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GEOSPATIAL MODELING FOR KARSTIC COLLAPSE PROBABILITY MAP IN THE DOUKKALA BASIN (MOROCCO)

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Abstract

A significant proportion of the Doukkala (Western Meseta of Morocco) is composed of limestone. This rock is susceptible to a rapid evolution to karst in some particular environment and, hence, a collapse may occur in such a karstic feature. The aim of this study is to develop a methodology that can predict where future sinkhole collapse will occur in the Doukkala basin and establish a map with areas more susceptible to this phenomenon. This document could be a useful tool for decision makers.
The data was integrated into a geographical information system (GIS). Combining the most important factors that play a role in the dissolution process of rock; lithology, geomorphology and hydrology enables us to delineate areas of low, moderate and high risk.

1. INTRODUCTION

Sinkholes developed in karstic terrain have environmental and engineering consequences in several populated regions of the world, where they pose hazards to property and the environment(Beck 1984; Waltham 1989; Jonson 1991; Waltham et al., 2005; Gutiérrez et al., 2008a).Collapse structures in karst terrains are the most serious geological hazards because they can damage engineering structures, settlement areas, natural lakes, and allow infiltration of contamination into the groundwater (Yilmaz, 2006). Knowing when catastrophic events will occur is not possible; however, understanding where such occurrences are likely to take place is possible. (Kuniansky, 2015).Subsidence from sinkhole collapse is common in areas underlain by water-soluble rocks such as carbonate and evaporates rocks (Ford and Williams, 2007). In Doukkala (Morocco) the presence of both limestone and gypsum, in addition to other natural factors mainly existing in water depressions have caused the development of important surface and subsurface karstic features. Hydrogeological data and geological mapping informations were used to create a geo-hazard map.

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Records of former collapses were also investigated. (Lamelas, 2008).

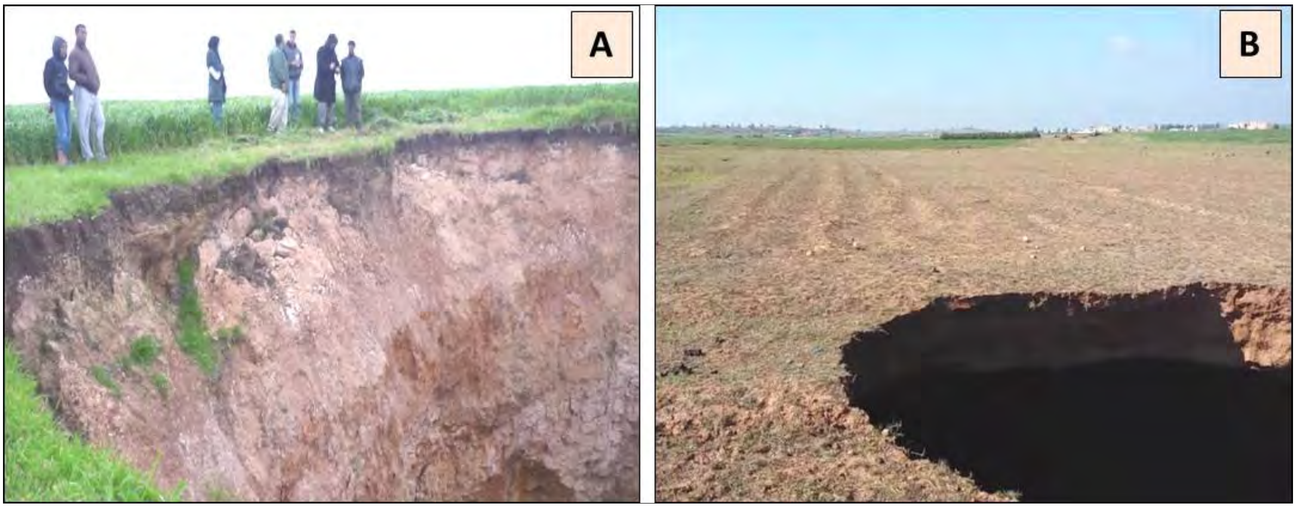

Fig. 1- Examples of the mapped sinkholes in the study area. A. Sinkhole collapse formed as a result of limestone dissolution near Sebt-Saïss Commune, Doukkala. The collapse feature (15 m wide and 20 m deep).B. New sinkhole collapse formed as a result of gypsum dissolution in Beni-Hilal Commune, Doukkala. The collapse feature occurred in 16 February 2016 (8 m wide and 15 m deep).

According to Paukstys et al. (1999), the most cost-effective way of planning in these areas lies in avoiding existing dolines and most subsidence prone areas. The application of this preventive philosophy requires the recognition of the areas affected by subsidence and the production hazard-maps (Guerrero et al. 2004).

