, in Côte d'Ivoire the rate of access to appropriate sanitation does not exceed 60% ([26], [27]). Specific case of wastewater and excreta is very problematic. However, pH of human urine varies between 8 and 9 ([3]) with nitrogen concentrations ranging from 3 to 8 g/L depending on the mode and time of collection ([14]). These characteristics make human urine an ideal co-substrate for the anaerobic digestion of manioc liquid waste.

Mainly, this work aimed to evaluate the efficiency of the use of human urine as a co-substrate, in order to improve biogas production during anaerobic digestion of manioc liquid waste.

2 MATERIAL AND METHODS

2.1 REACTORS DESIGN AND EXPERIMENTAL CONDITIONS

Three anaerobic experimental reactors (R1, R2 and R3) were used (Fig. 1). Each reactor was composed of two metal barrels of 100 liters and 186 liters, each opened on one of the bases. The largest barrel contained digestion substrate and the smallest barrel was used as gasometer to store the produced gas. The three experimental reactors used were fed as follows: (i) 124 L of manioc effluent; (ii) 70 L of manioc effluent + 54 L of human urine; (iii) 70 L of manioc effluent + 54 L of human urine + 5 kg of cow dung.

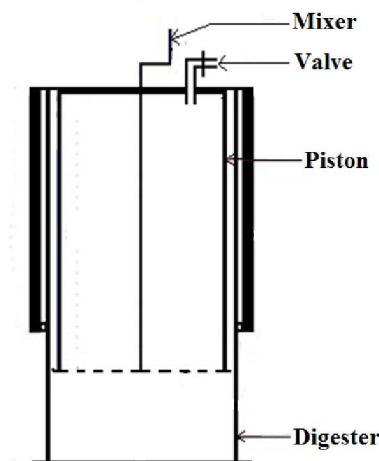


Fig. 1. Schema describing the experimental device

2.2 SOURCES AND CHARACTERISTICS OF SUBSTRATES

Liquid waste of manioc used in this study was collected from the attiéké factory of Azito (Ebrié village in Yopougon, District of Abidjan, Côte d'Ivoire). Its pH varied between 3.0 and 4.2 units pH. Human urine was collected from dry latrines with urine deviation and lavatories designed by the Water and Sanitation for Africa of Côte d'Ivoire (WSA - Côte d'Ivoire).

2.3 TECHNICAL ANALYSIS

Volume (V) of biogas produced was measured daily using this formula: $V = \pi \times R^2 \times H$; with H = height of rising of the gasometer (small barrel); R = Radius of the gasometer (small barrel).

Temperature, pH and Chemical Oxygen Demand (COD) were determined according to the standard methods ([28]). Total nitrogen was estimated by the Kjeldahl method. Temperature and pH were monitored daily in the reactors, while COD and TKN were determined twice per week.

Carbon is the principal component of the organic substances found in wastewater. By biodegradation process under anaerobic conditions, microorganisms use carbon compounds to generate energy. In this study, carbon and nitrogen compounds were respectively determined as COD and TKN.

2.4 STATISTICAL ANALYSIS

In order to determine whether the observed differences between reactors performances were significantly different, data were subjected to the non-parametric comparison tests (Kruskal-Wallis test and Mann-Whitney test). Differences between co-substrates' addition effects were compared with 0.05. All statistical analyses were carried out by the software Paleontological Statistic (PAST) version 2.15 ([29]).

3 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 WASTE CHARACTERISTICS

Variation of temperature recorded in this study under diverse conditions is illustrated by Fig. 2A. Values obtained vary between 25.5 and 29.1 °C for reactor 1 (manioc effluents), between 25.0 and 32.2 °C for reactor 2 (manioc effluents + human urine) and between 24.1 and 35.4 °C for reactor 3 (manioc effluents + human urine + cow dung). Although all reactors functioned under mesophilic condition, values of temperature in the two reactors containing human urine (2 and 3) were significantly higher than those in reactor 1 without human urine ($p < 0.05$).

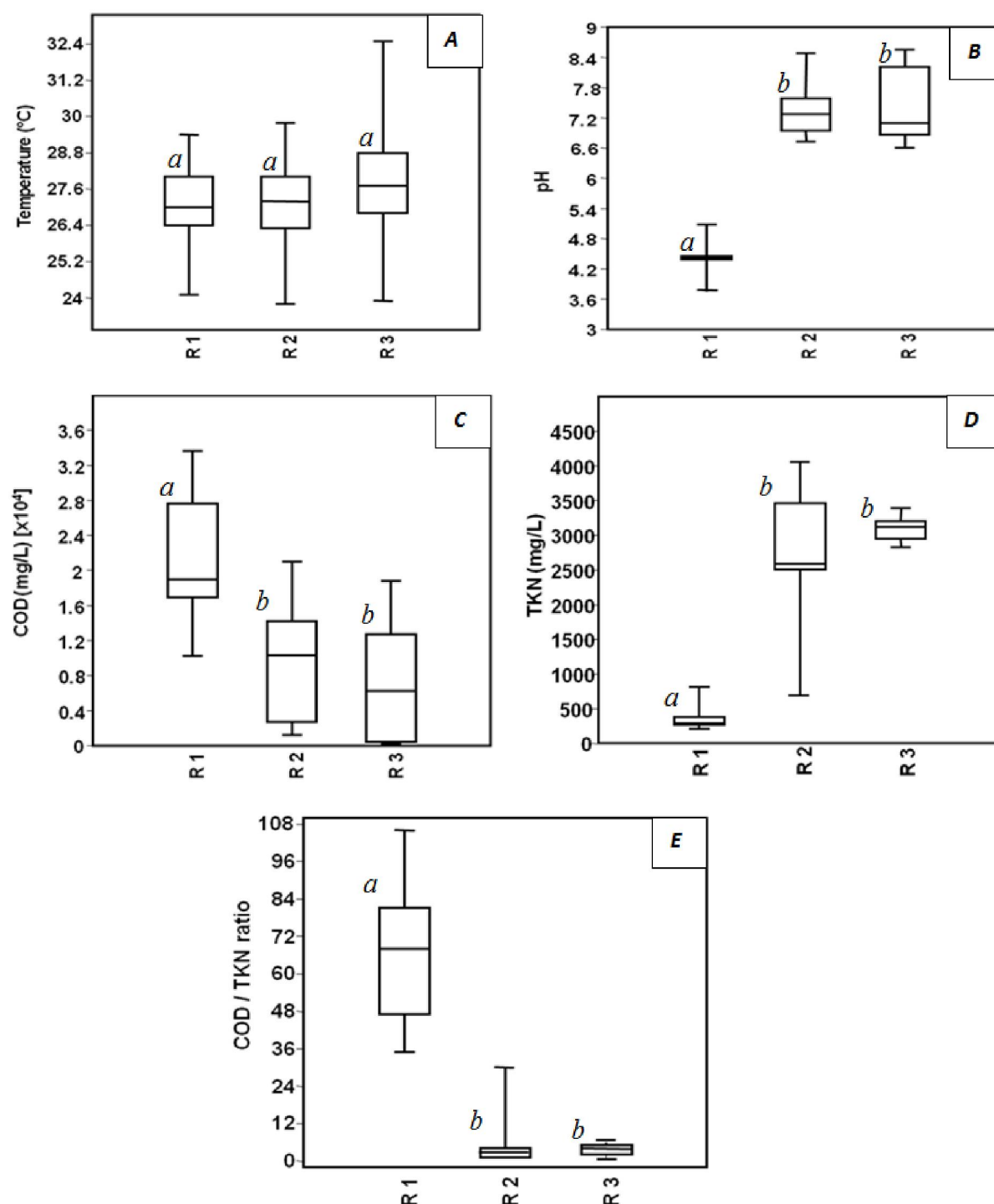


Fig. 2. Boxplots comparing A) temperature, B) pH, C) chemical oxygen demand (COD), D) total Kjeldahl nitrogen (TKN) and E) COD/TKN ratio in the three anaerobic digesters: R1 = effluent of cassava; R2 = effluent of cassava + urine; R3 = effluents of cassava + urine + cow manure. The different alphabets (*a*, *b*, *c*) indicate significant differences between the clusters based on the Mann-Whitney comparison test ($p < 0.05$).

Evolution of pH values obtained under different conditions is presented in Fig. 2B. The pH of reactor 1 oscillated between 3.7 and 4.5 during the experimentation. In reactors 2 and 3, the pH evolves in a similar way. Values fluctuated respectively between 6.75 and 8.47 and 6.72 and 10.29. Values of pH in reactor without urine remained significantly ($p < 0.05$) lower than

those in reactors containing urine. Compared to the reactor without urine which had an acid environment, those neutralized with the human urine had an alkaline environment all along the experimentation.

Values of chemical oxygen demand (COD) recorded fluctuated from 10,247 to 33,686.4 mg/L in reactor 1, from 1,212.8 to 21,001.4 mg/L in reactor 2 and from 350.22 to 18,795.5 mg/L in reactor 3 (Fig. 2C). COD in reactor 1 was significantly ($p < 0.05$) higher than COD in reactors 2 and 3.

Total Kjeldahl nitrogen (TKN) measured varied between 210 and 812 mg/L for reactor 1, between 700 and 4060 mg/L for reactor 2 and between 2,828 and 3,388 mg/L for reactor 3 (Fig. 2D). The TKN concentrations varied significantly ($p < 0.05$) from one reactor to another. Higher concentrations were recorded in reactor 2 and the lowest in reactor 1.

The COD/TKN ratio varied between 34.85 and 105.66 in reactor R1, between 0.66 and 30.00 in reactor R2 and between 1.22 and 5.64 in reactor R3 (Fig. 2E). Values of COD/TKN ratio recorded in reactor R1 without human urine were significantly higher ($p < 0.05$) than those observed in reactors R2 and R3 buffered with human urine. No difference was appeared ($p > 0.05$) between the COD/TKN ratios of the last two.

3.1.2 BIOGAS PRODUCTION

The production of gas in reactor 1 occurred on the 13th day of experimentation and this only during three day with a volume varied between 1.62 and 14.63 dm³ (Fig. 3A). The flammability test of the gas produced by this reactor was negative. For the reactor 2, gas production has occurred from the 3th to the 34th day with a volume varied between 1.61 and 60 dm³ (Fig. 3A). The flammability test of the gas produced was positive from the 7th to the 34th day. Concerning the reactor 3, the gas production was recorded from the second to the 113th day with a volume varied between 2.61 and 81.80 dm³ (Fig. 3A). The flammability test of the gas produced by the digester 3 was also positive from the 4th to the 113th day.

Volume of gas produced by the two reactors containing human urine was significantly higher than that of the reactor without urine ($p < 0.05$). Cumulative volumes of gas produced by the three reactors were 21.13 dm³ for reactor 1, 827.04 dm³ for reactor 2 and 3, 601.95 dm³ for reactor 3 (Fig. 3B).

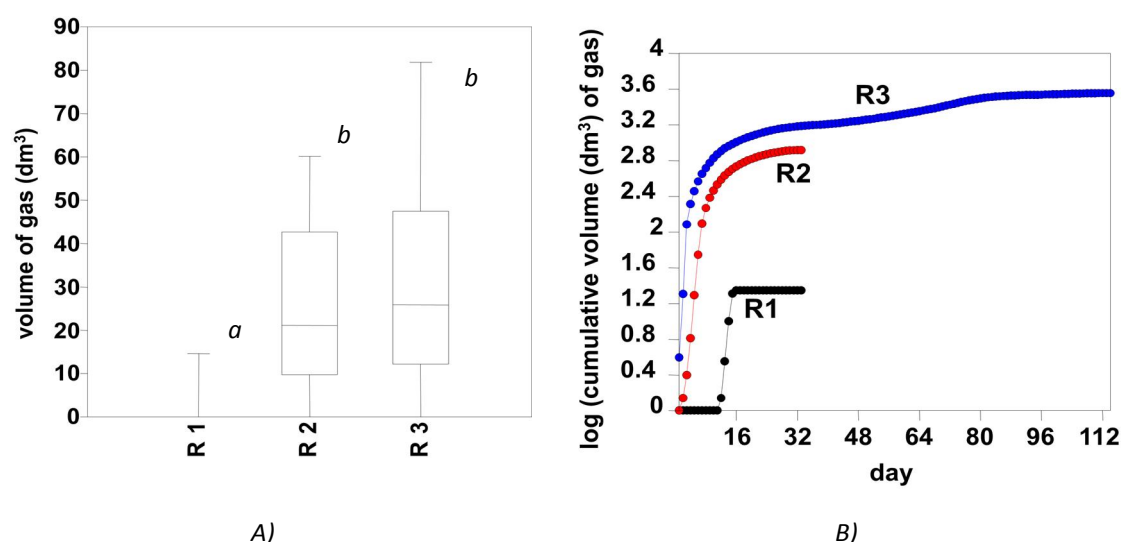


Fig. 3. A) Boxplots comparing biogas volume variation and B) cumulative volume of biogas in the three anaerobic digesters: R1 = effluent of cassava; R2 = effluent of cassava + urine; R3 = effluents of cassava + urine + cow manure. The different alphabets (a, b, c) indicate significant differences between the clusters based on the Mann-Whitney comparison test ($p < 0.05$).

3.2 DISCUSSION

Results from anaerobic mono-digestion in digester 1 indicate that pH of effluents was low (3.71 - 4.5) during the study. According to [5] and [30], this acidity of the effluents of cassava is due to their composition (rich in starch, presence of cyanogenic compounds). Reference [31] establishes that initial C/N ratio played an important role in the acidification efficiency of sewage sludge. Moreover, the acidity of brut effluent would be partly due to the fermentation step performed during the manufacturing process of attiéké. Indeed, according to [32] and [33], lower pH, in case of the production of

fermented products, can be explained by the activity of the lactic microflora. These microorganisms hydrolyze the starch contained in the effluents to produce lactic and acetic acids. Reference [32] also indicated that the amylolytic activity observed during the fermentation can directly transform cassava starch into lactic acid. In addition, persistent acidity observed during the process of anaerobic degradation in the digester 1 could also be explained by the accumulation of volatile fatty acids and hydrogen introduced during the hydrolytic and acidogenic stages ([15], [34]).

