International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 19 No. 1 Jan. 2017, pp. 242-251

http://www.ijias.issr-journals.org/

Geomorphological analysis and estimating the water potential in the region of Sahel Doukkala (Morocco)

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ABSTRACT: The use of water resources is steadily increasing with respect to the population growth. This theory also applies in the Kingdom of Morocco specifically in the Sahel-Doukkala region and therefore requires special attention as the water resources are in limited quantity. For industrial, agricultural and domestic reasons, aquifers of this region are subjected to excessive pumping, resulting in environmental harms such as declining groundwater level, which considerably affects both its quality and quantity. The agency of Oued Oum Er R'bia watershed has therefore established a number of strategies for a proper management of those aquifers among which an artificial aquifer recharge to reduce this imbalance; preventing irreversible degradation. This paper is thus devoted to explore solutions that can help characterizing components of the hydrological system of the region in order to determine the potential areas of surface water for its possible remobilization. With an area of 7700 Km^2, the semi-arid characteristics and the endoreism at certain location of the region, the geomorphological analysis from digital elevation model (DEM) and the modified equation of Beven-Kirkby index allowed us to locate useful wet and hydromorphic soils from their physical properties revealing remarkable traces of a regular water saturation.

KEYWORDS: Digital elevation model (DEM), wetness index, semi-arid, endoreism, sustainable management.

1 INTRODUCTION

Morocco's hydrological context is mainly influenced by an annual irregularity and a considerable variability in rainfall with a spatial disparity.

At first, we noticed that the total precipitation is mainly concentrated in autumn and winter, spreads over four months (November to February) with raining days ranging from 20 to 70 from south to north. There is an important disparity in the concentration of rainfall across regions in the entire country. In the North, wetter, we can record up to 2000 mm against 100 mm in the South [1]. This uneven distribution is mainly associated with the respective geographical position [2].

Secondly, the population growth in this region (Sahel Doukkala) has yield an excessive exploitation of the aquifer for industrial, agricultural and domestic needs. This situation makes the management of water resources very complex as studies have shown vulnerability of this groundwater in various regions [3], [4], [5], [6], [7], [8], [9], [10].

These two combined effects have the gift to accentuate problems related to water resources, making its management more complex [11]. Indeed, for industrial, agricultural and domestic consumption needs; underground water are subjected to excessive pumping causing environmental harm such as declining groundwater level followed by groundwater damage from quantitative and qualitative perspective.

Knowing that it is first necessary to have the resource to manage it, we decided to quantify the potentiality of water in the region in order to contribute to the planning of a sustainable management model.

2 BACKGROUND

2.1 DESCRIPTION OF STUDY AREA

Sahel Doukkala is located downstream the Oued Oum Er R'Bia watershed along the north and northeast boundaries. This is a coastal region located between latitudes 32 ° 15' and 33 ° 15' north and longitudes 8° and 9°15' covering an area of 7700 Km^2 with about 150 km of coastline. Southern Sahel Doukkala occupies a fragmented relief and underlines the base of the hills of Mouissate and the Rehamna primary massif (Figure 1). The region is divided in two parts; the first part is the eastern zone represented by Doukkala and the second, Sahel in close proximity to Atlantic Ocean.

The Sahel is an area, in which the prevalence by regular chain of dunes covers the inter-dunes, in which accumulate the meteoric waters. These hilltops completely covered by loamy and sandy soils follow each other, covering long distances giving them the appearance of Appalachians Mountains. [12].

And secondly the Doukkala; this concerns a loamy soils and large region on a sloping ground (2-3%), facing south-east to north-west with the altitude decreasing from 300 m along the Rehamna to 120 m at the Sahel Boundary. The hydrography of this region is typically influenced by variety depressions, in which surface waters often get lost forming endorheic basins.