In this paper, Geospatial techniques are used for the task of evaluating sinkhole susceptibility map. Causative factors for soluble rock instability namely lithological properties of individual units in the cover and hydrological conditions such as lakes and water flow are integrated in a geospatial model and generate the susceptibility map. This map, showing the place where the future sinkhole will be occurring, constitutes useful tool for hazard avoidance that have relevance to planning and engineering.

2. THE STUDY AREA

The studied field called Doukkala is located between latitude (31˚N -32˚N) and longitude (9˚W - 8˚W), and lies to the W of the Atlantic Ocean. It is limited by the Rehamna Massif to SE, OumEr-RbiaRiver to NE and Abda plateaux to SW (Fig.2).

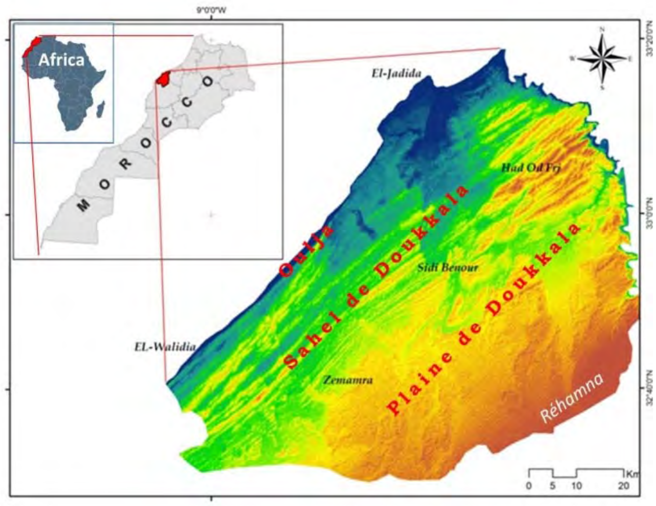

Fig.2- Location of the study area.

Geomorphologically, three natural areas are distinguished and generally arranged as parallel bands to the shoreline: the Oulja is a coastal strip,the Sahel coastal endorheic basin and the plain ofDoukkala to the east (Gigout, 1947; Gigout, 1951; Choubert, 1955; Ferreand Ruhard, 1975; Akil 1990, Ouadia, 1998; Fig.3).

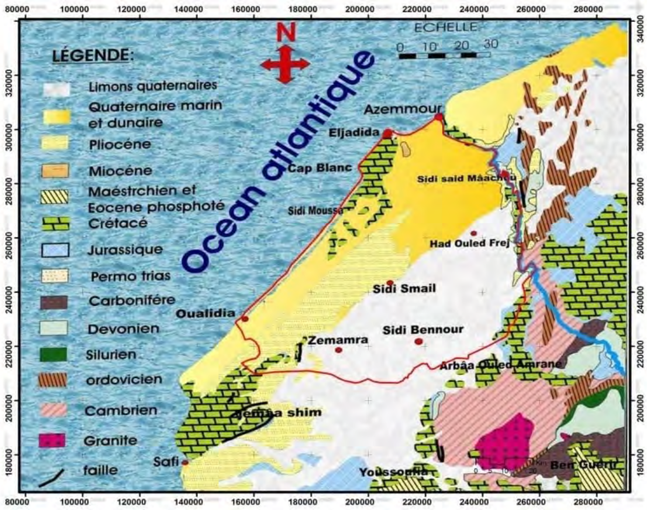

Fig. 3- Simplified geological map of the study area (red line), After the geological map 1/200 000 (Gigout, 1951), modified (Laaziz, 2004).

2.1. Geology

Lithostratigraphically, the Doukkala basin consists of diverse outcrops, which are:

The Paleozoic-age: throughout the region is covered by Meso-Cenozoic layers, it is flush in the Rehmna region and in Oum-Rbia Valley; elsewhere, it is overlaid by later deposits, except small outcrop of El-Jadida. The primary-age essentially made schists and quartzite.

The Permo-Triassic-age crops out in the Oum-Er-Rbia valley (between Talmest and Sidi Said Maachou). It is represented by deposits of red clay and mudstone with basalt flows. In M'tal, these formations are associated with red Carboniferous conglomerates. The Paleozoic basement that is folded and deformed during the Hercynian orogeny consists of a varied lithology (sandstones, quartzite, shale, limestone, dolomites and rhyolite) belonging to the Cambrian, Ordovician, Silurian and Devonian. This set is also described in several boreholes drilled in the Doukkala region.

The Jurassic-age is present South Doukkala; deposits consist of limestone and yellowish calcareous marl interlaced with gypsiferous clays (Ferreand Ruhard,1975).

