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Characterization of error on a digital elevation model (DEM) Based on morphological zones: Case of the Denguélé District (North-west of Côte d'Ivoire)

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ABSTRACT: A DEM is a numerical and mathematical sketch of an area in terms of elevation (Charleux , 2001). Thus this source of information is used in many areas of daily life (mapping, defense, development and urban planning, civil engineering, telecommunications, geomorphology, hydrology, etc.).The results of its use often contain errors that are not generally perceived by the user. In this study, contours of topographic map were used to create two test digital elevation models (DEM) by using two interpolation methods the TIN (Triangulated Irregular Networks) method and the IDW (Inverse Distance Weight) method. These two models were then compared to a reference DEM, product of interferometry radar technology (SRTM images) to detect major errors on our test DEMs. It is clear from this analysis that: On the interpolated DEMs, summit areas are affected by underestimation of altitude and thalweg areas are affected by overestimation of altitude. However, these errors are not impacted on the overall quality of the DEM.

KEYWORDS: DEM, TIN, IDW, Summit, Thalweg, Denguélé district.

1 INTRODUCTION

In this article, we discuss the impact of errors on digital terrain models quality. Digital terrain models (DEMs) are often used in many applications without the user having quantified the impact of these errors on the results of simulations (Wechsler, 1999). According to (Hottier, 1990) and more recently (Wise, 2000), the accuracy of a DEM is linked to the mode of data acquisition and its construction method. We are not dealing here errors related to data used in the construction of a DEM. Many studies have shown the importance of the accuracy of the initial data on the overall quality of DEM (Carter, 1992) and (Chang et al 1991). Moreover, it was also shown that the type of interpolation selected from the same type of input data, give similar results in terms of overall accuracy (Carrara et al 1997). There are several data sources allowing the construction of digital elevation models. The most current data is usually derived from contours or correlation from satellite images. We will study in this article only DEM constructed from contours.

If DEM construction method is spreading more and more, it is, according to (Heitzinger et al 1998), thanks to the increasing number of cheap paper maps at different scales, and including a representation of contours. This is also why many national mapping agencies have begun to create DEM by scanning contours of their existing cards (Auman et al 1990).

To build a DEM, representing a continuous surface, from these data, it is necessary to interpolate. There is a distinction (Monier, 1997) between exact interpolation methods (input data remain the same after the interpolation) and non-exact interpolation methods (input data is changed by the interpolation method). The two raster interpolation methods (IDW, RST) are non-exact, unlike the interpolation method TIN.

We present below very briefly one raster interpolation methods and the TIN interpolation method. There are many articles and thesis on this subject (Burrough et al 1998] and (Wood, 1996) and many Internet sites to download the described algorithms. Widely used in the 90s thanks to their simplicity of use and treatment, most of the analysis algorithms are programmed to raster. However, this format has some disadvantages. The first is the size of the cell: it determines the file size and especially the quality of the result. The second is the difficulty in representing the slopes break lines. Finally, the strict application of the point of view, raster interpolated DEM poorly manage the flow paths (Moore et al 1991) Because of a zigzag effect that does not exist on the TIN. We Propose to choose one raster interpolation methods (non exact interpolation method): The IDW method (Inverse Distance Weight) which is a conventional interpolation method, implemented in many GIS softwares. Regarding the choice of the exact interpolation method, the main method is the famous Delaunay triangulation TIN (Triangulated Irregular Networks).

The aim of this paper is to study the spatial distribution and the impact of errors that recur regardless of the type of interpolation selected. An error is the difference between the measurement of a quantity and its true value. Using the same input data (contours), we compare a DEM with exogenous control values supposedly more "accurate» (reference DEM) and two interpolated DEMs (test DEM) to evaluate these errors. The reference DEM was SRTM DEM which was acquired with an interferometry technology. We assume that the spatial distribution of more important errors is not dependent on the choice of the interpolation but relief type. First, we highlight the similarity of recurring errors areas on different types of DEM. We show, in a second step, the impact of the errors on these areas and their effects on major topographic parameters (altitude, slope). These errors areas are usually linked to a lack of information on important structures of the terrain (crests, thalwegs). But even if there are methods to solve these problems (Jaakkola et al 2000), they are generally taken into account by a small minority of users (Wechsler, 1999). We conclude with a discussion of the benefits from an automatic characterization of a DEM. Determining automatically certain types of forms (areas) with success allow the user to automatically know the potential quality of the DEM based on these morphometric areas. However, such an approach is only possible from a robust detection giving limits of specific areas.

