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A New Morphometric-SIG approach to Detect Quaternary Deformation Using Abnormal Drainage Indicators

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Abstract - *The integration of structural, seismologic, morphologic, and drainage anomaly data represents a new methodological approach that can be helpful to detect and predict neotectonic deformation in Quaternary deposits where accidents are not well exposed and are usually sought by thick recent sediments.*

In this paper, we have implemented this integrative methodology in order to put in evidence the active tectonics in the region of Kasserine. In fact, we have used a morphometric methodological approach by the semi-automatic determination of drainage anomaly. Data processing and improvement is determined by the Geographic

Information System (GIS). Mapping results of drainage anomaly are validated by field observations at three quite different sites located near a recent seismic earthquake (dated back to 2010 with a Magnitude of 3.4). Results of observations clearly prove the existence of N110 structural direction that corresponds to an alignment of drainage anomalies and pinpoint the existence of another alignment of seismic focal corresponding to that recent earthquake. These results also emphasize the presence of an active accident in the quaternary deposits in the trough of Kasserine.

Keywords - *Abnormal drainage, GIS, Kasserine, Morphometry, Tectonic accident, Quaternary.*

I. INTRODUCTION

This study is part of a relief survey to explore recent deformation. The application of morphometric parameters on the Digital Terrain Model and hydrographic network, as testified and used by [1], [2], [3], [4], [5], [6], [7], [8], [9]. These parameters allow us to develop the thematic maps of areas, which are tectonically active. A field validation is performed by tectonic accidents measurements in three different sites that are located on basis of the alignment of drainage anomalies and near a seismic focal with a magnitude of 3.4 (hit the region in 2010) [10].

Morphometric or geomorphometric analysis is a description of geologic relief with mathematical expressions of some parameters such as the hypsometric curve, the elongation ratio and the length of drains [11], [12], [13], [14], [15], [16], [17], [18]. Each parameter is an indicator of specific terrain characteristics. In our study, we are interested in applying the drainage anomaly parameter. Which is known by several authors [19], [20], [21], [22], [23], [24] and that can help us quantifying the tectonic deformation amplitude and sedimentary activity related to erosion [25], [26], [27], [28].

Morphostructural analysis is improved by developing a morphometric GIS based primarily on the use of topographic and geological mapping data. On the one hand, the performed process concerns the contours and the drainage patterns of the topographic map at 1/50000. On the other hand, it deals with the tectonic geological map at 1/50000 [29]. The results of processing are layers of information in vector format: "SHP", incorporated into a GIS using ArcGIS 9.3 software. They are presented on the same map with the coordinate system (UTM zone 32, WGS84). These vector layers are: 1 - tectonic accidents, 2 - water system and 3 - the drainage anomalies. They allow us to project the position of seismic focal on the same map.

We have applied this approach on the region of Kasserine, which is a privileged area marked by active recent tectonic and has the highest mountain in Tunisia (Chaambi) and a Quaternary plain fulfilled by a dense ramified hydrographic network.

Results confirm that the morphometric parameter and the drainage anomaly are good indicators of active tectonics. In fact, throughout the drainage anomalies mapping, different factors permit us to pinpoint the existence of an active tectonic accident of N110 direction. We can cite the location on the same map of the seismic focal, tectonic accidents and field observations at the three different sites near the seismic focal at Oued Htab in the region of Kasserine. The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. THE GEOGRAPHICAL CONTEXT

Kasserine is located in the central west part of Tunisia (Fig.1). It perfectly characterizes the high steppe. The average altitude of this zone is estimated to 1000 m. Chaambi Mountain (1544m) represents the highest relief in this zone and in the whole Tunisian territory. The study area extends over an area of 635 km ² and with a perimeter of 110 km.