Production of biogas occurred late (13th day of operation) and in a short period (3 days) with few volumes (between 1.62 and 14.63 dm³). This occurred could be due to low values of pH observed in the digester 1 which inhibited the production of gas as reported by [15]. Moreover, the inflammability test is negative. This indicated that the average of methane content of the biogas produced from this digester is insignificant or zero.

The results of co-digestion showed that the pH increased to alkaline value in digester 2 (effluents of manioc + human urine) between 6.75 and 8.47 and in digester 3 (effluents of cassava + human urine + cow manure) between 6.72 and 10.29. The outlet pH value increased with the addition of human urine (as co-substrate) and cow manure. Indeed, according to [15], such observations are due to the process stability and the activity of methanogenic bacteria.

The substantial low COD concentration, high pH value and nutrients concentrations in digester 2 and 3, compared to digester 1, indicated that these systems operated at methanogenic conditions as confirmed by [35] in landfill.

The values of COD/TKN ratio are on average much higher than 50 in digester R1 without human urine. These ratios suggest that the concentrations of nitrogen are lower than what is required for anaerobic treatment of such wastewater. Therefore, nutrients, especially nitrogen, have to be added to the manioc wastewater for effective biological treatment as observed [36]. In this study, the treatment of the effluent of cassava with human urine has reduced the value of COD/TKN below 50 as recommended by [37] - [39] and [31] for the anaerobic treatment. In fact, human urine, with an alkaline pH (> 8.6) ([40] - [42]) and richness in nitrogen (> 3 g/L) ([14], [41]), was used to neutralize the pH and fertilize the effluent of cassava in digesters 2 and 3, while the cow manure was used to inoculate the digester 3, boosting thus the production of biogas.

Analysis of gas production profiles when substrates are combined indicated that there were significant differences among the combinations tested. Compared to gas produced in the reactor containing only the effluent of cassava (21.13 dm³), co-digestions of the effluent of cassava + human urine and effluent of cassava + human urine + cow manure enhanced the production of biogas with 827.04 and 3601.95 dm³ respectively. These results showed that the high productivity was obtained by co-digestions of effluent of cassava/human urine/cow manure. Indeed for this co-digestions system, gas production was recorded during 111 days with a daily production varying from 2.61 to 81.80 dm³. In digester 2 (effluent of cassava/human urine), gas production lasted only 31 days with daily production ranging from 1.61 to 60 dm³.

Moreover, the flammability test of the biogas produced by these two co-digestions reactors was positive during 27 and 109 days respectively for digesters 2 and 3. In addition, the gas produced burns with a blue flame. This indicates the presence of a good deal of methane content in the biogas produced by those two co-digestions system. Results observed could be due to positive synergism in the digestion environment, especially for effluents of cassava/urine/cow manure combinations, supplying missing nutrients and reducing of inhibitory materials in feedstock by the co-substrates as mentioned by [43]. In addition, this higher biogas potential was probably due to the increased in available easily degradable compound ratio in the feedstock, as it was reported by [24]. The difference of results obtained in digester 2 and digester 3 may be due to differences in microbial communities for these two co-digestions system employed. Others reported that improvement periods of anaerobic digesters subjected to organic overload differed based upon the microbial communities initially present ([44] - [46]). Although, the rate of CH₄ content of the biogas produced in this study is not quantified, but it can range between 64% and 66% which is normally obtained from conventional anaerobic digestion of organic wastes as noticed by [47].

The use of human urine as a co-substrate for anaerobic digestion of cassava effluent requires a large quantity of urine (40% in terms of proportion) for a best productivity. This system of co-digestion, as well as allowing the production of biogas as a source of renewable energy, could also help to resolve the sensitive problem of sustainable management of human excreta.

4 CONCLUSIONS

In this study, the anaerobic co-digestions of manioc wastewater and human urine were implemented in batch experiments to test for energy recovery. The findings were recorded as follows.

- (1) The pollution generated in the manufactory of attiéké (cassava wastewater and urine) constitutes the raw material of the anaerobic biodigestion unit. Produced biogas can be used to prepare the attiéké, but can also be used as an energy source for lighting the site of the factory and for the machines used to crush cassava.
- (2) Human urine can replace chemicals generally used to adjust the pH during anaerobic biodigestion, in particular for the treatment of manioc liquid waste which is very acid.
- (3) Residues of the anaerobic bio-digestion (digestat), rich in nitrogen, can be used to fertilize agricultural parcels for the production of cassava, for example.

In this way, the work environment will remain healthy for women, the lagoon adjacent to the factory will be protected against acid and toxic effluents of cassava and women use less firewood for cooking attiéké.

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Diagnostic du fonds pédogéochimique des sols développés sur matériaux volcano-sédimentaires au Blafo-Guétô (Toumodi) dans le Centre-Sud de la Côte d'Ivoire

[Pedogeochemistry background Diagnosis of soil developed on volcanosedimentary materials at Blafo-Guétô (Toumodi) in South-central Côte d'Ivoire]

**Yao Kouman Nestor KOUAKOU¹, Guy Fernand YAO¹, Krogba Yves NANGAH²,
Thierry Philippe GUETY¹ et Albert YAO-KOUAME¹**

¹Laboratoire de Pédologie et de Géologie Appliquée,
Université Félix Houphouët-Boigny,
Abidjan, Côte d'Ivoire

²Laboratoire Géosciences et Environnement,
Université Nangui Abrogoua,
Abidjan, Côte d'Ivoire

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ABSTRACT: This study is made in order to establish a database, which can use as reference value for the current contents in Heavy metals, such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) in the manganese and gold-bearing region of *Blafo-Guétô* at the Center-South part of Côte d'Ivoire. So, the soil Diagnosis based on the pedogeochemistry background, through two lines, the one on the hill Blafo, the other one on the hill Guétô, allowed to know that except the manganese (Mn) and the copper (Cu), the studied heavy metals, does not exceed the naturally indicated limit values and are thus polluted. These measured values are included between 0.2 to 1.9 mg.kg⁻¹ for Cd, 12 to 56 mg.kg⁻¹ for Cr, 25 to 299 mg.kg⁻¹ for Cu, 6000 to 50000 mg.kg⁻¹ for Mn, 13 to 38 mg.kg⁻¹ for Ni, 13 to 49 mg.kg⁻¹ for Pb and 25 to 110 mg.kg⁻¹ for Zn. For As and Hg, the measured values are lower than 0.25 mg.kg⁻¹ and, Only Mn and Cu indicated a geochemical anomaly, because exceeding the natural contents in soil. The ranking, in the decreasing order, from the geochemical anomaly to the lowest contents measured in the Blafo-Guétô soils, indicates that: Mn>Cu>Zn>Cr>Pb>Ni>Cd>As, Hg.

KEYWORDS: Pedogeochemistry background, Heavy metals, Volcano sedimentary, Blafo-Guétô, Côte d'Ivoire.

RESUME : Cette étude a été menée dans la perspective d'établir une base de données pouvant servir de valeur de référence pour les teneurs actuelles en éléments traces métalliques (ETM) tels que l'arsenic (As), le cadmium (Cd), le chrome (Cr), le cuivre (Cu), le Mercure (Hg), le manganèse (Mn), le nickel (Ni), le plomb (Pb) et le zinc (Zn), dans les sols de la région aurifère et manganésifère du *Blafo-Guétô*, au Centre-Sud de la Côte d'Ivoire. Ainsi, le diagnostic du fonds pédogéochimique à travers deux toposéquences, l'une sur la colline *Blafo*, l'autre sur la colline *Guétô* a permis de savoir qu'en dehors du manganèse (Mn) et du cuivre (Cu), dans les sols développés dans cette région, les ETM étudiés, ne dépassent pas les valeurs limites naturellement indiquées et ne sont donc pollués. Ces valeurs mesurées sont comprises entre 0,2 à 1,9 mg.kg⁻¹ pour le Cd, 12 à 56mg.kg⁻¹ pour le Cr, 25 à 299mg.kg⁻¹ pour le Cu, 6000 à 50000mg.kg⁻¹ pour le Mn, 13 à 38 mg.kg⁻¹ pour le Ni, 13 à 49mg.kg⁻¹ pour le Pb et 25 à 110 mg.kg⁻¹ pour le Zn. Quant à l'As et le Hg, les valeurs mesurées sont inférieures à 0,25mg.kg⁻¹ et, seulement le Mn et le Cu présentent une anomalie géochimique, car excédant les teneurs naturelles dans les sols. Le classement, dans l'ordre décroissant, des concentrations anormales aux teneurs les plus faibles mesurées dans les sols du Blafo-Guétô indique que : Mn>Cu>Zn>Cr>Pb>Ni>Cd>As, Hg.

MOTS-CLEFS: Fonds pédogéochimique, ETM, Volcano-sédimentaire, Blafo-Guétô, Côte d'Ivoire.

1 INTRODUCTION

Les terrains géologiques volcano-sédimentaires Birimiens de la Côte d'Ivoire, structurés à l'orogénèse éburnéenne [1], [2], regorgent de nombreux gîtes et indices métallifères [3], [4]. Ces terrains, pour la plupart inexplorés jusqu'à la période 1990, se voient actuellement l'objet d'intenses activités de recherche minière. Cependant, différents travaux ont indiqués que l'industrie minière est reconnue pour être un des grands secteurs où l'on peut parler de « *crise de l'environnement* » ([5], [6], [7]-[15]). Dans le cas, par exemple de l'impact sur le sol, des auteurs [16], [17] ont admis et reconnu que les zones d'activités minières avaient un impact négatif, marqué presque exclusivement par la forte concentration en éléments traces métalliques (ETM), un pH très bas, une faible capacité de rétention en eau, une forte conductivité électrique et modifiaient régulièrement le paysage. Aussi, dans le cadre de la gestion et de la valorisation des déchets organiques ou de la gestion appropriée de sites pollués, il est explicitement demandé de se référer à l'état des sols « *naturels* » voisins [18], pour distinguer la part de la contamination des sols propre à l'installation industrielle de celle qui préexistait avant son fonctionnement. Ainsi, Connaître le statut d'un sol avant l'installation quelconque d'un projet est très important et peut servir de valeur de référence locale, comme l'ont souligné [19], [20], [21]. C'est donc dans ce cadre, que cette étude est entreprise au *Blafo-Guéto*, au Centre-Sud de la Côte d'Ivoire, dans la région de Toumodi. Cette région tropicale, en plus d'avoir des potentialités aurifères et manganésifères [4], a développé des sols bruns qui suscitent un intérêt scientifique majeur [22]. Il est question dans ce travail, de diagnostiquer ces sols bruns décrits sur les collines « *Blafo* » et « *Guéto* » en s'appuyant sur la pédogéochimie, avec pour objectif d'élaborer un référentiel *sol Blafo-Guéto* en éléments traces métalliques tels que l'arsenic (As), le cadmium (Cd), le chrome (Cr), le cuivre (Cu), le Mercure (Hg), le manganèse (Mn), le nickel (Ni), le plomb (Pb) et le zinc (Zn).

2 MATERIELS ET METHODES

2.1 CARACTERISTIQUES DU SITE DE L'ETUDE

2.1.1 LOCALISATION

L'étude est menée dans la localité de Tokréyaokro sur les collines *Blafo* et *Guéto* (fig. 1). Le village de Tokréyaokro est à 6°48'N et 4°58'O à une altitude de 415 m au-dessus du niveau de la mer et fait partie de la région de Toumodi. Il est plus au Nord de Toumodi et est particulièrement surplombé par les hautes collines du *Blafo* et du *Guéto*.

2.1.2 MORPHOLOGIE DU PAYSAGE

Le contexte géomorphologique dans la localité est dominé par la présence des deux grandes collines *Blafo* et *Guéto* avec l'existence de moyen et haut-glacis. Le plus haut sommet est autour de 501 m, où pour le cas de la colline *Blafo*, d'Est en Ouest, l'altitude varie de 100 à environ 450 m.

2.1.3 GEOLOGIE LOCALE

La région du *Blafo-Guéto* comprend trois (3) domaines géologiques dont les limites suivent la direction birrimienne NNE-SSW. Le premier domaine, situé au niveau des collines *Blafo* et *Guéto*, comprend les formations du complexe volcano-sédimentaire birrimien. Le deuxième domaine est constitué des granites et des migmatites éburnéens, situé de part et d'autre du premier domaine, au sud-est et au nord-ouest. Quant au troisième domaine, il est constitué des schistes arkosiques [23]. Dans l'ensemble les formations rencontrées dans ce sillon sont des schistes, des grès, des quartzites, des conglomérats, des brèches, des roches basiques et acides, tous faiblement métamorphisés.