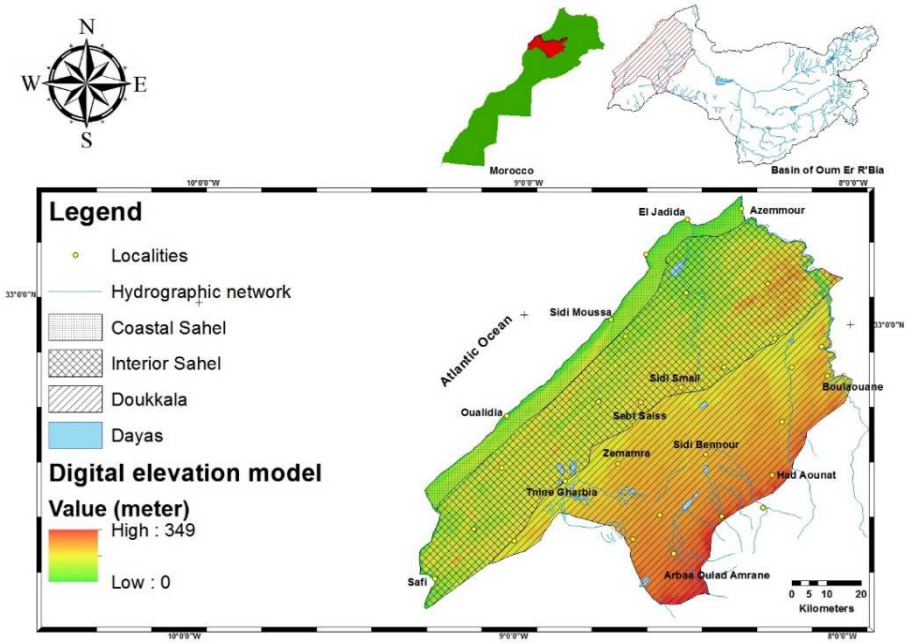

Fig. 1. ***Presentation of study area***

HYDROGEOMORPHOLOGY CONTEXT

Very close to the ocean, its relief is almost negligible as regards the possible influence on the climate. Temperatures are moderate in areas near the ocean, and more contrasting inside from the classification of Morocco climates G. Debrach (1953), based on the temperature [13], [14]. Thus, the climate in the Sahel is moderate, while the plain Doukkala would be placed in the hot climate semicontinental characteristic of Morocco to the north of the Atlas.

Overall, the dune morphology is regular: the peaks are followed over long distances with the same SSW-NNE orientation, separated by depressions, filled with very sandy loams.

The hydrographic network includes two main wadis. It is much more developed in the Doukkala's plateaus (upstream) to the Sahel as well as evaporation values also decrease from upstream to downstream [13].

2.2 GEOLOGICAL CONTEXT

The geological context is well known. Indeed, the Sahel Doukkala belongs to the Mesata geological unit. It includes a tabular regime of secondary and tertiary deposits rests on Paleozoic formations highly folder by the effects of Hercynian orogeny. The Paleozoic basement consists mainly of shale and quartzite, appears to the northeast and east Doukkala, including in the Oum Er R'Bia valley. It should be furthermore noted that it is hidden by posterior deposits with the exception Cambrian outcroppings in El Jadida [15], [16], [17]

Data from studies that have been conducted enabled us to establish a simplified outline of the geology of the area (figure 2).

- The Permo-Triassic appears in Oum Er R'Bia valley in the form of clay deposits and red pelites with the basaltic flows. These formations are found together with carboniferous red conglomerates in M'Tal.
- Jurassic is only present in south of Doukkala however it crops out to constitute the Mouissate hills.
- Cretaceous extremely important and represents the bedrock almost continuous of Plio-Quaternary aquifer of Doukkala. Furthermore, some calcareous levels contain the most interesting concentration of groundwater in Sahel
- Lastly, a Neocomian transgression without interruption with Jurassic transgression extended much further north and east.

