EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(1), 196–206
https://doi.org/10.12912/27197050/154994
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Received: 2022.09.04
Accepted: 2022.10.10
Published: 2022.11.01

Contribution of Geomatics and Remote Sensing to Environmental Study in the Cretaceous Basin of Errachidia-Boudenib (Morocco)

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ABSTRACT

The present study aims at mapping areas vulnerable to water erosion based on the Priority Activity Program/Regional Activity Center (PAP/CAR) model guidelines, geomatics, remote sensing, and GIS in the Errachidia-Boudenib Cretaceous basin. This basin is located in south-eastern Morocco and covers an area of 13 000 km^2, the basin is 320 km long and 75 km wide. The method of estimating water erosion is composed of three phases; a predictive phase consisting of a mapping of predisposing factors such as slope, substrate, and/or soils and vegetation cover, a descriptive phase based on the mapping of actual erosion, and an integration phase to arrive at the identification and evaluation of the erosion risk. The mapping of areas vulnerable to water erosion indicates that 70% of the studied basin has low erodibility and 22% is notable, while only 8% has high to very high erodibility. The areas most affected by degradation are located at the end of the basin and correspond to lands with steep slopes (>35%). Consequently, this study has allowed us to locate certain sectors and roads that may be affected by this type of erosion, namely the mountainous areas of the High Atlas and roads numbered R13, R601, R 703, and P7106.

Keywords: water erosion, PAP/CAR model, GIS, Cretaceous basin, High Atlas.

INTRODUCTION

Erosion is one of the environmental phenomena in Saharan areas characterized by an arid climate to Saharan climate. Thus, the storms (2006–2010 and 2019) or heavy rainfall events that have occurred in recent years in south-eastern Morocco and have led in some cases to loss of life (National Road 13 and l9 in the Moroccan High Atlas), have frequently been accompanied by mudflows. These are a catastrophic form of erosion phenomenon that affects both agricultural areas and economic infrastructures and installations (gullying, mudflows submerging dams and roads, etc.) (Figure 1). Several methods and tools have been developed to estimate water erosion (USLE, RUSLE, LEAM, PAP/CAR, etc.).

The combined contribution of remote sensing and GIS has made possible the modeling and recognition of water erosion at a logical cost (Boggs et al., 2001; Pradhan et al., 2012; Bayramin et al., 2003, Raissouni et al., 2012; Bachaoui et al., 2014; Akalai et al., 2014). The PAP/CAR approach has been used by several researchers who have demonstrated its usefulness for mapping and modeling water erosion (Elbouqdaoui et al., 2006; Bachaoui et al., 2007; El Aroussi et al., 2013; Iaaich et al., 2016).

In Morocco, several researchers have contributed GIS and the PAP/CAR (Priority

Activity Program / Regional Activity Center) approach to water erosion risk mapping. (Ousmana et al., 2017) The PAP/CAR method was used to map qualitative soil erosion in the Oued Zgane watershed (Tabular Middle Atlas, Morocco). GIS and the PAP/CAR method were also successfully used to map erosion patterns and land movements in the Oued Sahb Laghrik watershed (North West of Taza, Morocco) (Hili et al., 2016). In the north of Morocco, this method has also been applied to map the state of soil degradation in the Oued Arbaa Ayacha watershed in the western Rif (Ouallali et al., 2016). This study proposes to map the areas vulnerable to water erosion based on the PAP/CAR model guidelines, GIS, and remote sensing in the Errachidia-Boudenib Cretaceous basin. This approach is preferred for its ease of use. Preliminary results have already made it possible to superimpose and analyze several factors, such as slope, nature of materials, and vegetation cover (Mesrar et al., 2015).

LOCATION OF THE STUDY AREA

Geographical, climatic, geological, and hydrogeological contexts

The Cretaceous Erachidia-Boudnib basin is part of the South Atlas Trench structural unit. It is bounded to the north by the South Atlas fault and to the south by the Anti-Atlas outcrops and the Hammada de Guir. This basin covers an area of 13 000 km^2. The average altitude is between 1000 and 1100 meters and increases to the west towards the Imider threshold (Madani, 2012). Geographically, the north of the basin is a mountainous area (the highest altitude is 1300 meters); where the South Atlas Accident forms the boundary of the basin with the High Atlas. In places, the Cretaceous sediments are integrated with the Atlasic domain, a central area with a mainly Cretaceous sedimentary fill that is tabular or slightly inclined to the north and is often overlain by Quaternary formations. The domain is divided into three sectors; in the west, the plains and plateaus of the Ziz and Rheris can be distinguished; in the Center, a ravine between the High Atlas and the Guir valley; in the east, the Guir-Bouanane plain extends; the sedimentary line in the southern margin of the basin is thin and unconformable with the Paleozoic. The altitude is relatively low compared to the northern outcrop (Figure 2).