The Cretaceous-age is extremely important in the region and is almost continuous substratum of Pliocene-Quaternary deposits, which are composed of calcareous marl and sandstone.

The Miocene–age is described at a small outcrop in El-Jadida Cap (Gigout, 1965). It is also described inward Doukkala by (Khatmi, 1999). In general, it is strongly eroded and consists of yellow marl, sand and in places red or brown clay with basal conglomeratic.

The Pliocene-age is formed by sandy limestone. These consolidated marine sediments, which were taken in the dunes, form the bulk of the Sahel.

The Quaternary is made up of three formations groups:1) Coastal formations in the Sahel 2) River terraces 3) Colluvium filled within the plain.

2.2. Karst

The study area is affected by a high degree of karstification (Gigout 1951; Ferre and Ruhard 1975; Ouadia1998).

The geological unit where karstification likely occurs is:

- Upper Jurassic limestone and gypsum.
- Hauterivian limestone, dolomitic more or less.
- Low and middle Cretaceous Gypsum marls.
- Cenomanian limestone.
- Plio-Quaternary clastic limestone.

They do not all have the same ability to karstification; the most important is upper Jurassic. Further north, where the Jurassic disappeared, the most spectacular phenomena mainly from occur in marl Lower Cretaceous (Ferreand Ruhard1975).

2.3. Hydrology

The river system is well organized upstream (Oued Aouja, Oued M'tal, Oued Bouchane ...), on arrival in the plain, itbecomes disturbed and anarchic.

The Sahel-Doukkala Basin is naturally poorly drained. The natural barrier that prevents the surface runoff to the ocean Rain water is collected in dune slacks or karst origin; they are then evaporated or percolate into groundwater (Ouadia, 2000; El Achheb, 2002).

The major outfalls are constituted by:

- Oued Faregh which drains the northern part of Doukkala and joins the Oum Er-Rbia.
- Oued Fel Fel-which collects the western slope of the run off Rhamna, and the central part of the plain of Doukkala.

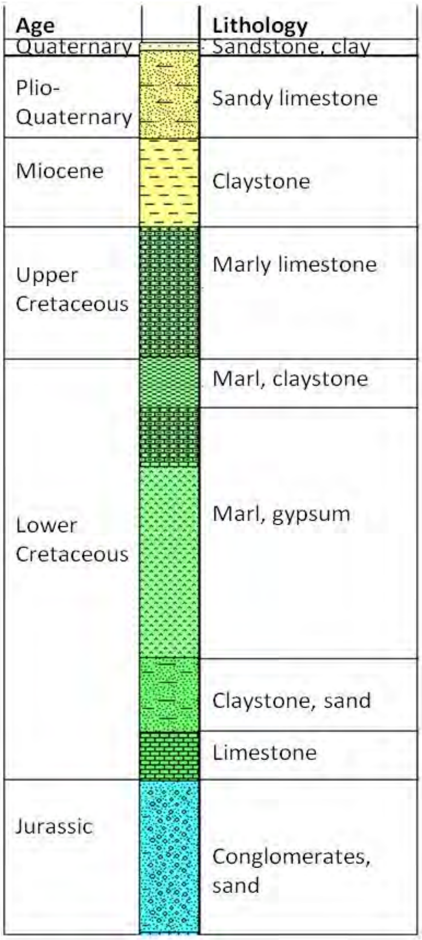

Fig.4- Synthetic stratigraphic log of the Doukkala basin.

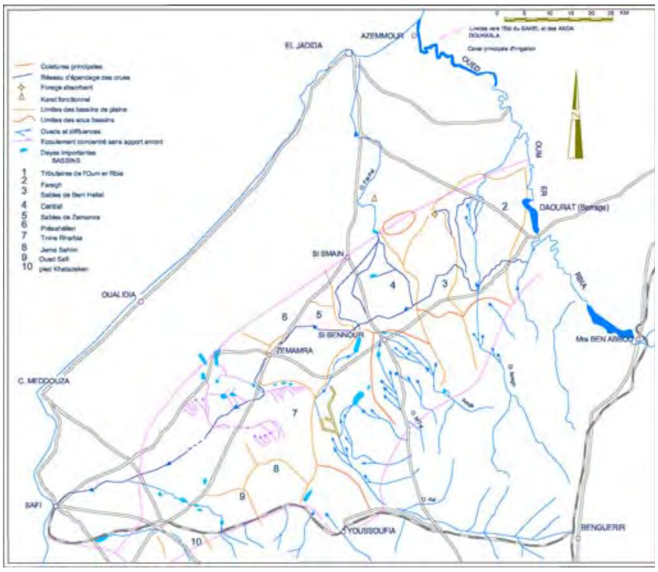

Fig.5- Hydrologic map of the Doukkala area (After Ferre and Ruhard1975).