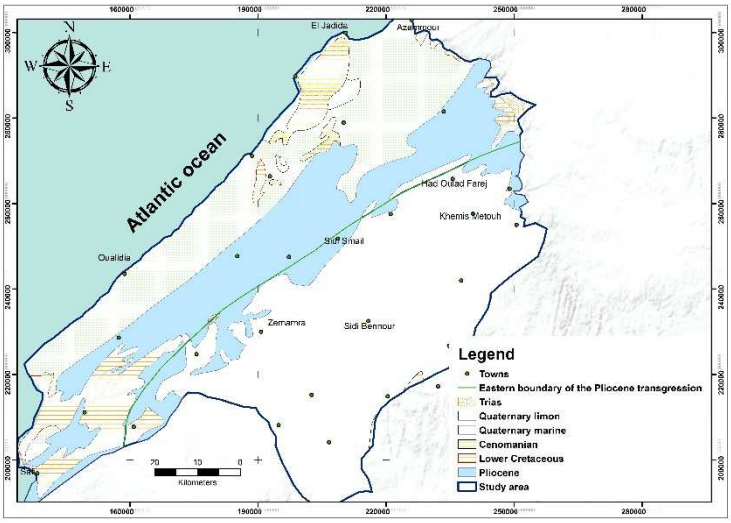

Fig. 2. ***Geological overview of the Sahel-Doukkala Elaborated from data of "carte géologique du Maroc 1982"***

2.3 MORPHOLOGICAL CONTEXT

This is mainly composed of three elements:

- The plateaus: they have less regular topography and represent remains of the filling surface by lower clayey silt, with a thin layer (1 to 2 m) of recent silt. We also notify the presence of red clay heavily encrusted and banks whose origin could be related the tectonic or river.
- The valleys: they represent the water system basement, with bright and dead thalwegs constituting endorheic basins.
- Relief dune: Far from being a uniform area, we mainly found in the Sahel a series of high dunes similar to the Appalachians regions. In general, dune morphology is regular with hilltops following each other over a long distance with the same orientations separated by depressions between dunes filled up by sandy silt.

In addition to the previous morphological elements, we can also add significant amount of karst phenomena known for its influence in the surface and subsurface influx. They appear in the morphology, along the boundary between Sahel and Doukkala areas. The silty mantle forms a thick layer on top of limestone and gypsum formations allowing karsts development within plains [18], [10].

3 MATERIEL AND METHOD

3.1 PRESENTATION OF DEM

Sahel Doukkala area has a geomorphological diversity. We used digital elevation model (DEM) at the experimental scale in order to reproduce correctly the landscape features. DEM is a very useful tool, it was then used at various occasions in many previous works [19], [20], [21], [22], [23], [24], [25], [26]; enabling us to perform the followings:

- Extraction of field parameters
- Drawings of topographic profiles
- Modeling and prediction of water flow

3.2 ANALYTICAL METHOD

No previous work was dedicated to the quantitative analysis of hydric potential in Sahel Doukkala. We may find in old works ; representations based on investigations on neighbor domains [27], [28]. It is during the geophysical or topographic prospection that we report confidentially the neighborhood of the terrain.

On the other hand, considering new technologies, satellite's images bring elements capable of drawing up a map of an entire area. Disadvantage of this methods remains on its cost; satellite's images are too expensive and we may misinterpret results according to the season.

Indeed, a picture in summer in an arid or semi-arid region may lead to underestimation of a daya to a temporary pond.

Therefore, in view of all these parameters, and because of the stability of topography, we relied on the DEM of 30 meters of resolution to determine high potential zones of water.

The morphological structure affects the hydrological system by interacting with their physical characteristics [28], [20]. Indeed, resultants of altitudes gradient and dunes landscape can infer possible presence of dayas that may contain water (in the low area between the dunes) [18].

But this is not sufficient, due to the large surface area hence less precise; it may be a river, wadi, hydromorphic soil rich in clay or simply moist soil [30].