2 Study area

The study area (Figure1) is located between Latitudes 8°28' 30'' N and 10 °21'50'' N and Longitudes 8°07'40'' W and 6°00'15''W ,the region couvers about 20 .600 Km^2.The climate is tropical and humid with two main seasons: a large dry season from November to May and a long rainy season from June to October. The precipitation ranges between 1400 and 1600 mm. Its population is estimated at 289700 inhabitants.The relief varies between 200 and 987 m essentially consists of plates, hills and mountains.

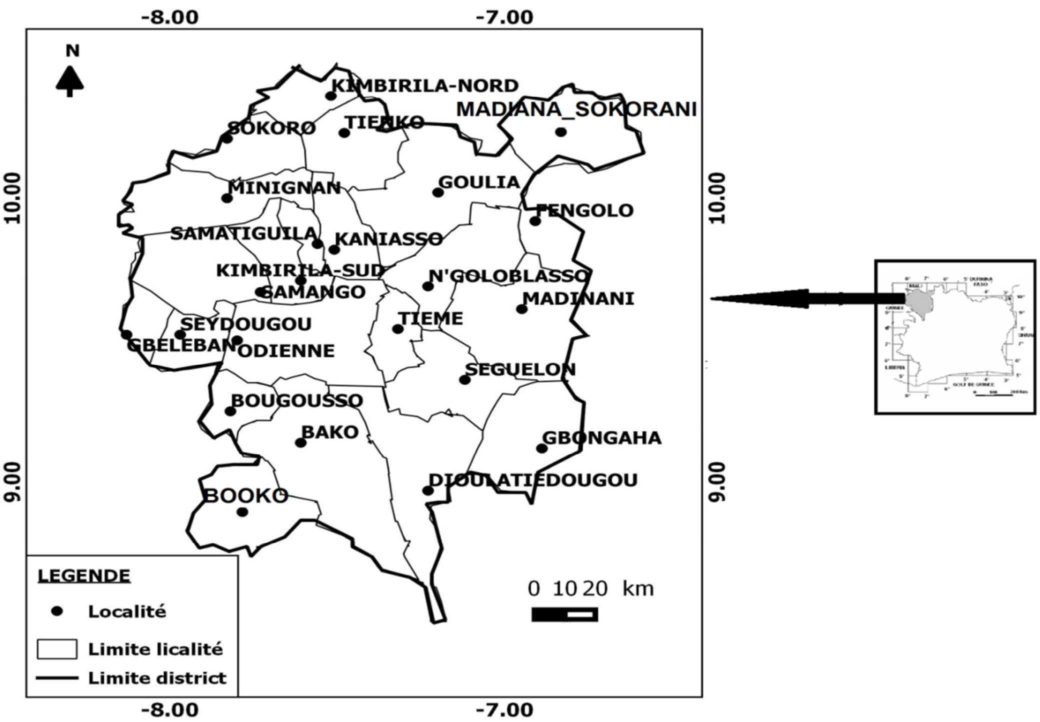

Figure1: Location of the study area

3 Material And Methods

3.1 Material

- **Data**

  - The topographic map of the study area was provided by the CCT (Mapping and remote sensing center), scale 1/200000, dating from 2000. To calculate our different DEMs we used contours from this map. Their equidistance is forty meters.
  - Our reference DEM is a DEM obtained by the SRTM (Shuttle Radar Topography Mission) mission of 2000 with the help of interferometry technology .The vertical accuracy is about 16 meters and the planimetric one about 90 meters.