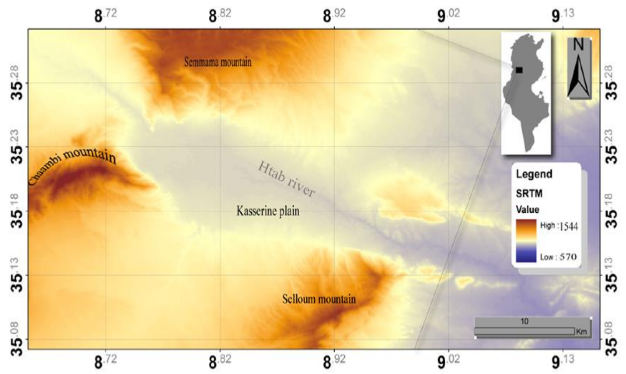

Fig.1: The study area's geographical location

III. THE GEOLOGICAL SETTING OF KASSERINE AREA

A. Geomorphology of Kasserine area

Kasserine is part of the central Tunisia. It is perfectly integrated in the Kasserine land domain developed since the Maestrichtian. It knows a significant Plio-Quaternary tectonics, especially in the South [30].

This recent tectonics shows that the Upper Paleolithic (Capsian) is affected by the fault of Kasserine [31]. This fault, trended E-W, corresponds to a dextral strike slip fault causing the compartmentalization of the area into two distinguishable provinces.

The Northern province is formed by Semmama and Maârgaba anticlines, which are separated by the large syncline of Garet El Atach. The southern province, however, comprises the anticlines Selloum and Kharrub Mountain.

Between these two parts, Kasserine trough is developed. A Triassic uplift structure appears along the border of Kasserine Graben. It is the Diapir of Chaambi Mountain ([32].

The study area is affected by several faults arrayed in three families (Fig.2). The E-W family of faults is the best representation, in which Kasserine fault is integrated. The NE-SW and NW-SE faults are also well represented in this study area.

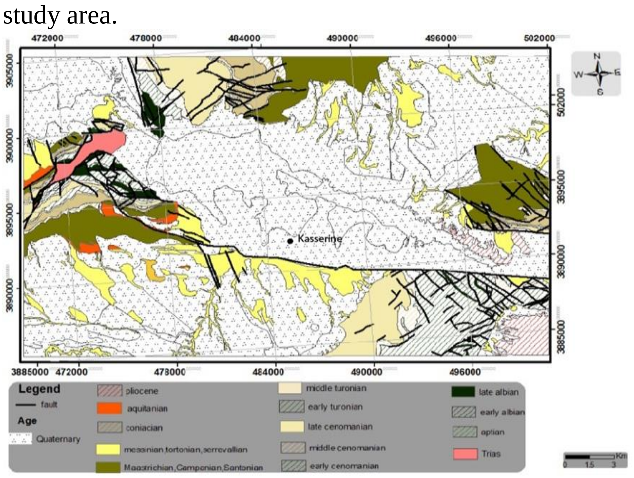

Fig.2: The geological map of Kasserine in 1/50 000 [33].

B. Kasserine Trough

Kasserine trough shows a combination of two branches. While the first is oriented NW-SE, the second is trended E-W. Kasserine Trough is the most southern one among the entire Tunisian Atlas troughs. It is bordered to the North by the Maârgaba normal fault [34], [35].

In ensures the separation of the EW subtabulaires lands of Maârgaba monoclinal, the Neogene and Quaternary series of the collapsed part of the graben, showing an estimated vertical displacement of about a hundred meters.

Neogene and quaternary deposits exceeding 1000 m in terms of thickness fill up Kasserine trough. These Neogene series are affected by a slight wrinkling, which are clearly seen on the edges, and a fracture dominated by normal faults, which direction varies between N130 and N140. The geomorphological evolution depends on the presence of the master fault of Kasserine [34], [35].

During Quaternary time, this movement continues ([36], [32], [37] to amplify the collapse of this trough.

IV. METHODOLOGY OF THE MORPHOMETRIC STUDY

A. Topographic and hydrographic Data

The diversification of data allows a better interpretation of the morphostructural sector.

Two types of data are used in this study: Topographic and geological data (Fig. 3).

The topographic data have been extracted from the topographic map of Kasserine scale 1/50000. After scanning, the map coordinates are adjusted by replacing the image coordinates of the ground contact: "georeferencing". Then, we have defined the projection system: UTM (Universal Transverse Mercator) / WGS84 (World Geodetic System). The last step consists in the digitalization of the contour lines that will lead us to the generation of DTM, and the digitalization of the hydrographic network.