Like many ecosystems, these are particular environments. They are characterized by their complexity, changing conditions, and uncertainty. They play a significant role in ensuring an environmental safety but also a sustainable development of areas [31], [32]. ArcGIS was used to determine wetness topographical index by Beven-Kirkby method [33], [34]. It is a mathematical expression showing the capacity of soils to accumulate water.

$$\mathbf{ln} = \left[\frac{(\mathbf{a}+\mathbf{1}).\mathbf{p}}{\boldsymbol{tanb}}\right] \quad (\mathbf{1})$$

Where:

- b : Local slope (radian)
- a : Specific area (Km^2)
- p : Pixels surface (depending of DEM, and projection)

4 RESULTS AND DISCUSSION

Modeling was performed in several steps

4.1 SLOPE AND ORIENTATION

A Full range of conditions was identified from which are observed the spatial slopes distribution including their orientations (Figures 3)

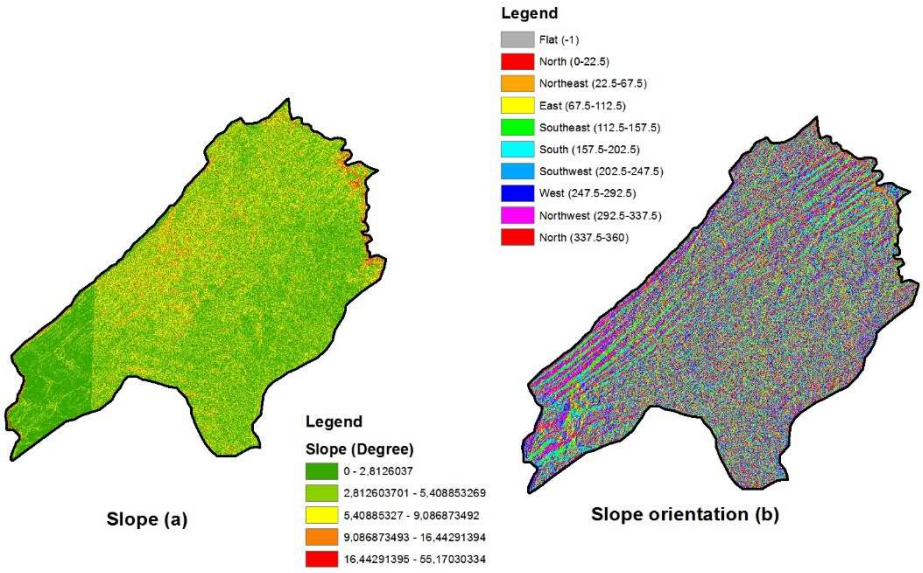

Fig. 3. ***Representative slope map of Sahel-Doukkala (a) and orientations of slopes (b)***

Calculation of upslope area depends on the way the accumulated area of upstream cells is routed to downstream cells. Traditionally, the area from a cell has been transferred in the steepest downslope direction to one of the eight neighbouring cells. Quinn et al. (1991) [23] introduced a multidirectional flow algorithm that allowed the area from one cell to be distributed among all neighbouring downslope cells, weighted according to the respective slopes

The (figure 3.a) above represents an average slope of 4 ° with a variation from 0 to 56 degrees. The higher slopes are indeed mainly situated in the North, especially in Oum Er R'Bia valley but also between Oualidia and Sidi Moussa located on the coast (Sahel). Towards the South, slopes values are less than the average. Understanding the channel head location is useful in understanding the associated geomorphology as well as the various components of catchments hydrological response [35].

We also see a rather peculiar slope orientation, parallel between them, but also in the littoral. This is the dune terrain located in particular in the Sahel and can present a barrier.

The first idea is that the cord interdunal accumulate more water. The idea would be to find these points of moisture brands.

We can say that this is a series of anticlines and synclines reputed on one side, by the quality of underground reservoir, and on the other side by the ridgelines determining the path of the meteorological waters.

This antagonist gives this region an endorheic character and thus constitutes a barrier surface sewage.

4.2 DETERMINING THE FLOW DIRECTION

Specific area is the surface onto which water flows on the soil. It consists of either simple or multiple flow under the Jensen, Domingo approach (1988) [36], [37] ; which is determined in two steps: the flow direction first and then the flow accumulation method.

The direction of flow is one of the key aspects responsible of the derivation of hydrological features of each raster pixel surface. Nevertheless, flow accumulation allows the calculation of accumulated flow in the form of cumulated average of all pixels moving through each pixel in downslope raster depending on direction code.