Hydrogeologically, the study area contains several hydrogeological units that are often interconnected: the Infracenomanian, Turonian, Senonian, and Quaternary. These aquifers produce several springs, the most important of which are Meski, Tarda, and Tifounassine.

Figure 1. Gullies and mudslides submerging the national road number R13

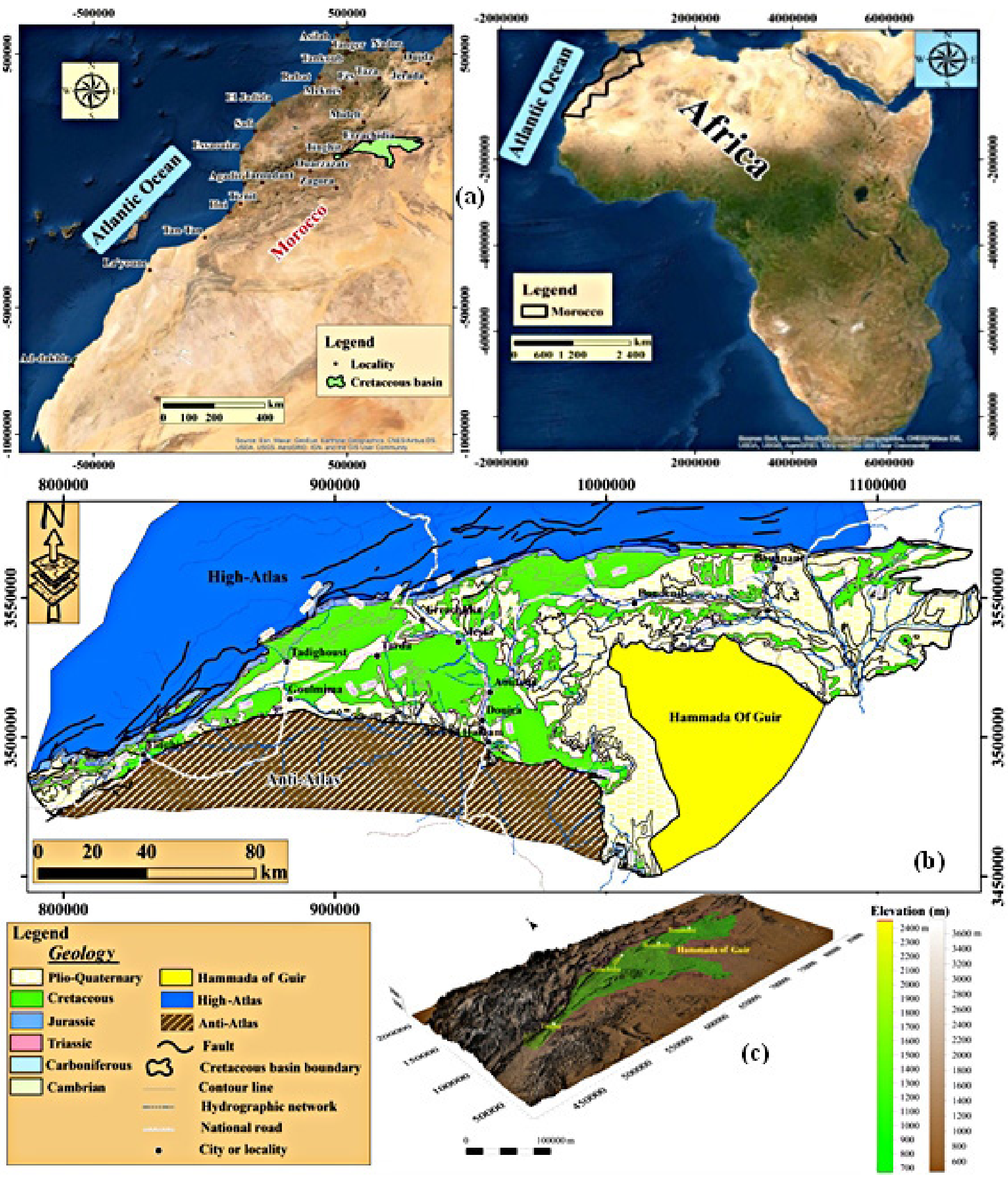

Figure 2. Geographical (a), geological (b) and 3D DTM (c) location map of the study area

The aquifers are generally recharged from the High Atlas by flow through faults linking the Cretaceous basin with the Jurassic formations and by direct infiltration of rainwater and irrigation water.