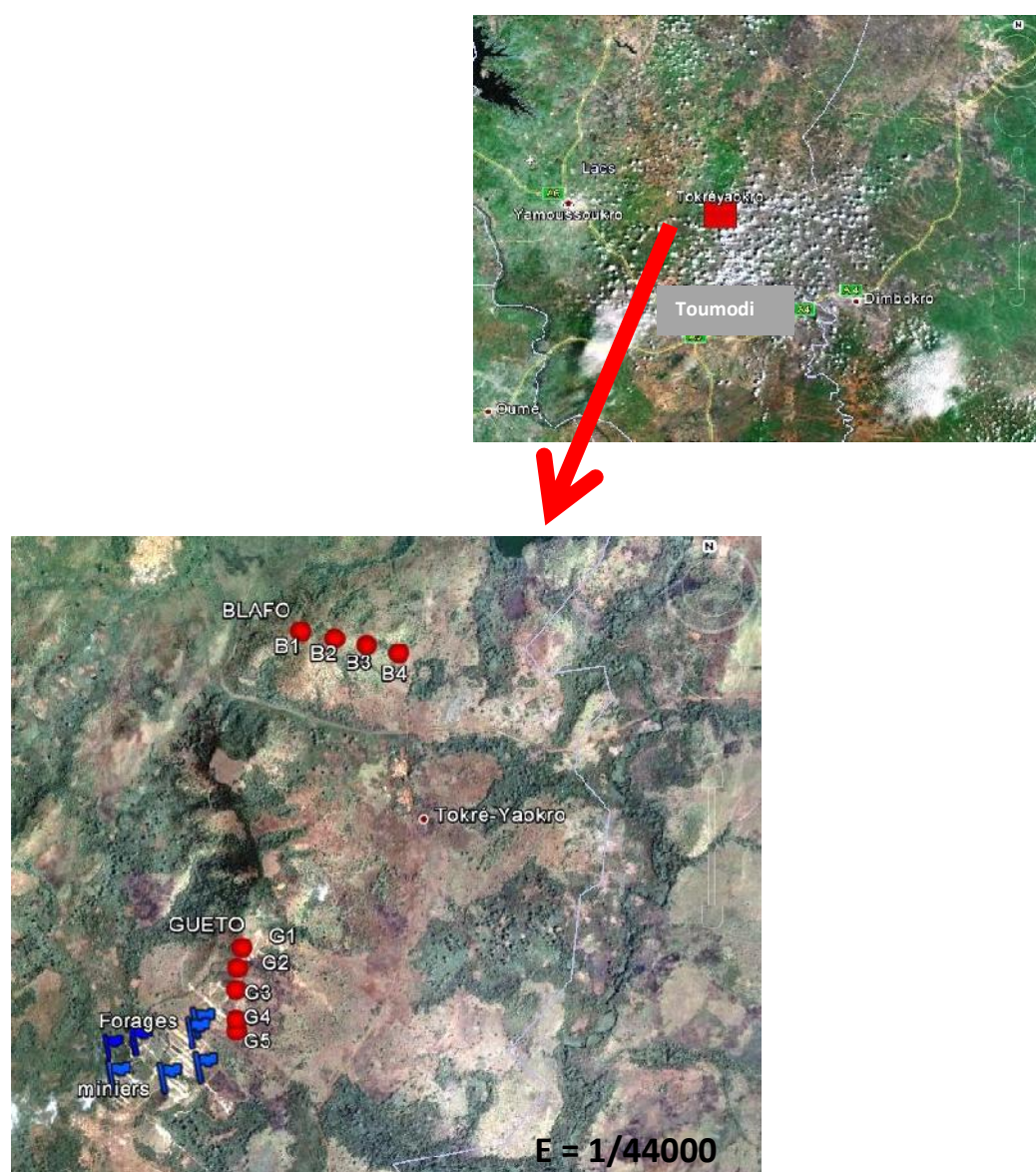


Fig. 1. Localisation du site d'étude

2.1.4 TYPE ET OCCUPATION DES SOLS

Les sols rencontrés au *Blafo-Guéto* sont bruns et eutrophes[22], développés sur la portion volcano-sédimentaire et, pourvus en un fort taux d'éléments grossiers. La région est essentiellement agricole, avec l'existence d'un parc, le parc d'Abokouamékro. En dehors des cultures, le secteur est le témoin d'une végétation arbustive et de reliques de forêt décidue.

2.1.5 ACTIVITES MINIERES

La région du *Blafo-Guéto*, est une région où les indices en manganèse et en or ont été avérés. Concernant l'or, plusieurs travaux de recherche ont été exécutés, avec notamment des campagnes de géochimie sol, de sédiments de ruisseaux, de forages destructifs et carottés. Les travaux exploratoires avancés, ont nécessité l'ouverture de plate-forme de forage (figure 1 et 2) ayant pour conséquence un début de dégradation de l'environnement par érosion et une accumulation de débris de roche en surface (figure 3).

2.2 DEMARCHE METHODOLOGIQUE

2.2.1 PRELEVEMENT DES ECHANTILLONS SOLS

Les échantillons sols prélevés sur le terrain, sont ceux issus de fosses pédologiques ouvertes sur chacune des collines *Blafo* et *Guéto*. L'ouverture des fosses s'est faite suivant deux toposéquences (fig. 1) en respectant les normes d'un dispositif stratifié par segment topographique (sommet, haut de versant, mi versant et bas de versant). La toposéquence de la colline *Blafo* est à une direction de 108°N avec 4 fosses pédologiques notées du sommet vers le bas de versant B1, B2, B3 et B4. Quant à celle du *Guéto*, elle est à 185°N et composée de 5 fosses numérotées G1, G2, G3, G4 et G5. Ces toposéquences ont été étudiées selon la méthode de [24], et les échantillons prélevés sont représentatifs des horizons décrits. Au total 40 échantillons ont été prélevés pour une répartition de 20 échantillons au *Blafo* et de 20 échantillons au *Guéto*.



Fig. 2. Plate-forme de forage minier



Fig. 3. Forte érosion du sol

2.2.2 ANALYSE QUANTITATIVE GLOBALE DES METAUX

Les échantillons sols soumis à l'analyse ont, dans un premier temps été séchés à l'ombre, à l'air libre pendant 14 jours, puis tamisés à la maille de 2 mm. Ensuite, la partie fine recueillie a été broyée, tamisée à 63 μm et environ 0.3 g a été digérée selon la méthode AIEA pour l'analyse. Cette analyse a été effectuée par Spectrométrie d'Absorption Atomique à Flamme (SAAF) et opérée trois fois pour chaque échantillon. Les éléments recherchés sont : As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Zn.

2.2.3 TRAITEMENT STATISTIQUE DES DONNEES

Les résultats d'analyse obtenus au laboratoire ont été traités à l'aide du logiciel Statistica 7.1et, pour des besoins d'identification, les tranches d'horizons (échantillons) sont numérotées en utilisant la lettre H, suivie du numéro d'ordre(en chiffre) de l'horizon. Les différences de concentration en éléments traces métalliques des échantillons ont été examinées au travers d'une analyse de la variance (ANOVA), suivies lorsqu'elles étaient significatives par le test de comparaison LSD de Fischer, qui permet d'identifier la ou (les) variable(s) très significativement différente(s) des autres. Les moyennes des variables ont été séparées au seuil $\alpha = 0,05$. Les considérations de compréhension du statut des sols en ces différents ETM, ont amené à apprécier la dynamique verticale et latérale, qui elle, distingue la concentration en chaque ETM selon les horizons humifères (Hs) et non humifères (Hp).

3 RESULTATS ET DISCUSSION

3.1 DYNAMIQUE VERTICALE DES ETM ETUDIES

Les valeurs moyennes indiquant la concentration en chaque élément trace métallique étudié, par tranche d'horizon et par profil de sol sont indiquées dans les tableaux I et II.

Toutes les valeurs indiquées dans ces tableaux, à l'exception de la teneur en cuivre (Cu), que ce soit au *Blafo* ou au *Guétou*, expriment une différence significative au seuil de $\alpha = 0,05$. Notons aussi que le mercure (Hg) et l'arsenic (As), ont des valeurs inférieures à $0,25 \text{ mg.kg}^{-1}$. La dynamique verticale des ETM étudiés est la suivante :

- Au niveau du *Blafo* : les éléments Cd, Cr, Mn, Pb, Zn du profil du sommet (B1) ont des teneurs qui décroissent de l'horizon de surface vers les horizons profonds. Cette situation est la même pour le Cd, au niveau du profil de haut de versant (B2). En revanche, les concentrations élevées pour le Pb concernent les 5 premiers horizons, et pour les autres éléments, les concentrations fortes sont plus en profondeur. Pour le profil de moyen versant (B3), la situation est inverse pour le Cd, où les teneurs élevées sont au niveau des horizons profonds. Seul, le Cu ne s'y apparente pas. Le Mn et le Zn décroissent de la surface vers la profondeur. Quant aux éléments Cr, Ni, ils sont abondants aux horizons intermédiaires. Au niveau du profil plus bas (B4), les horizons intermédiaires sont plus concentrés en ces éléments.

Tableau 1. Valeur moyenne des ETM étudiés au Blafo par tranche d'horizon

Profil	Horizon	Prof. (cm)	Concentration en mg.kg ⁻¹								
			As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn
B1	H1	0 - 5	<0,25	1,34	24,42	80,90	<0,25	11166,65	30,90	29,30	76,08
	H2	5 - 20	<0,25	1,01	18,67	118,96	<0,25	10543,21	20,89	21,73	77,71
	H3	20 - 39	<0,25	0,20	16,56	74,79	<0,25	10879,19	23,20	16,90	74,72
	H4	39 - 70	<0,25	0,62	13,85	93,27	<0,25	7176,55	25,92	11,33	48,16
B2	H1	0 - 7	<0,25	2,00	19,66	163,20	<0,25	13057,99	24,64	51,59	88,86
	H2	7 - 20	<0,25	0,24	18,33	102,41	<0,25	11050,86	28,54	33,68	76,00
	H3	20 - 50	<0,25	1,14	42,81	106,65	<0,25	13498,37	27,64	35,80	91,03
	H4	50 - 60	<0,25	0,63	22,88	164,06	<0,25	13261,76	48,96	37,60	92,64
	H5	60 - 100	<0,25	0,68	34,40	104,20	<0,25	8496,82	26,99	18,57	51,06
B3	H1	0 -10	<0,25	0,62	13,97	146,67	<0,25	15051,94	24,48	29,11	101,67
	H2	10 - 22	<0,25	0,20	20,05	178,38	<0,25	14527,26	28,94	25,05	105,94
	H3	22 - 35	<0,25	1,17	46,43	84,82	<0,25	11176,84	31,39	32,88	75,90
	H4	35 - 55	<0,25	0,37	38,20	77,11	<0,25	12423,32	25,56	12,53	89,86
	H5	55 - 70	<0,25	1,71	33,68	98,46	<0,25	9644,85	21,31	24,16	56,87
	H6	70 - 120	<0,25	1,21	12,71	92,93	<0,25	7515,80	12,85	21,45	36,46
B4	H1	0 - 5	<0,25	1,35	26,88	68,03	<0,25	8189,36	20,74	29,79	49,76
	H2	5 - 15	<0,25	0,09	25,90	75,54	<0,25	9695,84	14,40	24,92	19,80
	H3	15 - 30	<0,25	1,01	22,04	162,68	<0,25	9555,96	27,76	28,96	74,44
	H4	30 - 50	<0,25	0,06	20,24	121,41	<0,25	10123,20	20,52	30,87	64,94
	H5	50 - 70	<0,25	1,06	28,42	123,21	<0,25	7926,31	16,08	14,61	42,09

- Au niveau du *Guétou* : pour le profil de haut de versant (G1), les concentrations fortes en Cd, Cr, Cu, Mn, Ni, Zn, se rencontrent au niveau des 2 premiers horizons de surface. Pour le Pb, les horizons les plus profonds sont les plus concentrés.

Le Zn et le Cu, ont également leurs horizons de profondeur fortement concentrés. Concernant le profil de haut de versant (G2), les plus fortes concentrations en Cd, Cu, Mn, Pb, Zn sont dans les horizons supérieurs. Aussi, le Cu et le Pb sont forts élevés dans le dernier horizon le plus profond. Le Cr est très concentré dans les horizons de profondeur et le Ni dans les horizons intermédiaires. Les éléments Cd, Cr, Mn, Ni, Pb, Zn sont très concentrés dans les 2 premiers horizons de surface au niveau du profil G3. Seul le Cu est élevé dans les horizons de profondeur. Au niveau du profil G4, le Cd, le Cu, le Mn et le Zn sont forts concentrés dans les 3 derniers horizons. Le Cr et le Ni, plus riches dans les 2 premiers horizons. Quant au Pb, il est plus concentré dans les horizons intermédiaires. Les éléments Cu, Mn, Ni, Pb et Zn sont plus concentrés dans l'horizon de surface du profil de bas de versant (G5). Par contre le Cd et le Cr sont plus concentrés en profondeur.

Tableau 2. Valeur moyenne des ETM étudiés au Guéto par tranche d'horizon

Profil	Horizon	Prof. (cm)	Concentration en mg.kg ⁻¹								
			As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn
G1	H1	0 - 10	<0,25	1,34	16,67	195,30	<0,25	8811,28	26,11	14,44	53,34
	H2	10 - 25	<0,25	1,27	26,65	139,61	<0,25	9398,65	14,93	19,71	47,43
	H3	25 - 40	<0,25	0,07	15,11	101,74	<0,25	4734,32	13,62	22,57	26,94
	H4	40 - 65	<0,25	0,25	12,97	146,67	<0,25	5302,79	14,64	21,87	35,64
	H5	65 - 120	<0,25	0,50	18,42	133,67	<0,25	6779,31	12,62	35,29	39,35
G2	H1	0 - 10	<0,25	1,23	14,89	113,69	<0,25	6412,27	18,03	23,61	45,16
	H2	10 - 25	<0,25	1,67	15,70	81,40	<0,25	4930,82	26,87	20,52	30,00
	H3	25 - 43	<0,25	1,63	18,05	92,80	<0,25	8408,91	18,48	24,43	47,99
	H4	43 - 70	<0,25	0,64	17,79	102,33	<0,25	5149,76	27,86	19,29	30,09
	H5	70 - 160	<0,25	0,20	20,03	116,08	<0,25	4229,58	15,00	41,95	28,59
G3	H1	0 - 20	<0,25	1,99	57,07	45,53	<0,25	14538,74	23,86	25,58	95,20
	H2	20 - 60	<0,25	0,62	38,02	218,01	<0,25	15572,69	36,05	20,09	106,76
	H3	60 - 100	<0,25	0,26	16,71	188,85	<0,25	8909,99	17,89	18,81	51,23
	H4	100 - 200	<0,25	0,40	15,20	263,46	<0,25	10178,60	18,23	16,79	74,00
G4	H1	0 - 15	<0,25	0,05	30,16	98,23	<0,25	6502,68	21,92	13,10	35,48
	H2	15 - 47	<0,25	0,55	38,91	120,80	<0,25	7243,58	26,97	23,81	47,76
	H3	47 - 100	<0,25	2,51	20,08	107,53	<0,25	5903,16	16,31	48,51	34,49
	H4	100 - 140	<0,25	1,09	13,77	168,21	<0,25	11151,49	31,55	13,26	76,92
G5	H1	0 - 15	<0,25	1,24	39,49	117,32	<0,25	8781,15	31,31	44,38	52,90
	H2	15 - 200	<0,25	1,98	49,98	86,83	<0,25	7616,13	19,43	42,49	42,61

3.2 DYNAMIQUE LATÉRALE DES ETM ETUDIÉS

Les tableaux III et IV représentent les valeurs moyennes des différents ETM étudiés par profil et par tranche d'horizons humifères et non humifères. La couverture latérale de ces ETM a donc été appréciée depuis le sommet de chaque colline jusqu'au bas de versant. Les études statistiques, notamment l'analyse de la variance, ont indiquées une différence significative pour chaque ETM, au seuil de la probabilité $\alpha = 0,05$, à l'exception du Cu. Les figures 4 et 5 sont donc la représentation de la dynamique latérale de ces ETM au *Blafo* et au *Guéto*. Sur le site du *Blafo*, les concentrations en Cd, Pb, Mn et Zn sont plus élevées dans les horizons humifères du sommet jusqu'au bas de versant. En revanche le Cr est plus concentré dans les horizons profonds du haut de versant au bas de versant. Au niveau du Cu et du Ni, ils sont plus concentrés dans l'horizon humifère du moyen versant.