- **Software**

  Two software were used to achieve our study:

  - Quantum GIS 2.10 was used to digitalize contours, realize the different test DEMs by interpolating.
  - Grass Gis 6.4.2 was used to calculate the different errors (elevation errors)

3.2 Methods

- **Creation of test DEMs**

After the digitalization of contours on the topographic map, two interpolation methods were used to build digital elevation Models (DEM): the TIN (Triangulated Irregular Networks) which is an exact interpolation method. In this method DEM is calculated from a set of points (contours) connected by a network of irregular triangles. Unlike raster DEM (non exact interpolation methods), TIN is interpolated only from existing points. This is an irregular tessellation. Delaunay triangulation is defined as the dual of the Voronoi diagram of a set of nodes. Each triangle of the Delaunay triangulation satisfies the criterion of empty circle. This means that the circumscribed circle of the triangle does not contain any node triangulation other than the three vertices of the triangle. An extensive literature exists on the Delaunay triangulation and its various algorithmic methods. As Examples we can see the thesis of (Rognant, 2000).The second method is the IDW method (Inverse Distance Weight) which is a conventional interpolation method, implemented in many GIS market. IDW is a not exact interpolation method (input data is changed by the interpolation method) (Monier, 1997).

- **Determination of errors study areas**

We seek to characterize the relief of our study area. For this we used the help of a Geomorphology expert. Two different types of terrain characterized by enough errors on DEM were defined:

  - Thalwegs areas: they define mostly low and concave areas. These areas represent the lowest point of a valley. This is the area where we find the hydrographic networks;
  - The summit areas: they define mostly high and convex areas. This is higher zones, little erosion.

- **Calculation of errors**

We show in this section that the spatial distribution of the larger error is independent of the choice of the interpolation. We define by mistake the difference between the reference altitude and altitudes measured on the interpolated DEM. We seek to develop the types of errors that characterize the two areas that we have previously defined. For this, we calculate initially, cell by cell, the elevation difference between the reference DEM and the interpolated DEMs. These errors are calculated using the following methods:

The elevation errors were calculated using the following formula :

$$\text{mean difference} = \frac{\sum(Z_{SRTM} - Z_{MNT})}{\text{total number of points}}$$ (Bonin and Rousseaux, 2004).

The calculation was carried out with the *r.mapcalc* algorithm of Grass Gis 6.4.2. The following command permeated to do so:

$$\text{r.mapcalc ERROR} = \frac{(\text{SRTM} - \text{MNT})}{\text{SRTM}}$$

With

SRTM: The reference DEM;

MNT: The interpolated DEM

The r.mapcalc algorithm permits to achieve raster calculation (Pinatibi, 2015)

- **Calculation of slopes**

The calculation methodology is based on an algorithm permitting to have partial derivatives of the elevations (H) according to the East (x) and North (y) directions (Burrough, 1987). The equation is as follows:

$$\text{Slope} = \sqrt{(\frac{\text{dH}}{\text{dx}})^2 + (\frac{\text{dH}}{\text{dy}})^2}$$

The calculation was carried with the *r.mapcalc* algorithm of Grass Gis 6.4.2. The following command permeated to do so:

$$\text{r.mapcalc slope.aspect input} = \text{MNTor SRTM output} = \text{SLOPE}$$

With

SRTM: The reference DEM

MNT: The interpolated DEM

SLOPE: the result of calculations

4 RESULTS AND DISCUSSION

4.1 RESULTATS

4.1.1 DIGITIZED CONTOURS

Figure 2 shows the contour lines from topographic maps produced by the CCT (Mapping and remote sensing center). Indeed, as shown in the figure, these contours lines do not cover the entire district's territory. Note that equidistance between each contour line is 40 meters. Contours have altitudes between 320 and 1000 m (Tableau I). Localities and geomorphological areas concerned by each contour line are visible in Table I.