The geological data are provided from the geological map of Kasserine 1/50000. It followed the same steps as the topographic map to extract the structural map and vector map geological and seismic recordings of the National Institute of Metrology (INM).

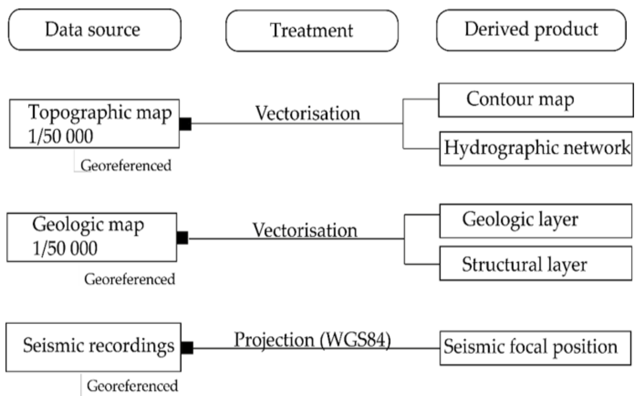

Fig.3: Data sources and derived maps or used layers to get the abnormal drainage index map.

B. Analyses of the DTM's morphometric indexes

In order to highlight the morphometric response of the study area, we have had recourse to the study of some morphometric parameters that can be extracted from the DTM.

The choice of the DTM is very important in the study of the morphometric parameters. it is essentially based on the accuracy of the model. Accordingly, we use the most accurate interpolation method for the generation of DTM: "Kriging" ([38].

For accurate results, it is necessary to estimate the DEM error by calculating the RMSE (Root Mean Square Error) ([39] which is equal to 2.23 m. According to [40] the DEM from a topographic map at a scale of 1: 50 000 with an equidistance of 10 m, must have a value of RMSE around 3.04 (Table.1).

TABLE1: RMSE estimated of DTM

Z measured(pi)	Z interpolated (oi)	Residual
1249.75	1251	1.25
652	649.26	2.74
684	683	1
841.38	840	1.38
637	640	3
708	705	3

RMSE=2.23

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}}$$

C. The Abnormal Drainage

The abnormal drainage can be defined as a local deviation of the regional drainage and/ or style of the runoff model. It is largely linked to either the tectonic or the topographic structures [41].

According to the work of [42], [43], [44] the abnormal drainage can be caused by phenomena of River erosion and alluvial deposition, or by active tectonic deformation, which is, most often, related to the main River. We also urge that the drainage anomalies can be indicators of recent tectonics.

Throughout this study, we have tried to use a semi-automatic procedure for defining the drainage anomalies with reference to the work of [20] and [45], which are modified according to the flowchart (Fig. 4).

In order to extract the abnormal drainage, we have had recourse to the map data correlated with the hydrographic network and the digital terrain model.

The choice of semi-automatic study of abnormal drainage has replaced the manual processing which was a source of different errors that could occur mainly while distinguishing the hydrographic network mainly in flat areas and while determining the angle of the drain within the River system with regards to a natural surface.

In the first stage of treating this subject, we are interested in the MNT model for extracting the land cover surface that is considered a primitive surface without considering the hydrographic network effect.

In order to extract the higher points of the relief, the surface envelope production is made by a filter. Then, we generate the land orientation map that is converted into vector polygons with each polygon containing the orientation of the field value type.

Since abnormal drainage is influenced by the orientation of the field and essentially by the direction of drainage, the latter is orientation is determined by scanning the River system in the direction of the drains flow from the topographic map of the area.

The resulting layer is superposed on the vector orientation of the field layer.

Hence, there are two layers of the orientation map and the hydrographic network, which will be detailed in the following figure of cartographic processing. The latter concerns the value orientation of the land through which it passes on to attribute each segment drain.

The next step is to calculate the direction of these segments using the "polyline_Get_Azimuth_9x" tool in ArcGIS to finally get in the attribute table of the River system a field that contains the field orientation and the other drainage orientation.