Au niveau du *Guêto*, le Cd est concentré du sommet au moyen versant dans l'horizon humifère, de même que le Mn, le Zn et le Cr. Le Ni est concentré de sommet au bas de versant dans l'horizon humifère. Quant au plomb, c'est seulement au niveau du moyen versant qu'il est plus concentré dans l'horizon humifère. Enfin, le Cu est mieux concentré dans les horizons de profondeur du sommet au tiers inférieur du moyen de versant.

Tableau 3. Valeur moyenne par horizons humifères et non humifères et par profils des ETM étudiés au Blafo

Profil	Horizon	Prof. (cm)	Concentration en mg.kg ⁻¹								
			As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn
B1	Hs	0 - 39	<0,25	0,85	19,88	91,55	<0,25	10863,01	24,99	22,64	76,17
	Hp	39 - 70	<0,25	0,62	13,84	93,26	<0,25	7176,55	25,92	11,33	48,15
B2	Hs	0 - 50	<0,25	1,12	26,93	124,08	<0,25	12535,74	26,94	40,35	85,29
	Hp	50 - 100	<0,25	0,66	28,64	134,13	<0,25	10879,29	37,97	28,08	71,85
B3	Hs	0 - 22	<0,25	0,41	17,01	162,53	<0,25	14789,6	26,71	27,08	103,8
	Hp	22 - 120	<0,25	0,41	32,75	88,33	<0,25	10190,2	22,77	22,75	64,77
B4	Hs	0 - 15	<0,25	0,72	26,39	71,79	<0,25	8942,6	17,57	27,35	34,77
	Hp	15 - 70	<0,25	0,7	23,56	135,76	<0,25	9201,82	21,45	24,81	60,49

Tableau 4. Valeur moyenne par horizons humifères et non humifères et par profil des ETM étudiés au Guêto

Profil	Horizon	Prof. (cm)	Concentration en mg.kg ⁻¹								
			As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn
G1	Hs	0 - 40	<0,25	0,89	19,47	145,54	<0,25	7648,08	18,22	18,9	42,57
	Hp	40 - 120	<0,25	0,37	15,69	140,17	<0,25	6041,05	13,63	28,58	37,5
G2	Hs	0 - 43	<0,25	1,51	16,21	95,96	<0,25	6584	21,12	24,52	41,05
	Hp	43 - 160	<0,25	0,42	18,91	109,21	<0,25	4689,67	21,43	30,62	29,34
G3	Hs	0 - 60	<0,25	1,3	47,55	131,77	<0,25	15055,72	29,95	22,83	100,98
	Hp	60 - 200	<0,25	0,33	15,95	226,15	<0,25	9544,3	18,06	17,8	62,62
G4	Hs	0 - 47	<0,25	0,3	34,54	109,51	<0,25	6873,13	24,44	18,46	41,62
	Hp	47 - 140	<0,25	1,8	16,92	137,87	<0,25	8527,33	23,93	30,89	55,7
G5	Hs	0 - 15	<0,25	1,24	39,48	117,32	<0,25	8781,15	31,31	44,38	52,9
	Hp	15 - 200	<0,25	1,97	49,97	86,82	<0,25	7616,13	19,43	42,49	42,61

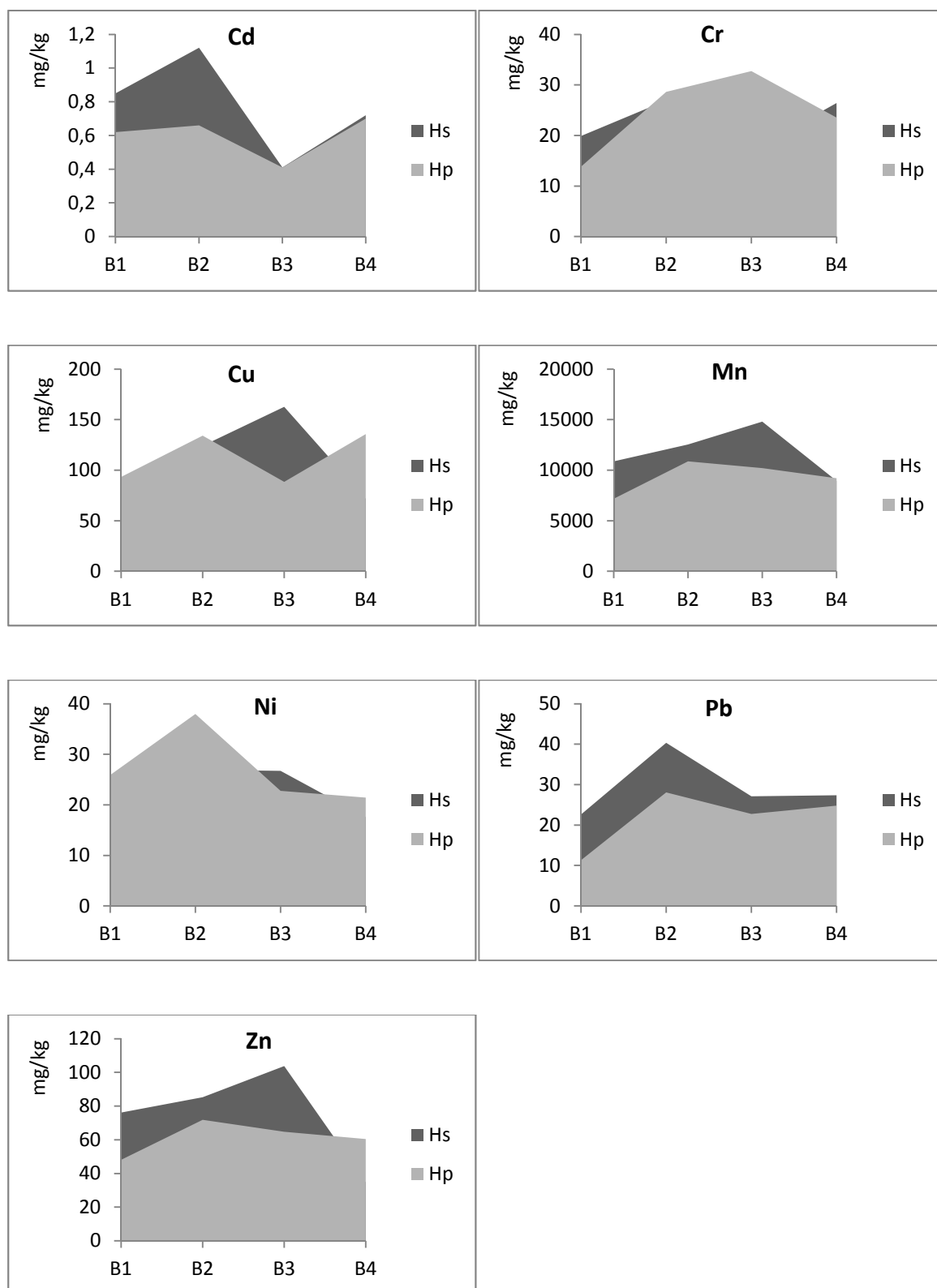


Fig. 4. Couverture latérale des ETM étudiés par tranche d'horizon humifère et non humifère du sommet au bas de versant de la colline Blafo

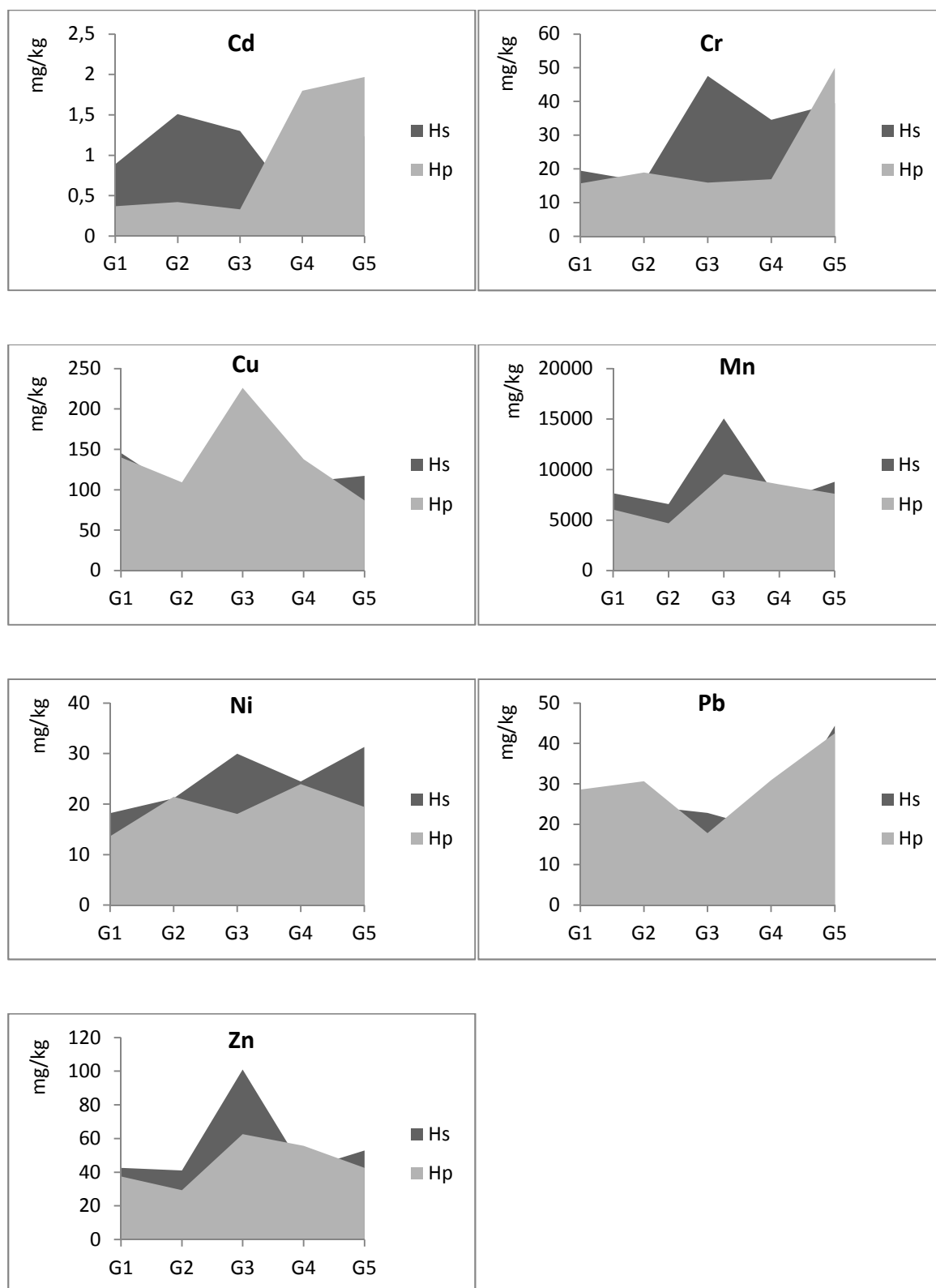


Fig. 5. Couverture latérale des ETM étudiés par tranche d'horizon humifère et non humifère du sommet au bas de versant de la colline Guétou

3.3 DISCUSSION

L'appréciation de la dynamique verticale et latérale des ETM étudiés au Blafo-Guéto, nous indique, de façon générale que les sols de ce secteur ne sont pas pollués en ces éléments. En effet, la part géogène des ETM étudiés, à partir des moyennes des teneurs totales en ces éléments dans les horizons de surface et de profondeur, est inférieure aux teneurs naturelles indiquées communément dans les sols. D'après [25], Les teneurs naturelles des sols en Pb sont en moyenne de 32 mg.kg^{-1} et varient entre 10 et 67 mg.kg^{-1} . Dans notre cas, ces teneurs varient jusqu'à 44 mg.kg^{-1} avec une forte concentration dans les horizons de surface. Ce constat est d'autant plus vrai que [26] ont indiqué une forte réactivité entre le Pb et la matière organique, ponctuée par une faible solubilité et mobilité du Pb [27].

Au niveau du Zn, [28] évalue la teneur moyenne à 50 mg.kg^{-1} en indiquant que les teneurs naturelles dans les sols varient entre 10 mg.kg^{-1} et 300 mg.kg^{-1} . Dans les sols étudiés, les teneurs se retrouvent dans cette fourchette avec un maximum de 106 mg.kg^{-1} . L'étude de la dynamique verticale du Zn fait ressortir une forte concentration dans l'horizon enrichi en argile, démontrant son caractère mobile tel qu'indiqué par [29].

Selon [30], les teneurs naturelles de cadmium dans les sols sont comprises entre 0,06 et $1,1 \text{ mg.kg}^{-1}$ et comparées à nos valeurs mesurées, elles s'y accordent en dehors du site *Guéto*, où nous avons une concentration allant jusqu'à $1,97 \text{ mg.kg}^{-1}$ au bas de versant. Ce constat pourrait s'expliquer par la rétention du Cd par les hydroxydes de fer, telle qu'indiqué par [28]. En effet les profils G4 et G5, ont des horizons à induration de fer.