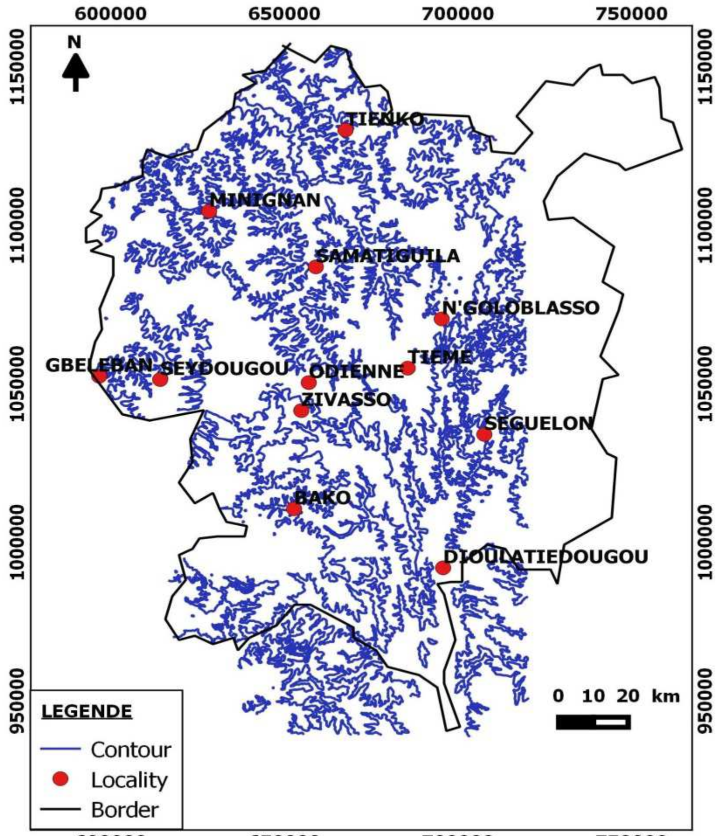

Figure2: Digitized Contours map

Tableau I: Elevation and localities with the same elevation level

Contour	Altitude (m)	localities
1	320	Bokoba, Dioulatiédougou
2	360	Tinikoro, Tchékorodougou, Tinédirima-Sokourala, Kimbirila-Nord, Lélé
3	400	Tienko, Koliko, Kouroulingué, Soukouraba, Koutoula, Kabangué, Kémissiga, Sanzanou, Dioronzo, Odienné
4	440	Tienni,Samokoroko,Lossoko,Kokona,Gbéléban,Seydougou,Gnamana,Gbessasso,Sirana,Késsedougou,Bassokodougou,Zevasso,Bako,Goulia
5	480	Foula, Korodougou, Tourani, Néguéla, Kodougou, Ninguésso
6	520	Gnamatogola, Fasséronzo, Feredougou
7	560	Sokouraba, Doyodougou, Siensoba
8	600	Soba, Késianko, Bouko, Bédougou, Boolo
9	640	Seriso (summit)
10	700	Kenguélé (Summit)
11	740	Séssébo (summit)
12	800	Foula, Gbandé (summit)
13	840	Tangué, Siratitigui, Kourouba (summit)
14	900	Tyouri, Bougouri (summit)
15	1000	Koulouba (summit)

4.2 INTERPOLATED DEMS

DEMs of Figures 3 and 4 respectively resulting from the interpolation methods IDW (Inverse Distance Weight) and TIN (Triangulated Irregular Networks). They are the result of the interpolation of contour lines from a topographic map of the district Denguélé. Two major conclusions are made after the analysis of these two computer models of the relief: The entire summit area in the east of the district is not covered by topographic information; elevations on both models range between 361 and 535 m for the IDW method and between 335 and 583 for the TIN method. However the large sets of topographical formations seem the same on both terrain models. It is necessary to examine the errors related to the technical used to produce these models.