3. MATERIALS AND METHODS

3.1. Data collection

The data used in this study comprises:

Three Geological maps 1/200000: 1) Geological map area in Casablanca, 2) Geological map between Mechraa Ben Abou and Safi (Abda-Doukkalaand massive Rehamna), 3)Geological map between Settat and Mazagan (Doukkala and Chaoui West) and Shuttle Radar Topography Mission (SRTM) DEM.

3.2. Susceptibility map generation

In order to predict collapse, it is necessary to assume that collapse occurrence is determined by collapse related factors, and that future collapses will occur under the same conditions as past collapses. On this basis, the relationship between areas where a collapse has occurred and collapse related factors can be distinguished from the relationship between areas without past collapses and collapse related factors (Yılmaz, 2006).The lithology is the principal predisposing factor to collapse. In fact, dolines are especially common in terrains underlain by carbonate rocks, and are widespread on evaporate rocks (Williams, 2006).The development of all karst requires the presence of rock which is capable of being dissolved by surface water or underground water.

Hence, the most important factors that cause the sinkhole collapse are lithology (rock type), geomorphology and hydrology (accumulation of water).To map the areas susceptible to this phenomenon in the future, each of these factors, are represented in GIS as a separate layer. Each of these layers is categorized and given a score, to give an indication of the contribution it might make to the overall degree of soluble rock hazard. Those with a strong influence will have a high score; those with a slight influence will have a low score.

The karst geohazard layer is created in GIS by intersecting all datasets into one, creating a mosaic of intersected polygons. For each resulting polygon, the sum total of each of the contributing factors is then used to give an overall potential hazard score.

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3.3. Geology

In this part, maps five classes that reflect the lithological behavior of geological formations overlooked water are created from geological maps. After georeferencing the three geological maps that cover the study area, all geological units have been digitized in addition to their lithologic facies.

All kinds of lithological units identified on geological maps were grouped into 5 classes according to degrees of dissolution (Table 1). Furthermore, a map grid with the retained classes was made (Figure 6).

clue	*facies*
1	**Clays and silts**
2	**Conglomerates, sandstones, shales**
3	**Sandstone**
4	**Marl andMarlylimestone**
5	**Limestone and Gypsum**

Table 1- Facies classes.

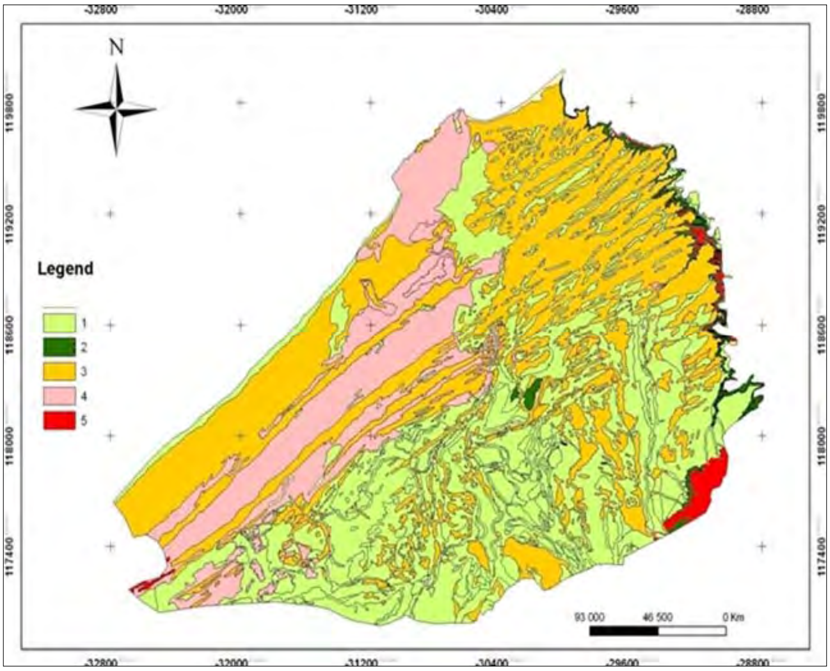


Fig.6- Geological map of the Doukkala region.