Concernant l'As, [31] situe la valeur moyenne à 6 mg.kg^{-1} , en indiquant une variation comprise entre 0,1 et 40 mg.kg^{-1} et, dans nos sols étudiés, les valeurs en As sont inférieures à $0,25 \text{ mg.kg}^{-1}$. C'est le même constat pour le Hg, où [32] à indiquées les valeurs limites à 1 mg.kg^{-1} .

Aussi [32], signifie les valeurs limites du Cr, Cu, Ni, respectivement à 150 mg.kg^{-1} , 100 mg.kg^{-1} et 50 mg.kg^{-1} . Ces valeurs indiquées sont largement supérieures à celles que nous avons mesurées pour le Cr et le Ni en dehors, du Cu dont quelques valeurs vont jusqu'à 226 mg.kg^{-1} . On peut donc parler, pour le cas du Cu, d'un phénomène d'anomalie géochimique.

Ce même phénomène est observé pour le Mn, où nous avons des teneurs arrivant jusqu'à 15000 mg.kg^{-1} . Le Mn, est naturellement présent dans les sols et peut contenir entre 770 et 1000 mg.kg^{-1} , tel que constaté au Québec par [33]. Au-delà il présente une anomalie. Dans notre cas, les deux sites *Blafo* et *Guéto* sont au-delà de ces valeurs avec, le cas du site *Blafo* plus accentué.

4 CONCLUSION

Définir la base référentielle du fond pédogéochimique actuel des sols développés dans l'espace volcano-sédimentaire du *Blafo-Guéto* a été un sujet particulièrement intéressant. Ainsi, cette étude permettra de guider et d'orienter, en cas de besoin, une quelconque gestion de cet environnement. Les sols au *Blafo* et au *Guéto*, comme il a été démontré, en l'état actuel, ne sont pas pollués en arsenic (As), en cadmium (Cd), en chrome (Cr), en Mercure (Hg), en nickel (Ni), en plomb (Pb) et en zinc (Zn). Seuls, le manganèse (Mn) et le cuivre (Cu) présentent un phénomène d'anomalie géochimique. Les concentrations pour le Mn sont plus élevées dans les horizons humifères et le Cu, dans les horizons de profondeur.

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Utilisation de la fonction de transfert morphologique pour la simulation des transferts d'eau dans le bassin versant de Débo (Région de SOUBRE au Sud-Ouest de la Côte d'Ivoire)

[Use of the morphological transfer function for the simulation of water transfers in Debo catchment (SOUBRE area, southwest of Ivory Coast)]

Vano Mathunaise Sorokoby¹, Mahaman Bachir Saley¹, Koffi Fernand Kouame¹, Baliet René², Eric M'moi Valère Djagouda¹, Kouadio Affian¹, Jean Biemi¹ et Blaise Koffi²

¹Centre Universitaire de Recherche et d'Application en Télédétection (CURAT),
UFR STRM, Université Félix Houphouët-Boigny (UFHB),
22 BP 801 Abidjan 22, Côte d'Ivoire

²Laboratoire des Sciences et Techniques de l'Eau et du Génie de l'Environnement (LASTEGE),
UFR des Sciences de la Terre et des ressources Minières (STRM), Université Félix Houphouët-Boigny,
22 BP 582 Abidjan 22, Côte d'Ivoire

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ABSTRACT: The climate variability has affected pejoratively the groundwater recharge in Soubre area. Thus, the simulation of surface flows is an answer to the problematic of water supply in the area. The aim of this study is the simulation of surface flows in Debo catchment by estimating flood flows.

The methodology is based on the application of morphological transfer function (MTF) of DEMIURGE software (Digital Elevation Model In Urgency). It consisted of the determination of fractal parameters related to water systems, the estimation of maximum flow at the outlet, the study of the sensitivity of the simulated hydrographs based on the simulation time step.

The results show that the reference time is $t = 20$ minutes. For simulation times different from $t = 20$ minutes, the geomorphologic pulse histograms (GPH) do not fit the times transfer frequency histogram. The specific flow at the outlet of the catchment is $3.394 \text{ m}^3 \cdot \text{s}^{-1}$ for a rise time of 31.33 hours under the assumption of a uniform effective rainfall of 1 mm. The maximum flows simulated evolve with the rainfall blade and the rushed water. For a blade of 188.08 mm past, the maximum flow rate is at least $634.111 \text{ m}^3 \cdot \text{s}^{-1}$. For a rise time of 33 h 20 minutes, the volumes assessed are estimated at $1.06 \cdot 10^8 \text{ m}^3$.

KEYWORDS: Simulation, Transfer, MTF, DEMIURGE, flood flow, Debo.

RESUME: La variabilité du climat a affecté de manière péjorative la recharge souterraine de Soubre. Ainsi, la simulation des écoulements de surface est une réponse à la problématique d'approvisionnement en eau dans la région. L'objectif de cette étude est la simulation des écoulements de surface dans le bassin versant de Débo par l'estimation des débits maxima de crue.

La méthodologie repose sur l'application de la fonction de transfert morphologique (FTM) du logiciel DEMIURGE (Digital Elevation Model In URGENCY). Elle a consisté en la détermination des paramètres fractaux liés aux réseaux hydrographiques, l'estimation des débits maxima à l'exutoire, l'étude de la sensibilité des hydrogrammes simulés en fonction des pas de temps de simulation.

Les résultats obtenus montrent que le pas de temps de référence est de $t = 20$ minutes. Les différents histogrammes géomorphologiques impulsifs (HGI) ne s'ajustent pas à l'histogramme des fréquences des temps de transferts pour des temps de simulation différents de $t = 20$ minutes. Il en est de même pour les scénarii de pluie de gradients non uniformes. Le

débit spécifique à l'exutoire du bassin est de $3,394 \text{ m}^3 \cdot \text{s}^{-1}$ pour un temps de montée de 31,33 heures et un temps de base de sous l'hypothèse d'une pluie efficace uniforme de 1 mm. Les débits maxima simulés varient en fonction des lames d'eau précipitées et écoulées. Pour une lame écoulée de 188,08 mm, on observe un débit maximum de $634,111 \text{ m}^3 \cdot \text{s}^{-1}$. Les volumes écoulés pour un temps de montée 33 h 20 min, s'évaluent à $1,06 \cdot 10^8 \text{ m}^3$.

MOTS-CLEFS: Simulation, FTM, DEMIURGE, Débit de crue, Débo.

1 INTRODUCTION

L'application d'une fonction de transfert morphologique pour simuler les transferts d'eau de surface dans le bassin versant de Débo région est une grande première pour la zone d'étude mais aussi pour la Côte d'Ivoire. Le bassin versant de Débo est une région où l'activité agricole est très intense car cette région fait partie de la nouvelle boucle du cacao ivoirien. La population y est très dense et cet état de fait accentue la vulnérabilité de la région aux effets du changement climatique. Une simulation des écoulements de surface pourrait permettre de mieux gérer les effets du changement climatique sur les ressources naturelles de la zone dans une perspective d'atténuation. Le modèle de simulation que nous voulons appliquer est la fonction de transfert morphologique (FTM) du logiciel DEMIURGE (Digital Elevation Model In URGENCY) mis en place par l'IRD (Institut de Recherche et Développement) [3].

2 GENERALITES SUR LA ZONE D'ETUDE

Le bassin versant du Débo fait partie intégrante du degré carré de Soubré et se situe entre $5^{\circ}30'$ et $6^{\circ}01'$ de latitude Nord et entre $6^{\circ}07'$ et $6^{\circ}27'$ de longitude Ouest. La figure 1 présente ce bassin.

Son cours d'eau principal, le Débo constitue presque une frontière naturelle de quatre sous-préfectures : au Nord la sous-préfecture de Guibéroua, à l'Ouest la sous-préfecture de Soubré, les sous-préfectures de Gagnoa et de Guéyo à l'Est et la sous-préfecture de Sassandra au Sud du bassin. Le bassin versant de Débo est une pédiplaine ondulée s'inclinant du Nord vers le Sud avec des altitudes moyennes de 200 m à 55 m. Il est dominé par une vaste couverture végétale constituée essentiellement de forêt. Les hautes altitudes appartiennent à une série de collines appelées les Monts Trokoua (413 m). Les sols sont en majorité ferralitiques adaptés à l'agriculture. Le bassin présente un réseau hydrographique dense favorisé par un climat chaud et humide (type baouléen au Nord et type attien au Sud). Il est caractérisé par des pluies saisonnières abondantes (1500 mm). La température moyenne annuelle oscille entre $24,5^{\circ}\text{C}$ et $27,2^{\circ}\text{C}$ avec une très faible variation. L'amplitude thermique est inférieure à 3°C . La surface totale du bassin est de 1015 Km^2 avec une population estimée à plus de 40000 habitants soit une densité de 40 habitants au kilomètre carré. L'activité économique est basée sur le commerce des produits agricoles (cacao, café, palmier à huile, bananes plantains et riz). Les formations géologiques du secteur sont constituées des roches métamorphiques appartenant au mégacycle éburnéen (micaschistes à deux micas, staurotides, andalousite, gneiss à biotite, à biotite et muscovite subordonnée, migmatites à biotite, migmatites à biotite et grenat), des roches plutoniques (granites à deux micas, granites à biotite, granites à biotite et muscovite subordonnée, granodiorites à faciès orthogneissique), des dolérites post-éburnéennes sous forme de filons ou de petits stocks plus ou moins parallèles de direction générale NW-SE.

3 MATERIELS ET METHODES

3.1 DONNEES

Les données cartographiques utilisées sont une carte topographique à l'échelle 1/200000 (datant de 1966) et une autre à l'échelle 1/500000 (datant de 1996) acquises au CCT, une carte géologique du Sud-Ouest de la Côte d'Ivoire à l'échelle 1/500000 (domaine SASCA) établie d'après les travaux de [8] par le BRGM (Bureau de Recherche de Géologie Minière) en 1973 et obtenue auprès de la Direction de la Géologie, une carte de l'esquisse pédologique de la Côte d'Ivoire (feuille Sud-Ouest) à l'échelle 1/500000 dressée par [9], une carte géologique du degré carré de Soubré à l'échelle 1/200000 établie d'après les travaux de [11] provenant également de la Direction de la Géologie.

Les données satellitaires utilisées dans ce travail sont le MNA (Modèle Numérique d'Altitude) de la zone d'étude obtenu à partir des images SRTM (Shuttle Radar Topography Mission) extraites de la base de données GTOPO30 de l'USGS (United States Geological Survey). Le MNA de la zone d'étude est présenté à la figure 2.

3.2 METHODOLOGIE

3.2.1 PRINCIPE DE LA FONCTION DE TRANSFERT MORPHOLOGIQUE (FTM)

La réflexion méthodologique a porté sur la conceptualisation d'une fonction de transfert reposant sur une représentation physiquement satisfaisante des écoulements dans les chenaux d'un réseau hydrographique schématisé sous la forme d'un modèle de drainage dérivé d'un MNT. Des formules empiriques sont proposées permettant d'estimer la largeur des chenaux en fonction de la taille des bassins et de la pente locale du dit chenal. Ces largeurs estimées servent à leur tour à définir des longueurs et des pentes d'écoulement des chenaux physiquement plausibles et peu sensibles à la résolution spatiale. Ceci est rendu possible en introduisant la dimension fractale du réseau comme facteur de modulation des longueurs et des pentes en fonction du pas de mesure soit le pas du MNT [2]. Cette méthode est utilisée dans le module de simulation baptisé Fonction de Transfert Morphologique (FTM). Dans sa version actuelle, le transfert ne procède que d'une translation des volumes d'eau générés par des pluies impulsionnelles. Ainsi, la longueur et la largeur du chenal apparaissent comme deux critères intervenant dans l'estimation d'une longueur d'écoulement « conventionnelle ».

3.2.1.1 EQUATIONS GOUVERNANT LA FONCTION DE TRANSFERT MORPHOLOGIQUE

Le processus consiste à calculer les indices morphologiques ou hydrologiques appropriés correspondant à l'hypothèse de la dimension fractale du réseau hydrographique, tout en générant un hydrogramme géomorphologique impulsionnel (HGI) [3], [12]. Il apparaît possible d'estimer pour chaque maille d'un MNT les caractéristiques suivantes du chenal la traversant :

- largeur du chenal : λ ;
- longueur dite « intra-maille » du chenal : L .

La représentation des chenaux à l'intérieur de chaque maille (représentation intra-maille) offre la perspective d'établir un « modèle d'écoulement » dans les chenaux qui soit plausible en termes hydrologiques.

Partant de la formule de Strickler dans laquelle on confond profondeur moyenne et rayon hydraulique, et d'un débit d'ampleur moyen dans un très large éventail de surfaces drainées on estime la valeur du débit Q dans l'équation 1:

$$Q = S^{0,75} \quad (1)$$

On arrive à établir la proportionnalité de la largeur de la rivière avec la surface drainée élevée à une certaine puissance, et avec l'inverse de la pente élevée à une autre puissance. On aboutit à la formule donnée par l'équation 2, qui fixe un ordre de grandeur tout à fait acceptable dans une gamme très étendue de surface et de pente :

$$\lambda = S^{0,45} . i^{-0,25} \quad (2)$$

Avec λ la largeur du chenal, S la surface drainée et i la pente.

En appelant ℓ la longueur du tracé du cours d'eau entre l'entrée et la sortie du bief, L la distance en ligne droite qui sépare l'entrée et la sortie du bief et D la dimension fractale du tracé des rives, on a, par définition de la propriété fractale donnée par l'équation 3 :

$$\ell / L = (\lambda / L)^{1-D} \quad (3)$$

D'où l'on obtient l'équation 4 :

$$\ell = \left[L^{4D} [10^{-9} . S^{1,8} . \Delta H^{-1}]^{1-D} \right]^{1/(D+3)} \quad (4)$$

Où ΔH est la dénivelée en mètres entre l'entrée et la sortie du bief. En particulier, si le bief correspond à la traversée d'une même maille de la grille du MNT de résolution r et si n est le nombre de mailles drainées par le bief dans la maille qu'il traverse, sa longueur est estimée à l'équation 5 par :

$$\ell = \left[r^4 [10^{10,8} . r^{0,4} . \Delta H . n^{-1,8}]^{D-1} \right]^{1/(D+3)} \quad (5)$$

La dimension fractale attribuée au tracé du cours d'eau permet d'évaluer la longueur effective parcourue pour l'écoulement. Il en résulte une nouvelle estimation de la pente. La vitesse du transfert de l'eau en dépend, de même que, a fortiori, le temps de transfert de l'écoulement d'une maille à l'autre.