We should nevertheless clarify that the water system is temporary and that only the Oum er R'Bia River flows to the ocean.

Using this equation (1), we obtained the following results

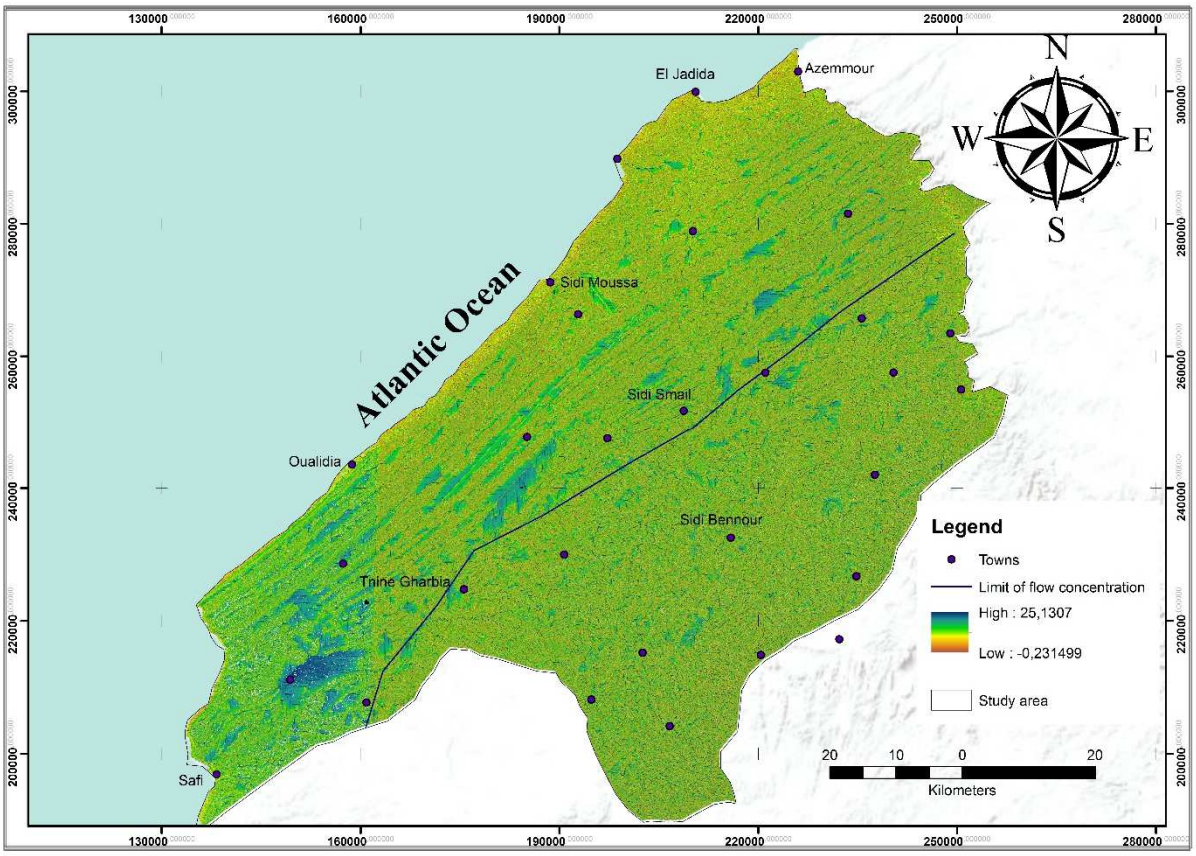

Fig. 4. ***Topographic wetness index map of Sahel Doukkala***

The index value varied from 0 to 25.13; with an average of 7.23 reflecting a low drainage coefficient.

4.3 DISCUSSION

The first observation is consistent with previous studies notifying the lack of permanent watercourses from which was derived the following hypothesis:

- Existence of karst system
- High permeability of the soil
- Higher evaporation compared to the water supplies

Secondly, the index spatial distribution reveals a low water points in average across the area of study (7.23) and a standard deviation of 3.93 synonyms of large disparity. It arises primarily from non-uniform nature of the field; alternating the active and passive thalwegs present in the area.