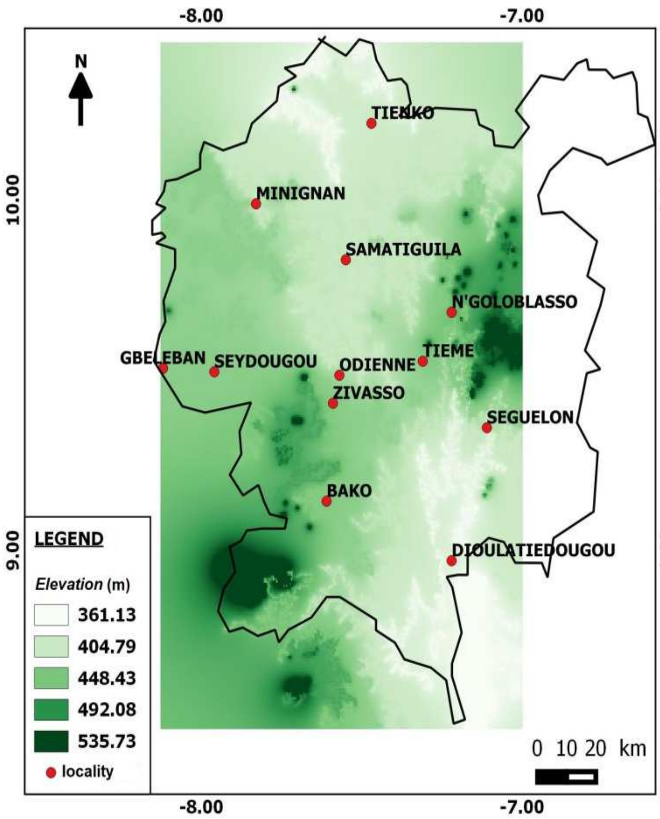

Figure3: DEM built with IDW interpolation method

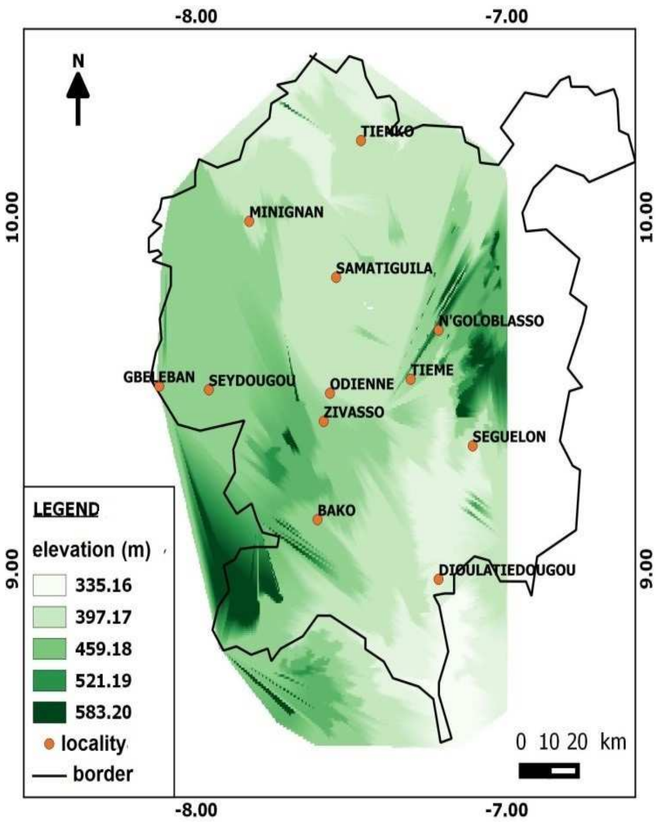

Figure4: DEM built with TIN interpolation method

4.2.1 REFERENCE DEM

The reference DEM Figure5, is a SRTM one, it is the result of the interferometry radar technology. This model covers the entire district in topographic information and altitudes vary between 279 and 979m.