Ainsi, la fonction de transfert morphologique peut s'exprimer comme suit dans l'équation 6 :

$$Q = \lambda.H.V \quad (6)$$

Avec Q le débit spécifique à l'exutoire du bassin, λ la largeur du chenal et V la vitesse des écoulements dans le chenal.

Ainsi la vitesse s'obtient de la façon suivante dans l'équation 7 :

$$V = k.H^{2/3}.i^{1/2} \quad (7)$$

Avec H profondeur du chenal, k coefficient de Strickler, i la pente.

Il vient alors dans l'équation 8 que la profondeur est :

$$H^{2/3} = V / (k.i^{1/2}) \quad (8)$$

Les équations 1 et 2 permettent d'écrire avec pour hypothèse que Q et λ ne dépendent que de S et de i l'équation 9 :

$$Q / \lambda = S^{0,3}.i^{0,25} \quad (9)$$

Il vient dans l'équation 10 que :

$$(Q / \lambda)^{2/3} = (H.V)^{2/3} \quad (10)$$

D'où l'équation 11 :

$$(S^{0,3}.i^{0,25})^{2/3} = V / (k.i^{1/2}).V^{2/3} = V^{5/3}.(k.i^{1/2})^{-1} \quad (11)$$

La vitesse peut donc être estimée en fonction de S, i et k par l'équation 12 :

$$V = S^{0,12}.i^{0,4}.k^{0,6} \quad (12)$$

Dans l'équation 13, comme :

$$H = Q / \lambda V = S^{0,75-0,45-0,12}.i^{0,25-0,4}.k^{0,6} \quad (13)$$

On déduit alors l'équation 14 :

$$H = S^{0,18}.i^{-0,15}.k^{0,6} \quad (14)$$

Le coefficient de Strickler k représente la « rugosité » du lit de la rivière au regard de l'écoulement. Il intervient à ce titre dans l'estimation de la vitesse V des écoulements et de la profondeur H du chenal. Selon la rugosité, cet indice varie entre 10 et 30. Dans la nature, les torrents ont un lit pierreux en forte pente ce qui les rend rugueux au regard de l'écoulement. Inversement, les fleuves ont un lit en faible pente formé de bancs alluviaux argilo-sableux qui réduisent sensiblement la rugosité. On pose donc comme hypothèse supplémentaire que k est fonction de la superficie S du bassin et de la pente i du lit [1]-[2].

Si on pose dans l'équation 15 que :

$$k = a.S^m.i^n \quad (15)$$

On peut écrire empiriquement dans l'équation 16 que :

$$k = 10. S^{0,04} . i^{-0,03} \quad (16)$$

En remplaçant k dans les équations 13 et 14, on obtient des estimations de la vitesse V et de la profondeur H ne dépendant plus que de la surface S du bassin et de la pente i du chenal dans l'équation 17 :

$$V = 4. S^{0,144} . i^{0,382} \quad (17)$$

En intégrant l'expression de la vitesse de l'équation 12 à l'expression de H dans l'équation 13, on obtient l'équation 18 :

$$H = 0,25 S^{0,156} . i^{-0,132} \quad (18)$$

Si on admet que la puissance mécanique de l'écoulement par unité de largeur est constante de l'amont à l'aval (signifiant que le seuil de résistance du sol au creusement est homogène), la quantité QV^2/λ est constante ce qui revient à admettre dans l'équation 19 que :

$$S^{0,588} . i^{1,014} = c \quad (19)$$

Attribuons à cette constante c, la valeur arbitraire de 0,4. La pente i du lit ne dépend plus que de la surface S du bassin soit l'équation 20 :

$$i = 0,405 S^{-0,58} \quad (20)$$

On retrouve là la loi de pente de Horton selon laquelle la pente est proportionnelle à la surface drainée élevée à une puissance négative [12]. L'exposant de S est négatif ; ce qui signifie que les profils en long des rivières sont globalement concaves. Cet exposant pourrait éventuellement être calibré sur les profils en long observés.

3.2.1.2 DETERMINATION DE L'HYDROGRAMME GEOMORPHOLOGIQUE IMPULSIONNEL

Connaissant la largeur λ , la longueur ℓ , la profondeur H du chenal et la vitesse V d'écoulement dans ce chenal en chaque maille, une fonction de transfert peut être établie sur la base du modèle de drainage dérivé du MNT.

Deux caractéristiques sont calculées à partir de ces valeurs [6] :

- le temps de transit intra-maille en secondes soit l'équation 21:

$$T = \ell / V \quad (21)$$

- le volume du chenal en m³ soit l'équation 22:

$$C = \lambda . \ell . H \quad (22)$$

En ajoutant les temps de transit de l'amont vers l'aval des chenaux en fonction du modèle de drainage, on obtient pour chaque maille le temps de transfert à l'exutoire T donné par l'équation 23 :

$$T = \sum_{i=1}^n T_i[m(i)] \quad (23)$$

$m(1), m(2), \dots, m(i), \dots, m(n)$ étant les n mailles traversées entre la maille considérée $m(0)$ et la maille exutoire $m(n)$.

Appliquée à un bassin, la cartographie de ces valeurs permet d'obtenir des isochrones. L'histogramme de fréquences par classe de pas de temps Δt de ces valeurs esquisse la forme de l'hydrogramme géomorphologique impulsionnel (HGI) au même pas de temps du bassin (figure 3).

Nous avons donc dans le cadre de ce travail, appliqué la fonction de transfert morphologique au bassin versant de Débo en vue de comprendre la réponse hydrologique de celui-ci et d'étudier la sensibilité des différents HGI qui en découlent aux différents pas de temps de simulation.

3.2.2 SIMULATION DES TRANSFERTS D'EAU DANS LE BASSIN VERSANT DE DEBO SOUS FTM

L'essentiel des résultats de la simulation de la fonction de transfert morphologique (FTM) réside dans l'obtention d'un hydrogramme géomorphologique impulsif (HGI) à partir du calcul des paramètres hydrodynamiques liés au réseau hydrographique. Ces paramètres sont la largeur et la longueur du chenal et la dimension fractale du réseau hydrographique.

Généralement, l'hydrogramme géomorphologique impulsif est obtenu pour une résolution spatiale fixée (pas de référence) et pour une résolution temporelle (pas de temps). La variation des pas de référence et de temps permet d'obtenir des HGI simulés qui peuvent présenter un sensible étalement par rapport à l'hydrogramme des temps de transfert servant de référence. La résolution spatiale du MNT considérée dans cette étude étant fixe, seuls les pas de temps ont fait l'objet de variation ; ce qui nous permet d'obtenir les différents HGI simulés en fonction des différents scénarii de pluie efficace.

4 RESULTATS ET DISCUSSION

4.1 LES FICHIERS DES INDICES MORPHOLOGIQUES DU BASSIN VERSANT DE DEBO

Les fichiers obtenus sont : le fichier des longueurs intra-maillages (LON) exprimées en dm, le fichier des pentes du réseau (PER) exprimées en cm, le fichier des vitesses d'écoulement dans le bief (VIT) exprimées en mm.s^{-1} , le fichier des temps de transit intra-maillages (TRA) en secondes, le fichier des profondeurs du bief en mm (PRO), le fichier des largeurs des biefs en dm (LAR) et le fichier des volumes des biefs en m^3 (VOL). Les caractéristiques de tous ces fichiers sont consignées dans le tableau 1 suivant.

Ces différents fichiers donnent un ordre de grandeur des paramètres fractaux des différents biefs du réseau hydrographique. Ainsi la largeur maximale des biefs est de 25 m quand la longueur maximale est de 78 m. les profondeurs des biefs vont jusqu'à 1,7 m. les pentes réseau sont estimées à 14,1 % maximum et les vitesses de transit intra-maillages sont maximisées à $2,79 \text{ m.s}^{-1}$. Les temps de transit varient entre 92 s et 4884 s soit 1 h 21 min 24 s. A partir de ces valeurs les différents hydrogrammes géomorphologiques impulsifs simulés sont déduits en fonction des pas de temps fixés.

4.2 LES HYDROGRAMMES GEOMORPHOLOGIQUES SIMULES DU BASSIN VERSANT DE DEBO

Le pas de temps est défini en minute par défaut mais doit tenir compte de la résolution spatiale du MNT c'est-à-dire du pas de référence ; c'est du moins la démarche adoptée et recommandée par [2]. Le pas de référence du MNT (μ) ayant servi dans cette étude étant de 92,42 m ($50 \text{ m} < \mu < 100 \text{ m}$), le pas de temps par défaut choisi est donc de 20 minutes.

Les pas de temps de simulation sont : 5, 10, 18, 20, 25, 30, 45 et 60 minutes sous l'hypothèse d'une pluie uniforme sur toute l'étendue du bassin versant.

Ainsi pour ces différents pas de temps, les hydrogrammes géomorphologiques impulsifs simulés sont présentés à la figure 4.

Pour le pas de temps de référence $t = 20 \text{ min}$, l'analyse de l'hydrogramme géomorphologique impulsif (HGI) montre que la courbe de débits unitaires simulés s'ajuste à l'hydrogramme des fréquences des temps de transit intra-maille. Le débit de crue maximum est observé pour un temps de 31,33 heures soit 1 jour 7 h 19 min 48 s après le début de la pluie. Ce débit maximum spécifique de crue est de $3,394 \text{ m}^3.\text{s}^{-1}$ pour une pluie efficace uniforme de 1 mm.

Pour les pas de temps ($t = 5 \text{ min}$ et $t = 10 \text{ min}$) très inférieurs au pas de temps de référence ($t = 20 \text{ min}$), les courbes de débits ne s'ajustent pas avec l'histogramme des fréquences des temps de transit intra-maille. On note un étalement des hydrogrammes qui indique un retard à l'écoulement. De même pour les pas de temps très supérieurs à $t = 20 \text{ min}$ ($t = 30, 45$ et 60 min), on note ici aussi un décalage entre les hydrogrammes et l'histogramme des fréquences des temps de transit intra-maille. En revanche, lorsque les pas de temps restent très proches de $t = 20 \text{ min}$ ($t = 18 \text{ min}$ et $t = 25 \text{ min}$), les hydrogrammes tendent à s'ajuster à l'histogramme des fréquences. Ainsi, il semble que dans la fonction de transfert morphologique des quantités d'eau à l'exutoire du bassin versant de Débo, le pas de temps optimum de simulation (pas de temps générant un HGI ajusté sur les temps de transfert) est de $t = 20 \text{ min}$.

Le pas de temps optimum de simulation étant ainsi déterminé, il a été possible d'étudier la sensibilité du modèle face aux différents scénarii de pluie. Dans l'exemple ci-dessus, la simulation a été faite sous l'hypothèse d'une pluie uniforme de 1 mm sur toute l'étendue du bassin. Nous avons donc considéré des scénarii de pluie selon les différents gradients Est, Ouest, Nord et Sud. La figure 5 présente les HGI et les volumes cumulés en pourcentage par rapport à ces gradients de pluie.

L'analyse de la figure 5 montre que, seul l'hydrogramme géomorphologique impulsif sous hypothèse de pluie uniforme, s'ajuste à l'histogramme des fréquences des temps de transfert. Pour les autres scénarii de pluie, les HGI simulés ne s'ajustent pas à l'histogramme des fréquences des temps de transfert. Toutefois pour les pluies selon les gradients Ouest et Nord, on note un retard à l'écoulement bien que les débits spécifiques de crue maximale soit élevés ($3,465 \text{ m}^3 \cdot \text{s}^{-1}$ pour le gradient Nord et $3,606 \text{ m}^3 \cdot \text{s}^{-1}$ pour le gradient Ouest contre $3,394 \text{ m}^3 \cdot \text{s}^{-1}$ pour la pluie uniforme). Par contre pour les gradients Est et Sud, on note que les écoulements sont plus rapides et les débits de crue élevés ($3,401 \text{ m}^3 \cdot \text{s}^{-1}$ pour le gradient Est et $3,695 \text{ m}^3 \cdot \text{s}^{-1}$ pour le gradient Sud). L'explication de cet état de fait réside dans la disposition naturelle du réseau hydrographique dans le bassin versant de Débo, qui est principalement orienté vers le Sud et vers l'Est. Ainsi selon ces gradients, les eaux pluviales sont plus importantes et plus rapidement drainées par le réseau hydrographique. Pour le gradient Nord, le retard à l'écoulement s'explique par le fait que le sens des précipitations est contraire à la direction naturelle Sud du réseau hydrographique.

L'évolution des volumes écoulés épouse également l'évolution des HGI et permet de confirmer l'explication donnée ci-dessus à ce phénomène. Ainsi on remarque un étalement des courbes de volumes cumulés pour les gradients Ouest et Nord qui explique ce retard à l'écoulement. Pour les gradients Sud et Est, on note au contraire une accumulation rapide des volumes écoulés qui met en évidence la rapidité de l'écoulement selon ces gradients.

Sous l'hypothèse de pluie uniforme, les courbes de volumes cumulés ont été représentées pour expliquer la sensibilité du modèle aux différents pas de temps (figure 6).

L'analyse de la figure 6 montre que, pour les pas de temps différents du pas de temps de référence ($t = 20 \text{ min}$), les courbes de volumes cumulés en pourcentage ne se superposent pas à la courbe de référence (courbe de $t = 20 \text{ min}$ en orange). Au contraire, on constate un étalement de ces courbes pour les pas de temps t ($t = 5, 10, 25$ et 30 min). On note cependant que lorsque le pas de temps est très proche ($t = 18 \text{ min}$) du pas de temps de référence, les courbes de volumes cumulés restent sensiblement proches.