Thirdly, zones with high indices are most of the time beyond the Pliocene transgression boundary (downstream). The dune system of Sahel is endowed with several points with high index values depending on the spaces between the dunes.

These areas indicate the presence of water at least marked by a rain period. It may also consist of moist and hydromorphic soils in some areas with physical marks of regular water saturation due to the low altitude (low slope), its proximity with rivers, specific vegetation (reeds) revealing the presence of clay and spots synonyms of anoxia in damp weather [38].

4.4 ESTIMATION OF THE EXPLOITABLE POTENTIAL

It was based on two field trip in period of high water and low water for two consecutive years (2014 and 2015) in order to perform a checking test. The aim is to identify wetlands before determining the threshold coefficient.

In order to appreciate the importance of these fields, we proceeded to the quantification of zones with high index ; greater than or equal to 10 because of the much lower average.

After screening, we obtained 54 zones with varied surfaces; an average of 10.49 km^2 and two zones beyond 50 km^2 (figure 5).

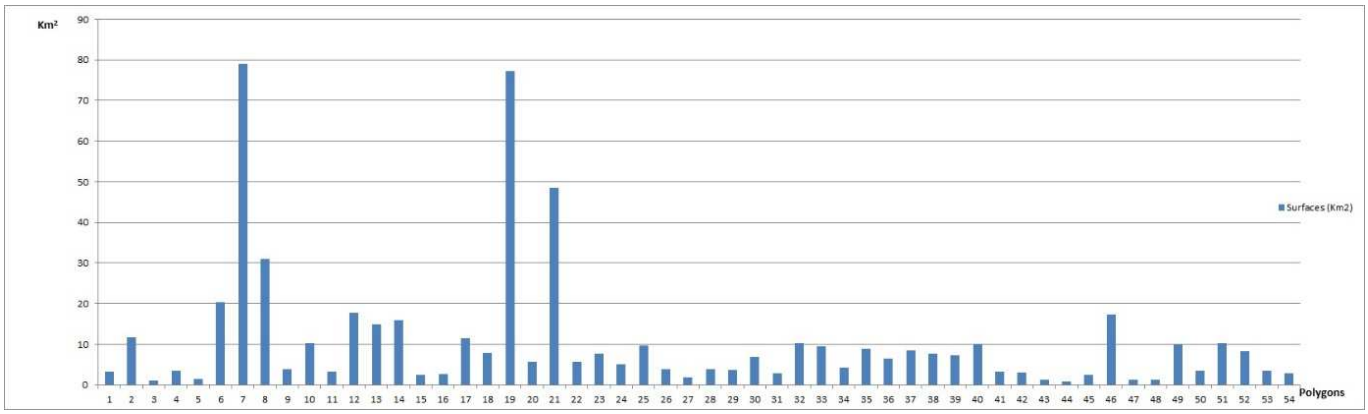

Fig. 5. ***Evaluation of surfaces with high index***

The estimation of accumulated surfaces are up to 567 km^2. They allowed us to review the situation because they represent 7.36 % of the region, which is not completely unimportant knowing the average rainfall of the region (350 mm).

These zones do not correspond to the irrigated areas which are situated upstream. When considering a perfect rain (according to the raindrop distribution) on the whole region, we obtain the following table (Tableau 1).

	Surface (Km^2)	Percentage	Volume (m^3)	Debit (m^3/s)
Total surface	567	1	198282770	6,283
>10 Km^2	386,14	0,68	135148057	4,283
< 10 Km^2	180,38	0,32	63134713.25	2

Due to their physical characteristics, these zones have potential porosity and can therefore store water in a large quantity, in varying proportions depending on the annual rainfall, possible topographic variations and by the various anthropic activities.