3.4. Geomorphology

Topography plays a crucial role in the dissolution of the rocks via accumulation water in depressions. The Low areas were extracted starting from the DEM according to following methodology made by Minelli 2007:

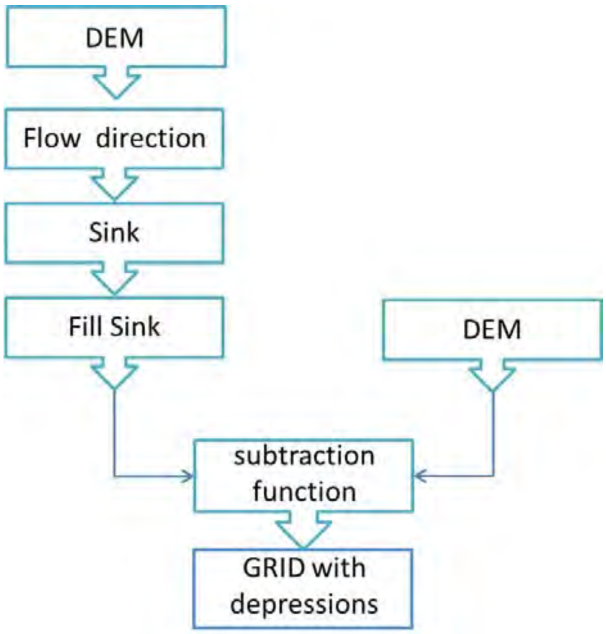


Fig.7- Methodology for the determination of low areas.

The result is a map Grid with different polygons that may correspond to water receptacles. They are grouped into 5 classes according to the water retention capacity.

depth	*classes*
No depression	**0**
< 0.5m	**1**
0.5m< and <1m	**2**
1m <and< 2m	**3**
>2 m	**4**

Table 2. Depression classes.

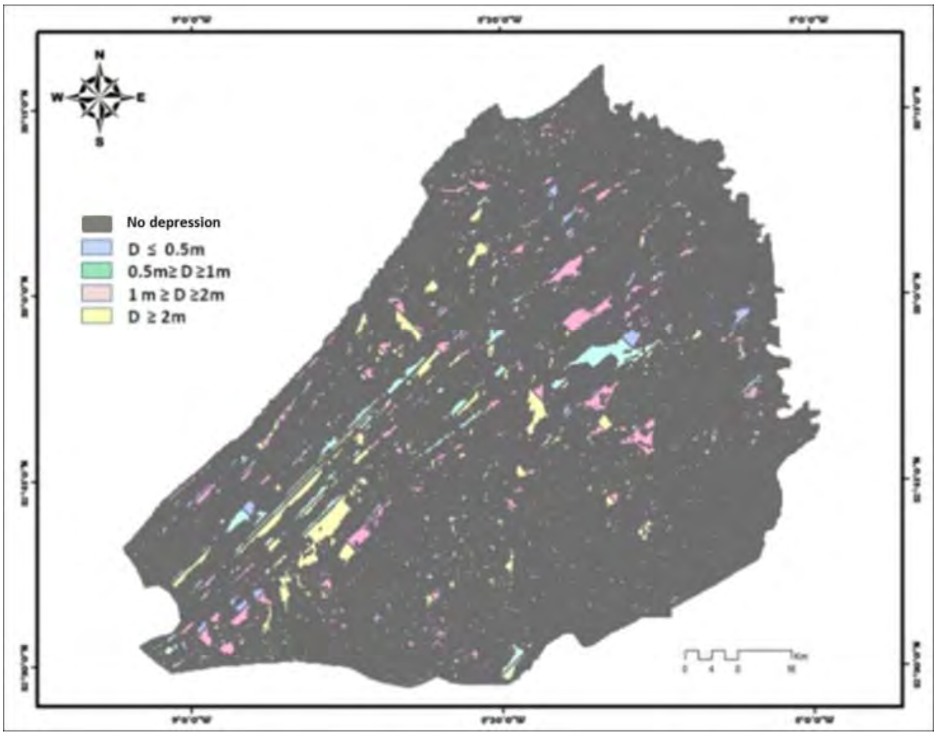


Fig. 8- Depressions Map.

3.4. The Drainage density

Temporary watercourses as ditches, basins and torrents, or permanent watercourses as rivers and creeks, provide both rock erosion and corrosion, and also infiltration in erosive or accumulative bedrock. Between the karstification processes intensity and drainage density, in equal rainfall conditions, ratios are proportional (Ilie, 1970).

This step aims to determine the density classes based drainage; it is estimated from the river network and wetland following the steps (fig.9).