En conclusion, le pas de temps optimum de simulation des transferts d'eau générant un HGI ajusté aux temps de transfert est donc de 20 minutes.

4.3 REPONSE HYDROLOGIQUE DU BASSIN VERSANT DE DEBO A UN SCENARIO DE PLUIE EFFICACE

A partir de l'hydrogramme géomorphologique impulsif (HGI) simulé au pas de temps optimum ($t = 20 \text{ min}$) ajusté à l'histogramme des fréquences des temps de transfert sous l'hypothèse d'une pluie uniforme de 1 mm, il est possible de voir ce que serait la réponse hydrologique du bassin versant pour des scénarii de pluie supérieure à 1 mm. Dans le cadre de cette étude la réponse hydrologique du bassin versant de Débo sous la forme d'un hydrogramme de crue impulsif a été étudiée pour des scénarii différents de pluie brute. Les différents scénarii de pluie brute initiale simulée sont de 10 mm, 20 mm, 78,54 mm et 188,08 mm correspondant à des lames précipitées de 73 mm, 100 mm, 200 mm et 1446,74 mm. Les caractéristiques des différentes réponses hydrologiques du bassin versant de Débo en fonction des scénarii de pluie sus-indiqués sont regroupées dans le tableau 2.

L'analyse du tableau révèle que les débits maxima de crue varient en fonction des lames d'eau écoulées. En effet pour une lame d'eau écoulée de 13 mm, le débit maximum de crue simulé est de $43,789 \text{ m}^3 \cdot \text{s}^{-1}$ alors qu'il est de $634,111 \text{ m}^3 \cdot \text{s}^{-1}$ pour une lame d'eau écoulée égale à 188,08 mm. On remarque que les temps de montée (temps correspondant à l'apparition de crue maximale) sont sensiblement identiques et varient entre 1920 et 2000 minutes (32 h et 33 h 20 min). Les volumes écoulés évoluent dans un ordre de grandeur de 10^6 m^3 à 10^8 m^3 . Les volumes écoulés les plus importants s'observent pour une lame écoulée de 188,08 mm, un temps de montée 33 h 20 min et s'évaluent à $1,06 \cdot 10^8 \text{ m}^3$. Les plus faibles volumes écoulés correspondent à une lame écoulée de 13 mm et sont estimés à $7,35 \cdot 10^8 \text{ m}^3$ pour un temps de montée égale à 32 h 40 min.

Ces caractéristiques sont mieux explicitées par les hydrogrammes de crue impulsifs qui matérialisent la réponse hydrologique du bassin versant de Débo en fonction des différents scénarii de pluie. Cette réponse est présentée à la figure 7.

Il ressort de l'analyse des hydrogrammes de crue impulsionnels plusieurs constats. Pour une même lame précipitée, la réponse hydrologique varie en fonction du volume écoulé. Plus les lames écoulées sont importantes, plus les débits le deviennent aussi. Pour une lame précipitée de 73 mm, les débits varient selon le taux d'écoulement. En effet pour un taux d'écoulement de 70,14 % (soit une lame écoulée de 51,2 mm), le débit de crue simulé est de $172,654 \text{ m}^3 \cdot \text{s}^{-1}$ alors que pour un taux d'écoulement légèrement supérieur de 72,53 % (soit une lame écoulée de 52,95 mm), le débit de crue simulé est de $178,517 \text{ m}^3 \cdot \text{s}^{-1}$. De même pour une lame précipitée de 200 mm et un taux d'écoulement de 13 % (26 mm d'eau écoulée) on obtient un débit de crue de $87,578 \text{ m}^3 \cdot \text{s}^{-1}$ alors que pour un taux d'écoulement de 24,10 % (une lame écoulée de 48,20 mm), le débit de crue est estimé à $162,518 \text{ m}^3 \cdot \text{s}^{-1}$. Le débit de crue le plus élevé est observé pour une lame précipitée de 1446,74 mm correspondant à la moyenne des précipitations dans la région de Soubré. Pour cette lame précipitée, les résultats du bilan hydrologique de la région ont estimé le taux d'écoulement à 13 % soit une lame écoulée de 188,08 mm. Ainsi, pour cette lame écoulée, le débit de crue est maximum et s'évalue à $634,111 \text{ m}^3 \cdot \text{s}^{-1}$. Les volumes d'eau mobilisés aussi varient selon les lames écoulées. En effet, plus la lame écoulée est importante, plus le volume mobilisé est important et que les débits de crue sont élevés.

4.4 DISCUSSION

La simulation des transferts d'eau sous le module FTM a permis de déterminer les caractéristiques fractales du réseau hydrographique du bassin versant de Débo tels que la largeur maximale, la longueur maximale, les profondeurs des biefs, les pentes réseau, les vitesses de transit et les temps de transit intra-maillages. A partir de ces valeurs, les différents hydrogrammes géomorphologiques impulsionnels simulés ont été déduits en fonction des pas de temps fixés. Le pas de temps est défini en minute par défaut ($t = 20$ minutes) et tient compte de la résolution spatiale du MNT selon les recommandations de [2].

L'analyse de l'hydrogramme géomorphologique impulsionnel (HGI) pour le pas de temps de référence $t = 20$ minutes, montre que la courbe de débits unitaires simulés s'ajuste à l'histogramme des fréquences des temps de transit intra-maillages. Le débit maximum de crue est observé pour un temps de montée de 31,33 heures est de $3,394 \text{ m}^3 \cdot \text{s}^{-1}$ pour une pluie efficace uniforme de 1 mm. Les hydrogrammes ne s'ajustent pas à l'histogramme des fréquences des temps de transit pour les pas de temps inférieurs ou supérieurs à $t = 20$ minutes. Ainsi, il semble que dans la fonction de transfert morphologique des quantités d'eau à l'exutoire du bassin versant de Débo, le pas de temps optimum de simulation (pas de temps générant un HGI ajusté sur les temps de transfert) est de $t = 20$ minutes [2]. La sensibilité du modèle étudiée à partir de ce temps optimum de simulation en fonction des différents scénarii de pluie selon les directions ou gradients Est, Ouest, Nord et Sud, montre que, seule la pluie uniforme donne des HGI qui s'ajustent à l'histogramme des fréquences des temps de transit. Néanmoins, les débits maxima de crue s'observent pour une pluie simulée selon le gradient Sud. Ce fait tire son explication dans l'orientation vers le Sud du réseau hydrographique et surtout de l'orientation des altitudes vers le Sud.

L'analyse de la réponse hydrologique du bassin versant de Débo sous la forme d'un hydrogramme de crue impulsionnel pour des scénarii différents de pluie brute initiale (10 mm, 20 mm, 78,54 mm et 188,08 mm correspondant à des lames précipitées de 73 mm, 100 mm, 200 mm et 1446,74 mm), révèle que les débits maxima de crue varient en fonction des lames d'eau écoulées. Pour une même lame précipitée, la réponse hydrologique varie en fonction du volume écoulé. Plus les lames écoulées sont importantes, plus les débits le deviennent. Les volumes d'eau mobilisés aussi varient selon les lames écoulées. En effet, plus la lame écoulée est importante, plus le volume mobilisé est important et que les débits de crue sont élevés. Pour une lame écoulée de 188,08 mm, on observe un débit maximum de $634,111 \text{ m}^3 \cdot \text{s}^{-1}$. Le pas de temps de simulation des transferts ainsi que la dimension fractale du réseau pourraient donc jouer un rôle prépondérant dans l'explication des valeurs élevées des débits de crue obtenus avec la fonction de transfert morphologique (FTM). C'est le constat fait par [7] dans le bassin de Yewa au Nigeria. En effet, on a montré que lorsque le pas de simulation est faible, les débits maxima simulés obtenus sont très faibles.

En conclusion, tous ces résultats montrent le potentiel du logiciel DEMIURGE en simulation et en prévision hydrologique et surtout en aménagement. La plupart des travaux exploitent le module TOPASE (Topographie appliquée à la simulation des écoulements). En effet ce logiciel a été appliqué dans le bassin du Bras-David en Guadeloupe par [4]. Il a été appliqué avec succès dans le Centre de la Tunisie pour la détermination des caractéristiques morphologiques, hydrologiques et hydrodynamiques du bassin de Merguellig par [5]. Il a été appliqué aussi sur le bassin de la Doure au Nord de l'Espagne dans le cadre de la détermination des caractéristiques morphologiques et hydrologiques par [10]. Son grand avantage est sa mise en œuvre facile.

Il faut néanmoins souligner que, malgré tous ses mérites et sa remarquable contribution à l'étude des modèles numériques de terrain (MNT), le logiciel présente quelques insuffisances dans son application. La question de l'échelle de

travail est importante. De plus, la r solution du MNT, autrement dit la taille des mailles, diminue la fiabilit  de certains r sultats ou rend l' tude de certains bassins versants difficile voire impossible. Cette r solution peut influencer le calcul des longueurs et rendre les mesures des distances fausses, comme la distance   l'exutoire par exemple. Ces distances sont donc   utiliser avec prudence, mais elles peuvent toutefois  tre utilis es   titre de comparaison entre plusieurs bassins versants.

5 TABLEAUX ET FIGURES

5.1 TABLEAUX

Tableau 1. *Caract ristiques des fichiers hydrodynamiques du bassin versant de D bo calcul s sous FTM*

	Fichiers					
	LAR en m	LON en m	PRO en m	PER en %	TRA en s	VIT en m.s ⁻¹
Valeur minimale	0	22,4	0,156	0,03	92	0,091
Valeur maximale	25	78	1,696	14,1	4884	2,79

Tableau 2. *Caract ristiques des r ponses hydrologiques du bassin versant de D bo en fonction des diff rents sc narii de pluie*

N� de simulation	Pluie brute initiale en mm	Lame totale pr�cipit�e en mm	% �coul�	Lame �coul�e en mm	Temps de mont�e en min	D�bit max. de crue en m ³ .s ⁻¹	Volume pr�cipit� en m ³	Volume �coul� en m ³
1	1	1	100	1	1860	3,390	5,65.10 ⁶	5,65.10 ⁶
2	10	73	70,14	51,2	1980	172,654	4,13.10 ⁷	2,89.10 ⁷
3	10	73	72,53	52,95	1980	178,517	4,13.10 ⁷	2,99.10 ⁷
4	10	100	13	13	1960	43,789	5,65.10 ⁷	7,35.10 ⁶
5	20	200	24,1	48,2	1920	162,518	1,13.10 ⁸	2,73.10 ⁷
6	20	200	13	26	1960	87,578	1,13.10 ⁸	1,47.10 ⁷
7	78,54	1446,74	13	188,08	2000	634,111	8,18.10 ⁸	1,06.10 ⁸

5.2 FIGURES

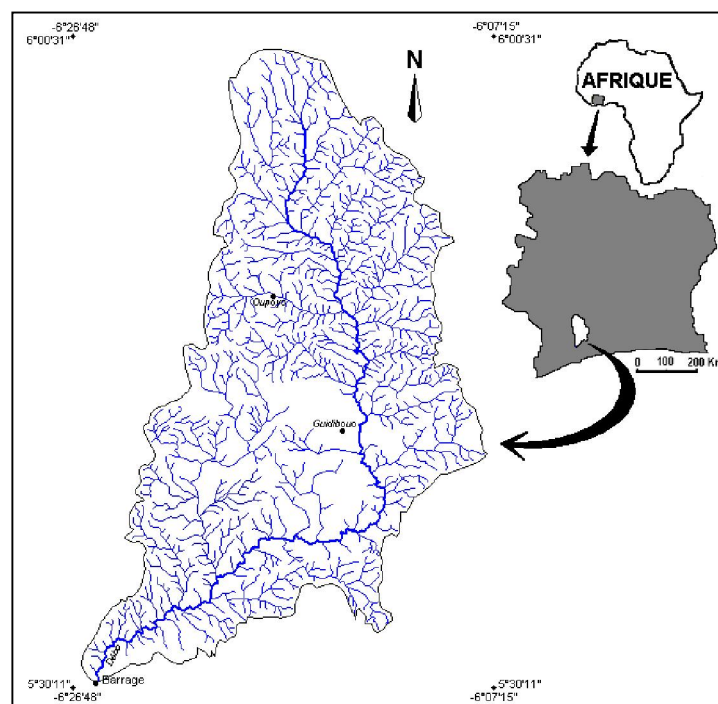


Fig. 1. *Pr sentation et localisation du bassin versant de D bo*

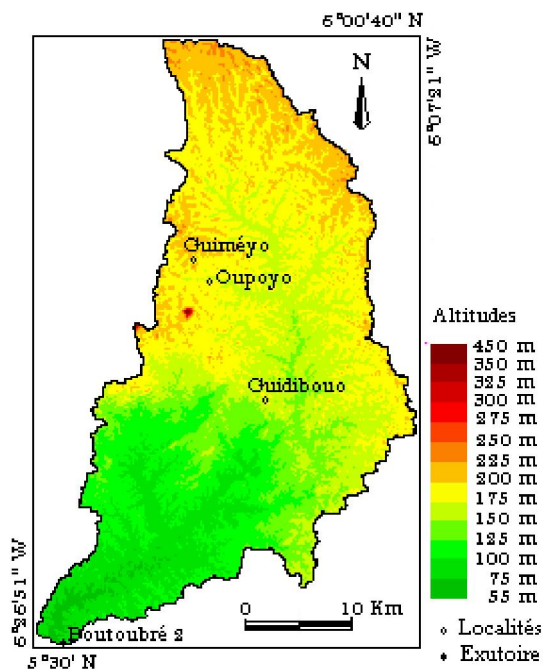


Fig. 2. Modèle numérique d'altitude (MNA) du bassin versant de Débo

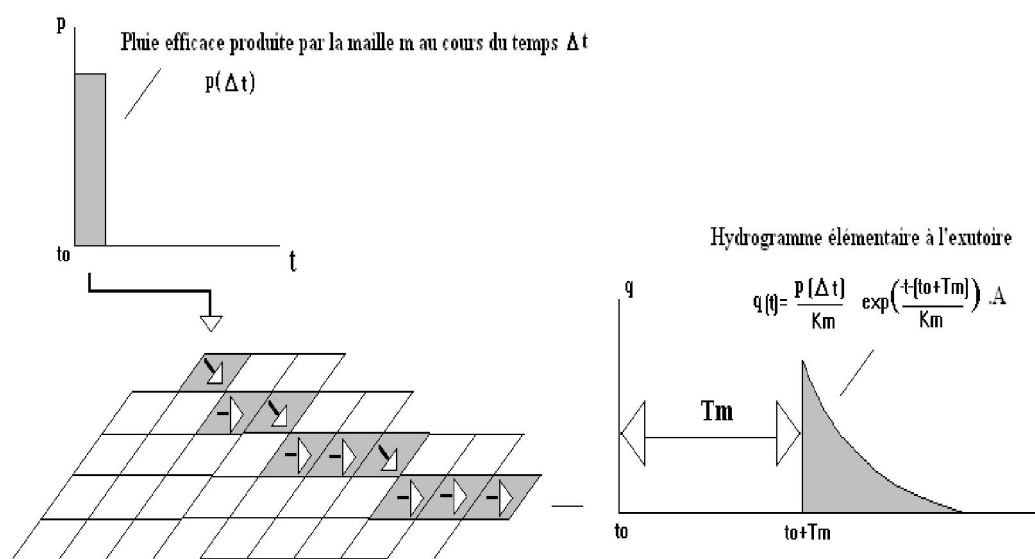


Fig. 3. Principe d'obtention de l'HGI [6]