The last step is to find out the difference between the direction of the River and that of the ground. According to [42], if the difference is between -180 ° and 180 °, we admit that this is a normal flow. Otherwise, the flow of the drain is anomalous.

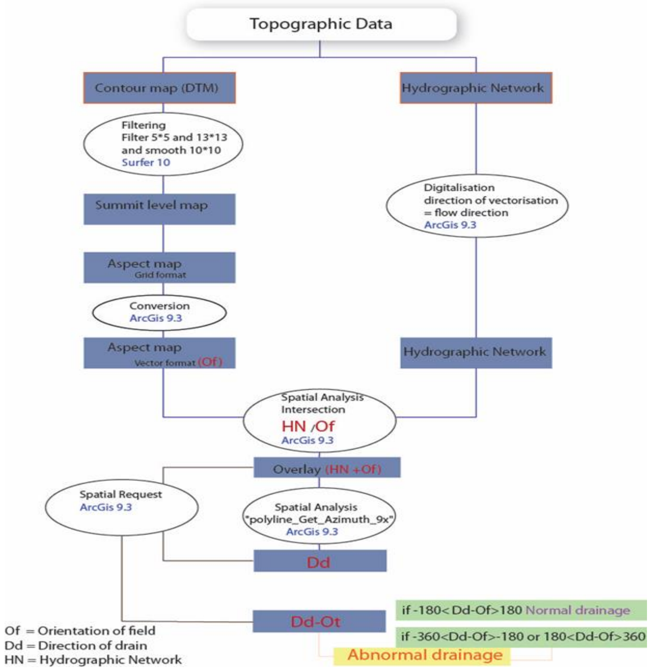

Fig.4: Presentation of the semi- automatic approach to extract the abnormal drainage index from DTM and the hydrographic network [45].

V. RESULTS AND DISCUSSION

The extraction of anomalous drainage from the sector's hydrographic network shows that the anomalies have been concentrated at Chaambi; Selloum and Margabaa

Mountains. These results are consistent with the fault system of the geological map of Kasserine. However, a difference in size between the abnormalities and the structural map drainage is detected. Indeed, it is through the drainage anomalies of Kasserine plain that we have revealed the existence of both a network of Quaternary faults at Htab River (Fig.5) and a tectonic activity [46]. This is confirmed by seismic records of the MNI that determine the presence of a seismic focus at Htab River (magnitude = 3.4). A field validation is performed at site 1 and site 2 in right bank of the Htab River and site 3 in left bank of the Htab River (Fig.5).

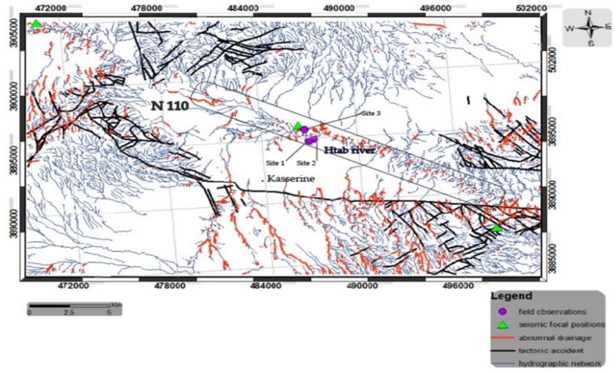

Fig.5: Overlay of abnormal drainage index, network faults, hydrographic networks, focal seismic position and location of observation sites.

The investigations done on the ground of the left bank of Htab River (site 2) demonstrate that sandy clay outcrops attributed to Mio-Pliocene are affected by several fractures (Fig. 6). Indeed, we have measured fault planes showing the following directions:

-Normal micro-fractures oriented N30-40 and N90-100; these are centimetric to decimetric play fractures.

-Oriented N70 fractures: they correspond to dextral strike-slip with metric lateral displacement.

-Oriented N30 fracture corresponding to a few centimetric inverse play.

-Oriented N110 faults with metric dextral displacement and their parallel faults: they inform about the reorientation of the meandering of Htab River in the site of UTM coordinates (486796m, 3895797m).