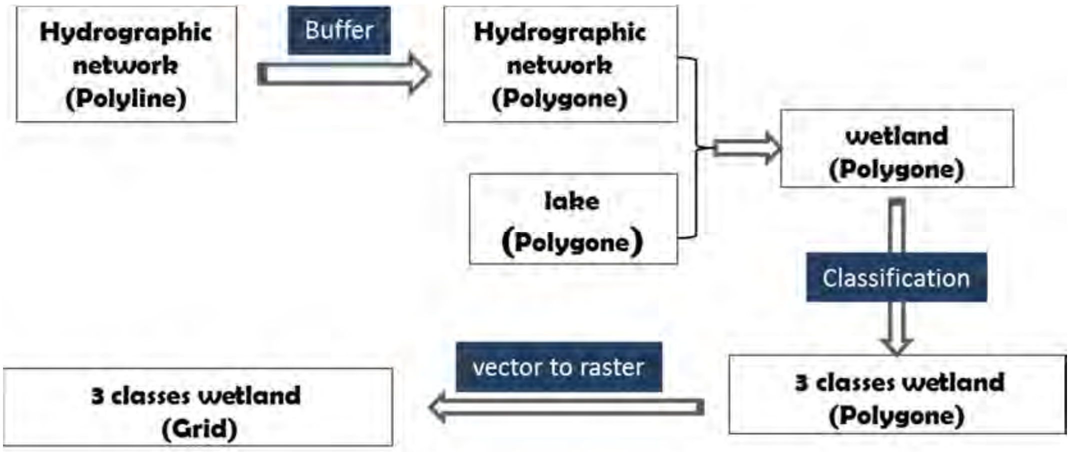


Fig.9- Steps to achieving the 3 classes of wetlands.

The grid generated contains three polygons according type of drainage: 1) permanent streams2) semi-permanent streams3) temporary streams. For each one we attribute a value depending on the importance in the process of dissolution.

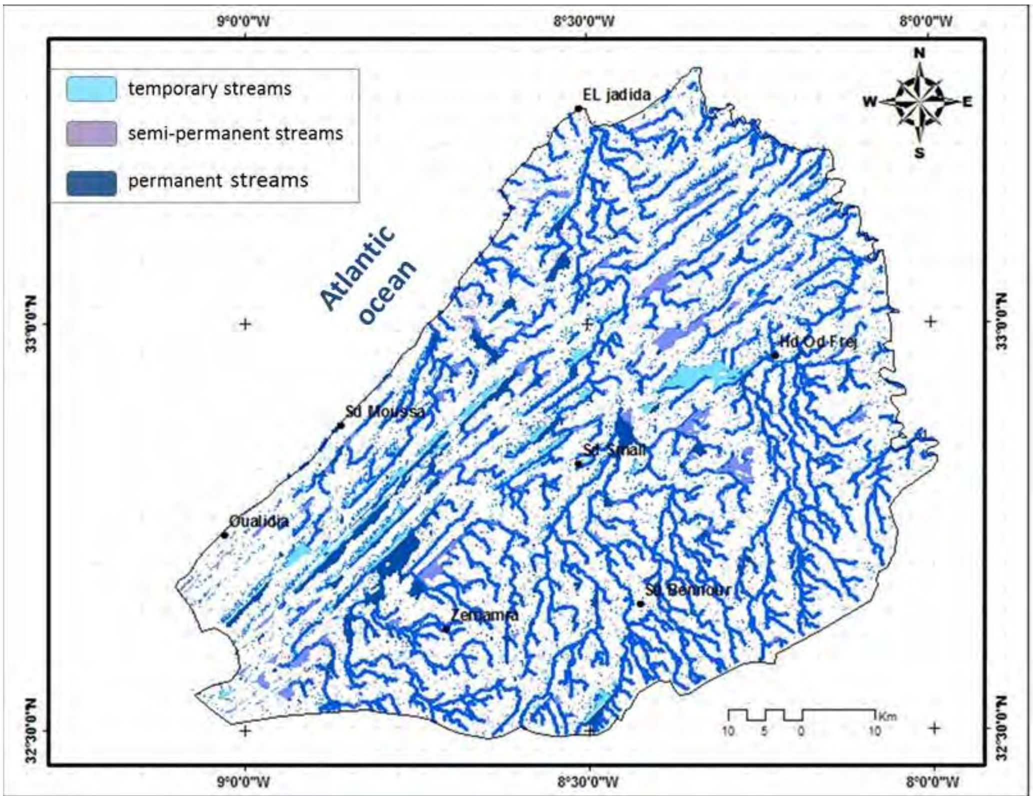


Fig.10- Drainage system map.