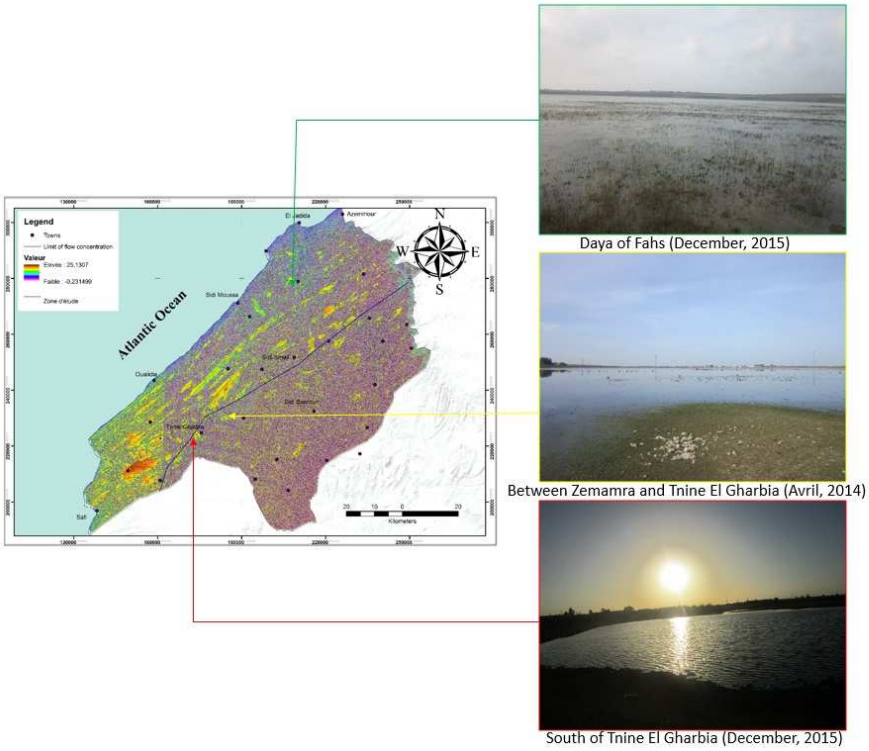

Fig. 6. ***Overview of wetlands in Sahel Doukkala***

5 CONCLUSION

In conclusion, the Sahel - Doukkala is a semi-arid region with varied topography and slight dominance of altitudes between 0 to 64 meters

It plays a key part in the hydrological system and consequently hydrogeologic system. We noticed that the climate and the successive dunes contribute to the weak drainage capacity of the region despite the presence of the Oued Oum Er R' Bia in the North [40].

The topographic wetness index has allowed us to notify the apparent difference between Doukkala upstream in which we find wadis (the system of intermittent streams) in diffuse flow and the Sahel located downstream and characterized by dune relief acting as a natural dam in flows.

The depressions, often endorheic suggests that waters undergo two effects; the infiltration and evaporation. We find several major dayas in Sahel, beyond the limit of transgression of the Pliocene which informs us about the soil characteristics; essentially hydromorphic, and rich in clay bands in some places approaching the Atlantic Ocean. According to this distribution, one can refer to vertical infiltration and hence the presence of unsaturated zone in groundwater (the space to be filled), for a possible recharge.

This method constitutes a decision-making support and in this way, we will proceed by the implementation of:

- Scenarios near potential places (Sahel) so as to mitigate the problems of logistics
- Infiltration basin, rather than inject through drilling.

Groundwater evaluation aimed at maintaining sustainable use constitutes a challenge in applied hydrology, in particular in drylands where this resource is crucial to socioeconomic development and, in some cases, for human survival [41]

The geographical information system tools (DEM) played a significant role in this study to the extent that it has allowed us to target areas which have the potential water resources for remobilization. Furthermore, it reduces logistical costs, pollution and the operating time.

ACKNOWLEDGMENT

This study is funded by the Basin Agency of Oum Er R'bia, the Natural Resources Research Unit Environment and Health (RNES), Sultan Moulay Slimane University, Faculty of Science and Technology. So, we want to thank all the teams who contributed to the development of this document.

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