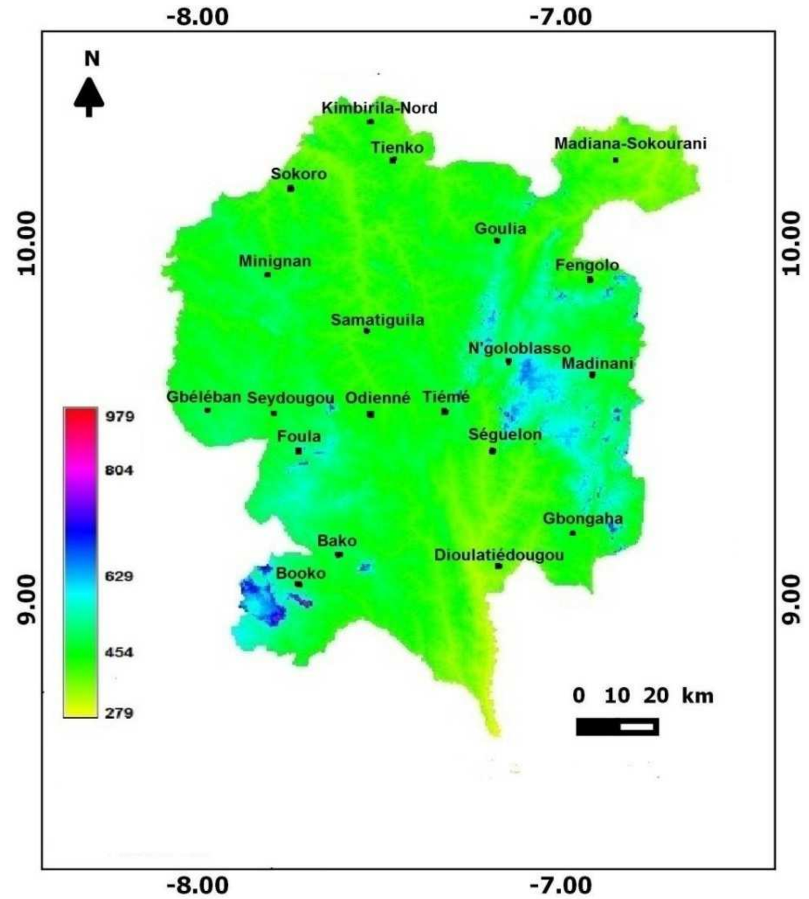

Figure5: SRTM DEM, built with interferometry technology

Compared to reference DEM interpolated DEMs show an underestimation of altitudes at the summit areas. On these areas elevations range to 535 m for IDW method, 583 m for TIN and 979 m for the reference DEM. Concerning thalweg areas they range to 361 m for IDW method, 335 m for TIN method and 279 m for the reference DEM. We notice that thalweg areas are overestimated by interpolation methods.

4.2.2 ESTIMATED ALTIMETER ERROR

In terms of geometric precision, we note that poor estimation summit and thalweg areas don't affect the overall quality of the DEM elevation calculated because errors are very law -0.36 and -68 respectively for IDW and TIN methods (Table II). The impact is rather local. The average error calculations are not significantly different as that is excluded or not the summit and thalweg areas, while the average error is slightly lower on IDW interpolation than TIN one. In (Table II), below, the calculations were made for significant errors greater than two meters.

Table II: estimating the average elevation error in meter by type of interpolation

Interpolation type	average error over the map	average error over the map without the summit and talwegs areas
IDW raster	-0.36	-0.25
triangulation	-0.68	-0.58

4.2.3 ESTIMATED SLOPES

Slopes are a major relief setting for numerous simulations. Examples are given in the area of risk and engineering by (Manche, 2000) to avalanches by (Charleux, 2001) for hydrology. The impact of elevation error affects quite widely on the slope calculation. If one chooses to study the average slopes of the summit and thalweg areas, similar biases appear in our two morphological test areas. The impact is more visible on thalweg areas because slopes are underestimated. The average figures are respectively 2 degree for IDW method, 3 degree for TIN method and 7 degree for the reference DEM

Table III: Average slopes in degree, by interpolation type and zone

	summit areas	Areas thalwegs
IDW	26	2
TIN	31	3
SRTM-reference	41	7

5 DISCUSSION

Comparison of types of terrain modeling highlights three important points:

- The topographic map provided by the CCT doesn't cover the entire district, as consequence the interpolated DEMs don't cover the entire district .This situation is sometimes caused by economic problems because it cost very much to build a topographical map. (Charleux, 2001) explained this situation in his thesis.
- The average of all errors that affect our various DEM is broadly similar. It is quite low and is between -0.36 (IDW) and -0.68 (TIN): DEMs are both affected by a slight underestimation affecting all areas (excluding crests areas);
- concerning the study of significant errors, we show that the two types of terrain, a wide disparity exists between the summit and thalweg areas and the rest of the test DEM. This distribution is very similar errors on the two tests DEMs. It is observed on the various interpolations of DEMs, and focusing not on the overall quality, as did (Carrara et al 1997), but the estimation error of major areas, the various DEMs have errors in the same types of place. Areas of underestimation are the summit areas and overestimated areas are the areas of thalweg.

On interpolated DEMs, the biases are due, firstly, to the lack of information on the entire areas. This is very often, areas included within the last contour line. The interpolations are calculated from many similar data. On the TIN, it is mainly flat triangles zones: the summit areas and talweg zones are assigned an artifact described in (Jaakkola et al 2000). This artifact is responsible for two types of systematic errors:

A mistake of underestimation, located in the summit zones: the flat shape of these zones is not usually real. The summit areas are rather characterized by a general convexity after geomorphological phenomena such as erosion. As the altitude of the calculated area on the DEMs is that the last contour, the altitude of this area is necessarily lower on the DEM than the ground reality.