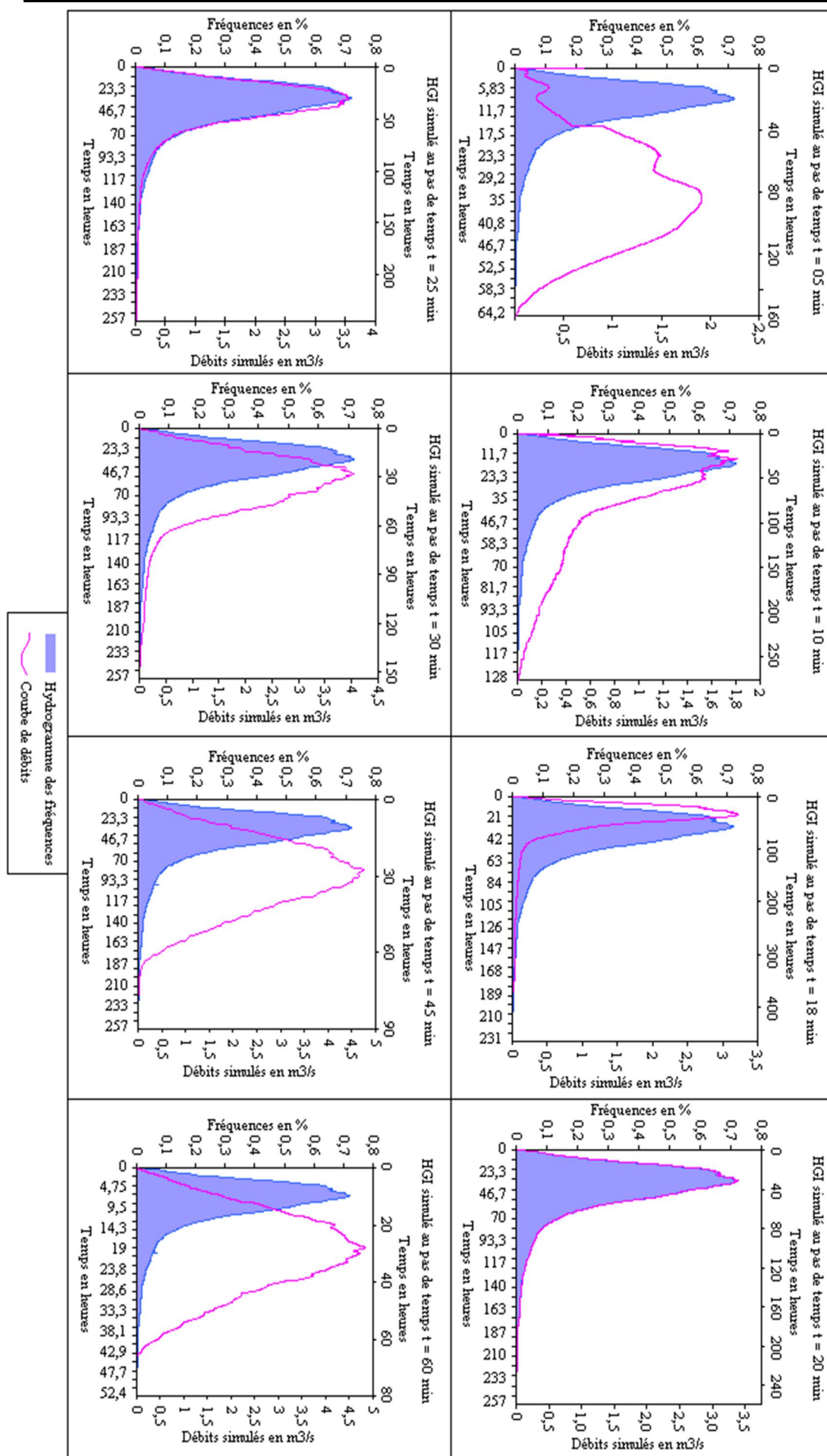


Fig. 4. Hydrogrammes géomorphologiques impulsifs simulés aux différents pas de temps t ($t = 5, 10, 18, 20, 25, 30, 45$ et 60 min)

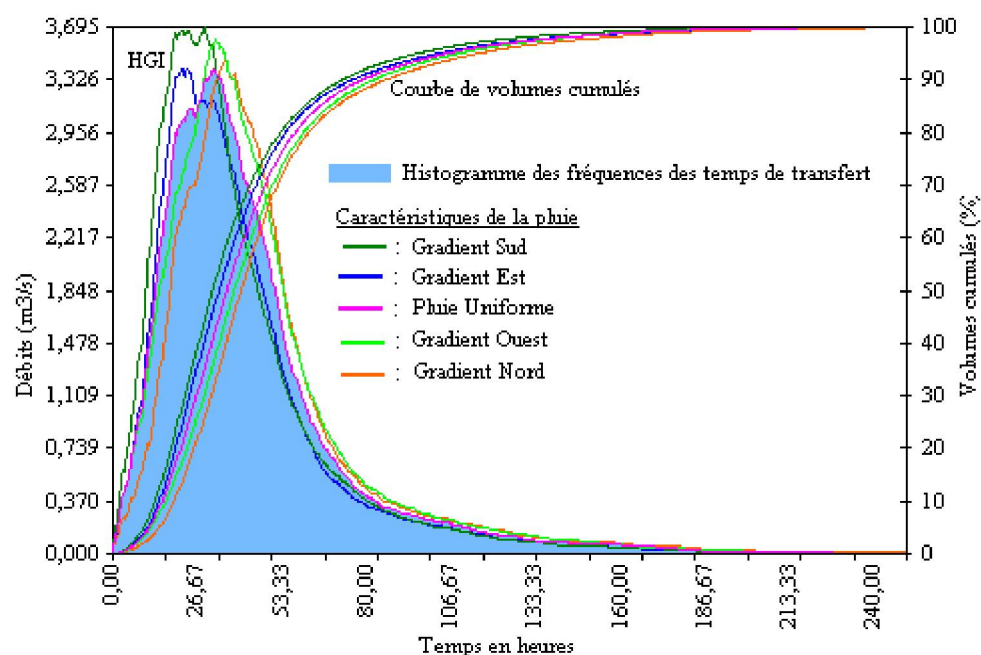


Fig. 5. HGI et courbes de volumes cumulés selon les différents gradients de pluie

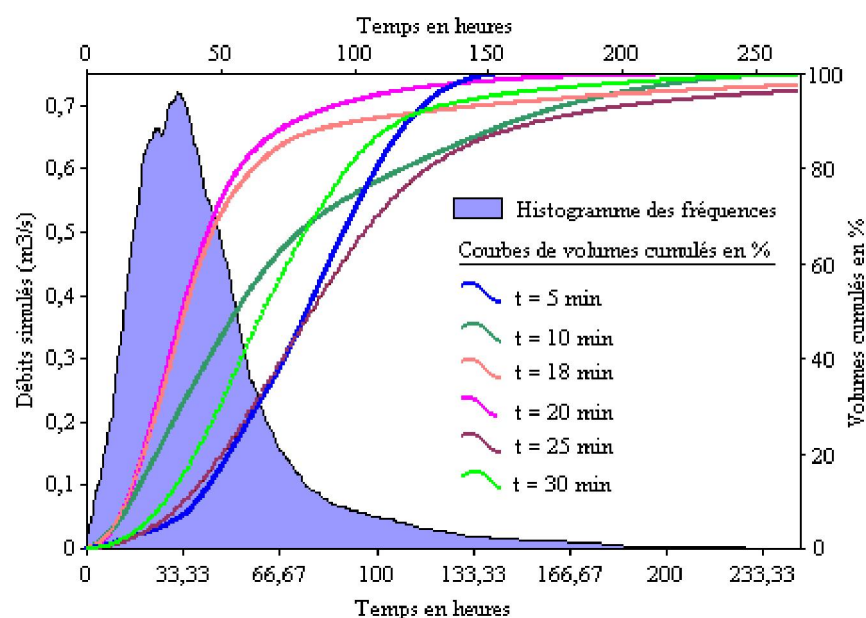


Fig. 6. Evolution des courbes de volumes cumulés aux différents pas de temps

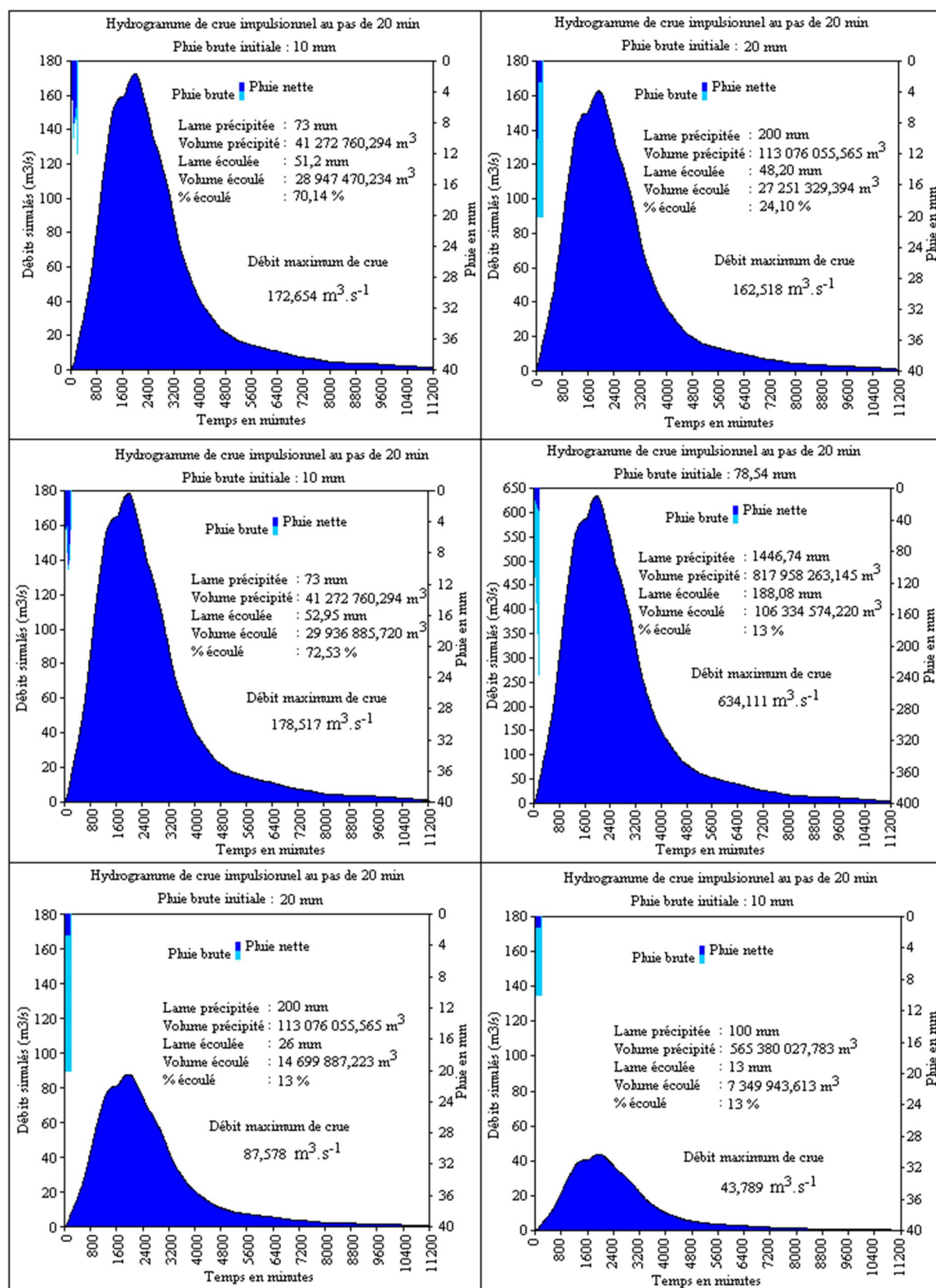


Fig. 7. Hydrogrammes de crue impulsionnelle du bassin versant de Débo au pas de temps $t = 20$ min en fonction des scénarii de pluie brute et nette

6 CONCLUSION

La fonction de transfert morphologique (FTM) a permis de simuler les transferts d'eau dans les différents chenaux associés aux réseaux hydrographiques des bassins versants de Débo à partir des seules informations issues du MNA. Ainsi les débits maxima de crue et les volumes mobilisés ont été estimés. Tous ces résultats permettent de rendre compte du fonctionnement de l'hydrosystème de Débo et de comprendre sa réaction face aux phénomènes de variabilité et de changements climatiques. Cette étude permet de mettre en évidence l'utilité du logiciel DEMIURGE et en particulier la fonction de transfert morphologique dans la prévision des crues et l'aménagement du territoire.

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