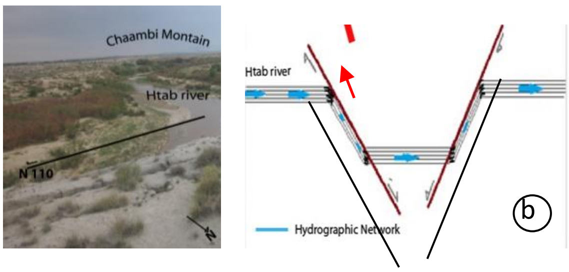

Fig.6: Photos (a) display Htab River meander, (b) a plane projection with the fault direction N110.

At the right bank of Htab River (Sites 1, 2), 4 Km road Sbeitla Kasserine-west crossing to Kasserine, we have found fractures in various directions. Measurements of these fractures (Site 1), with coordinates (486926, 3895544) in the local Datum Carthage 34, show:

Normal fractures oriented N30-40 with a centimetric displacement dipping the Northeast (Fig.7).

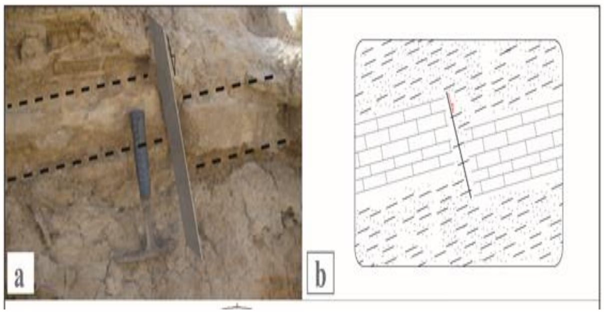

Fig.7: (a) portrays a centimetric set in quaternary deposits, (b) sketch showing a dextral strike slip with lateral set.

Moving westward to site 2, with coordinates (486809, 3,895,500), we may distinguish:

Normal fractures oriented N50 dipping south-east.

Dextral strike slip fractures oriented N70 with a lateral centimetric displacement (Fig.7).

The morphometric GIS is a fundamental concept in this study. It facilitates the extraction of morphometric parameters and geomorphometric analysis based on digital map data. The map product has allowed us to extract DTM from interpolated contours that helps determine the limits of sub-watersheds from the hydrographic network. The application of morphometric parameters on the DTM and the drainage network at the sub watershed has permitted us to analyze the tectonic activity and the importance of the effect of the erosion on the study area.

The presence of quaternary, which characterizes most of the sub-basins of Kasserine region, invites us not only to study the behavior of the River system but also to calculate the anomaly drainage. This can indicate the presence or absence of tectonic activity. Indeed, the behavior of the network through the drainage anomalies in particular indicates the presence of tectonic activity confirmed by field observations at Htab River. The direction of the accident is NW-SE, which is compatible with the direction of the drainage anomalies at the same level of that specific river.

This work contributes to extract useful information about the tectonic activity in the sector through Kasserine morphometric approach which has been endorsed by some authors [47], [48], [49], [50] [51] and [52], and which has been based primarily on the terrain and drainage network in a GIS.

VI. CONCLUSION

The relief of the region of Kasserine represents an exceptional site to study the relationship between morphology and tectonics in the quaternary deposit. Indeed the plain is almost entirely surrounded by mountain chains exceeding 1500 m of elevation.

On basis of the results of the analysis of the hydrographic network and the semi-automation of the determination of the drainage anomalies, an N 110 direction of recent

tectonic activity in the plain of Kasserine has been obtained.
This activity reveals the close relationship between the behavior of the hydrographic network and the tectonic activity.
The morphotectonic analysis by the abnormal drainage indicators shows a tectonic accident in the quaternary deposit. In fact, it confronts a certain difficulty in uncovering the accidents as the latter can reach 700 m.
Our approach, built on morphotectonic analysis and fieldwork validation, strengthen considerably the search for the detection of tectonic accidents in a semi-automatic way to automatic one, from morphometric data in a GIS environment.

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