An error of over-estimation, located in areas of talwegs: this is the opposite phenomenon. The low contour overestimates the thalweg area by leveling it to its altitude. The talwegs, on a large scale are generally dug by a river (which still exists or not). The natural shape of a thalweg corresponds only very rarely in a flat area as can be calculated systematically a conventional triangulation algorithm as Delaunay one.

6 CONCLUSION

We show in this paper that the two models of the relief that we use, some areas are systematically affected by several types of recurring errors, but the overall quality of DEM is really affected in terms of slope and aspect. Our application, however, shows that a better consideration of artifacts in summit and thalweg areas minimizes the error on these two parameters, useful for applications. However, this consideration allows only partial correction of these areas because of the difficulty to interpolate these forms correctly.

After the determination of errors by type of relief, the provision of automatic characterization of the land, as tried (Wood, 1996) is very interesting because it would define a potential error map automatically. This error map would be calculated based on morphometric areas detected. The first relief characterization tests with morphometric factors, such as the concavity, the convexity or the slopes (Bonin et Rousseaux, 2004), however, show that the multitude of detected areas likely require algorithms to manage the micro-reliefs, large generators noise DEM

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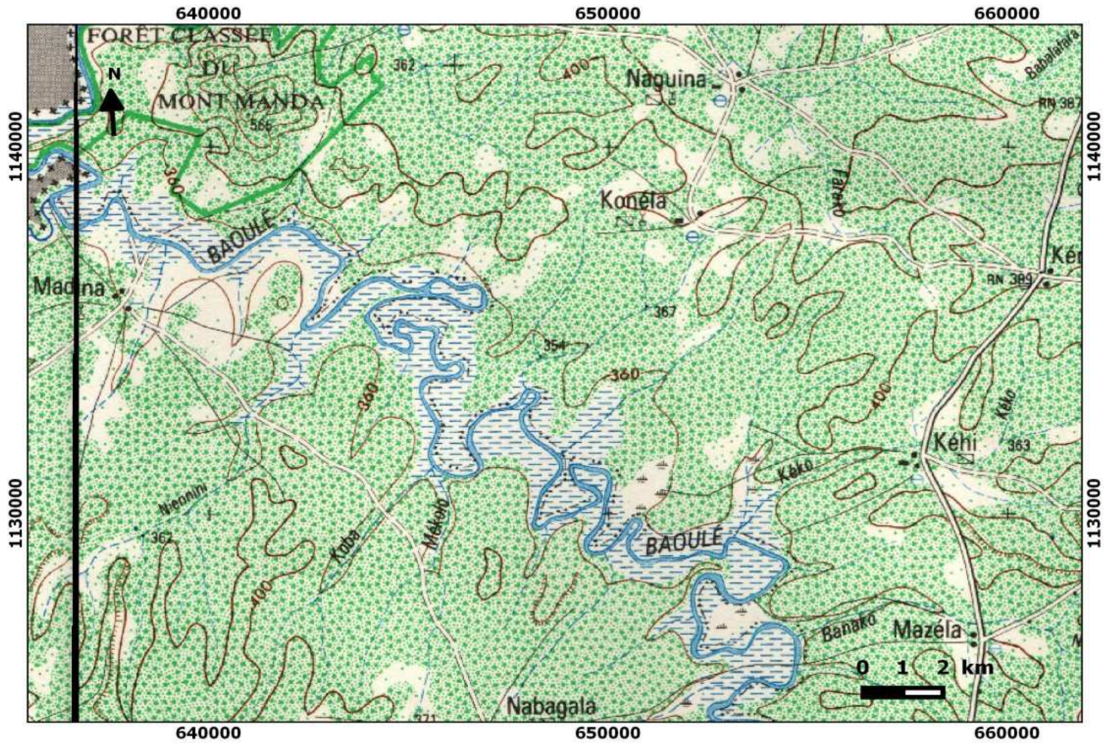
ANNEX: FIGURES ILLUSTRATING THALWEG AND SUMMIT AREAS ON DENGUÉLÉ DISTRICT

Photo1: Summit convex in the village of Foula



Map 1: thalwegs areas around the Baoule River