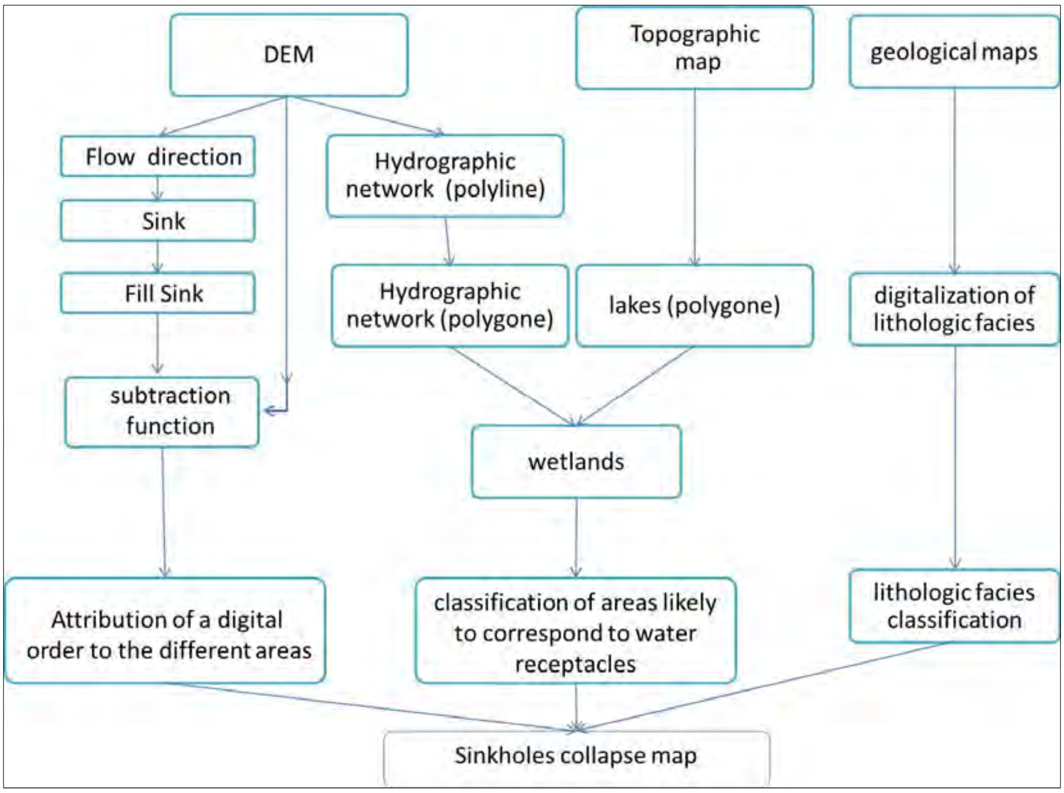
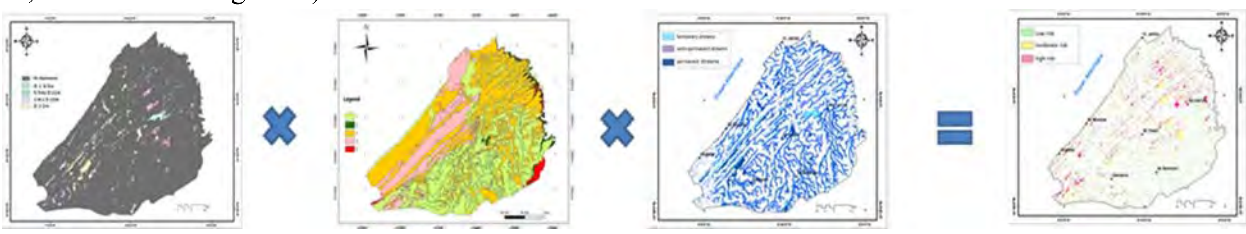


Fig.11- Methodology developed to generate the risk map collapses.

4. RESULTS

The three generated products 'Grid' (Lithology, Depression, and Drainage density) will be introduced to our model. The result "output" is a synthetic risk map of collapse showing three areas (low, moderate and high risk).

The resulting map generated shows the areas where sinkhole will be in the future not the existing sinkhole (even if some areas can contain the existing sinkhole).



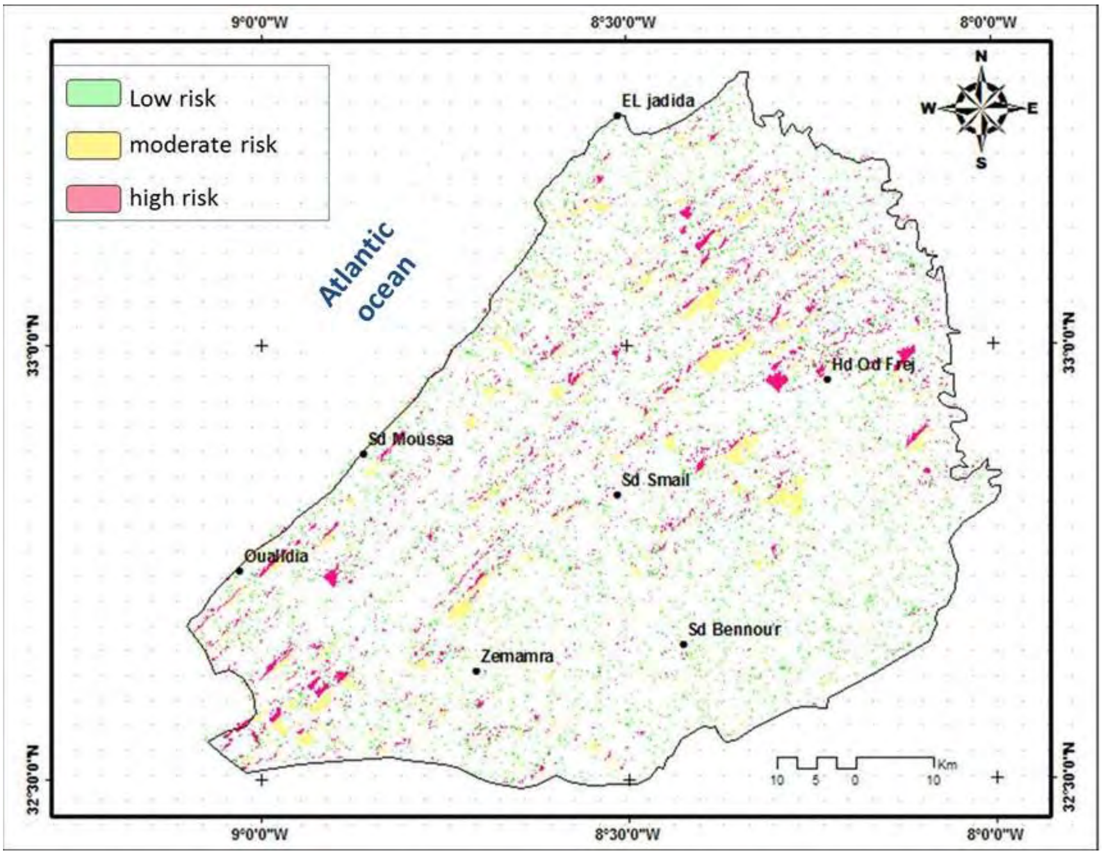


Fig.12- Collapse risk map.

The sinkhole probability map is consisting of three main areas:

1) The first one in the south of the study area at the plain of Doukkala: In this area, the collapse sinkholes are scarce and small, this can be explained by the lack of depression which is a water container needed to dissolve the rocks.

2) The second part which is located in the North East and South west of the region characterized by an abundance of wide sinkhole and high risk; this reflects a combination of three main factors with high degrees.

3) The third part in the middle of the Sahel: in this region sinkholes are numerous, but small sized and aligned; it's probably related to depressions which are located in the inter-dune areas.

The difference observed between the three areas is mainly due to the topographic difference, morphological contrast between the plain and the Sahel, Upstream, in the Massif Rehamna, the slope is relatively dip in its foothills. However, when you arrive at the plain, the slope falls rapidly. Meanwhile, towards the coast, the slope of the bed increases slightly because of the presence of dune relief Sahel (Ouadia and Aberkan 1996). Lithology also has an important role in this difference since in the Plain silts less soluble are dominant and cover all the susceptible rocks dissolution, while at the level of the Sahel the limestone and gypsum marl are dominant.

5. CONCLUSION

The aim of this study is the mapping of areas exposed to collapses sinkholes in the Doukkala using fundamental factors controlling dissolution of rocks mainly lithology, hydrology and geomorphology. The synergies among these three parameters in GIS environment were used for collapses sinkholes mapping. Certainly, this map could be an important tool for land use managers, and decision-makers especially in our study area. This working hypothesis may be used to derive, through the relationships between conditioning factors, a model that provides predictions on the location and size of occurrence of future sinkholes.

This study introduces three main factors in the subsidence hazard, but there are other influence factors: 1) geological factors (texture, porosity and permeability, thickness structure of formations, faults.) 2) Hydrogeological (flow velocity and regime, water infiltration, hydraulic gradient, depth and seasonal variations of the water table, thickness of the saturated, Quaternary deposits, chemical composition of the groundwater...). 3) Climate (existence of stormy events and high temperatures...) 4) Anthropogenic factors (irrigation, pumping, and constructions...) (Soriano and Simon, 1995).

All these factors make the model stronger but collecting data and treatment will be harder and need more time.

The performance's results of the methods used as well as the work described in this document may be considered satisfactory, especially for a fairly large area where there aren't maps showing the distribution of sinkhole, and where the data required is difficult to get.

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