WORKING METHODOLOGY

The PAP/CAR approach directs the research work on water erosion in mountainous areas towards a qualitative model that allows the classification of the surface of a catchment area into different units according to the vulnerability to erosion and to predict the trends of the simultaneously prevailing water erosion processes. The qualitative model adopted for the mapping of soil susceptibility to water erosion in the Cretaceous basin (Figure 3), is based on the exploitation of data relating to topography, geology, vegetation cover and field observations, Landsat-8 and Google Earth Prof satellite images, the digital terrain model (DTM) from ASTER GDEM radar images of 30 m resolution, and geological maps covering the basin at a scale of 1:100.000, have made it possible to delimit the study area and to produce the various thematic maps, using the functionalities of software dedicated to remote sensing and the Geographic Information System (GIS). These data were georeferenced to the Morocco coordinate system.

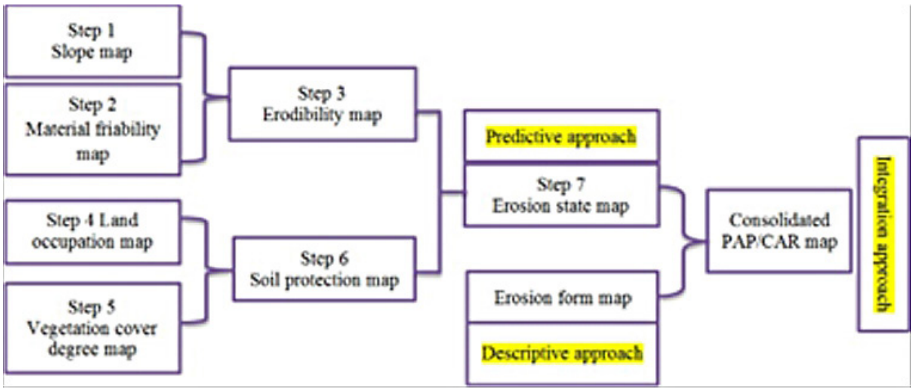

Figure 3. Methodology adopted for the estimation of potential erosion by the PAP/CAR method

Description of the predictive phase

The predicted phase's expected result is a map of erosive states where erosion classes are obtained by superimposing the maps of several factors. Each factor contributes to a certain degree to the different erosive states (Ousmana et al., 2017).

Erodibility

The erodibility map is the result of the superposition of the lithofacies map and the slope map. The fact that the steeper the slope, the more the weathering mantles of the rocks are rejuvenated by erosion is scientifically accepted. The erodibility of soil expresses the potential of a rock outcrop to provide elements for erosion. The weathering rate or friability of a substrate and the slope must therefore be taken into account.

The slope map

The process begins with the development of the slope map from the ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) images. It is produced in 2009 by the USA and Japan. This DTM was produced with the ASTER radar on NASA's Terra satellite and offers a large global coverage (99%) with a very fine resolution of 30 m (Terra spacecraft, 2009). According to the PAP/CAR guidelines, the slopes are divided into 5 classes (Table 1).

Table 1. Slope classes

PAP/CAR code	Slope class
1	Nil to low (0–3%)
2	Moderate (3–12%)
3	Abrupt (12–20%)
4	Very steep (20–35%)
5	Extreme (>35%)

The lithofacies map

The lithological nature, linked to the physicochemical variations of the materials, plays an important role in the erosive processes (Demmak, 1984; Terfous et al., 2001). Topographical conditions often combine with lithology to favor certain processes. Thus, the lithofacies map was produced based on the 1:1000.000 geological map of Morocco. The map of the resistance of materials to erosion is deduced from the lithofacies map. It is called the friability map in the PAP/CAR model and represents the main substrates, rocks, or surface sediments classified into 5 classes according to their relative degree of cohesion and resistance to erosion. For each class, a code is assigned according to the degree of friability; (a) for the most compact and resistant rocks and (b), (c), (d), and (e) respectively for progressively less compact and resistant rocks (Table 2). The water erosion susceptibility map was established using the PAP/CAR (Priority Activity Program/ Regional Activity Center) method, which essentially comprises three approaches (PAP/CAR 1998, Figure 3).

The map in Figure 4 shows the distribution of terrains according to their degree of friability (very high for silts and clays, high for sands and gravels, and medium for sandstones). In general, according to the PAP/CAR approach, the different geological outcrops are divided into five classes and each degree of friability is assigned a code, 1 for hard rocks and progressively 2, 3, 4, and 5 for less and less hard rocks. Summarizes the order of friability of the substrates (Fig. 4).

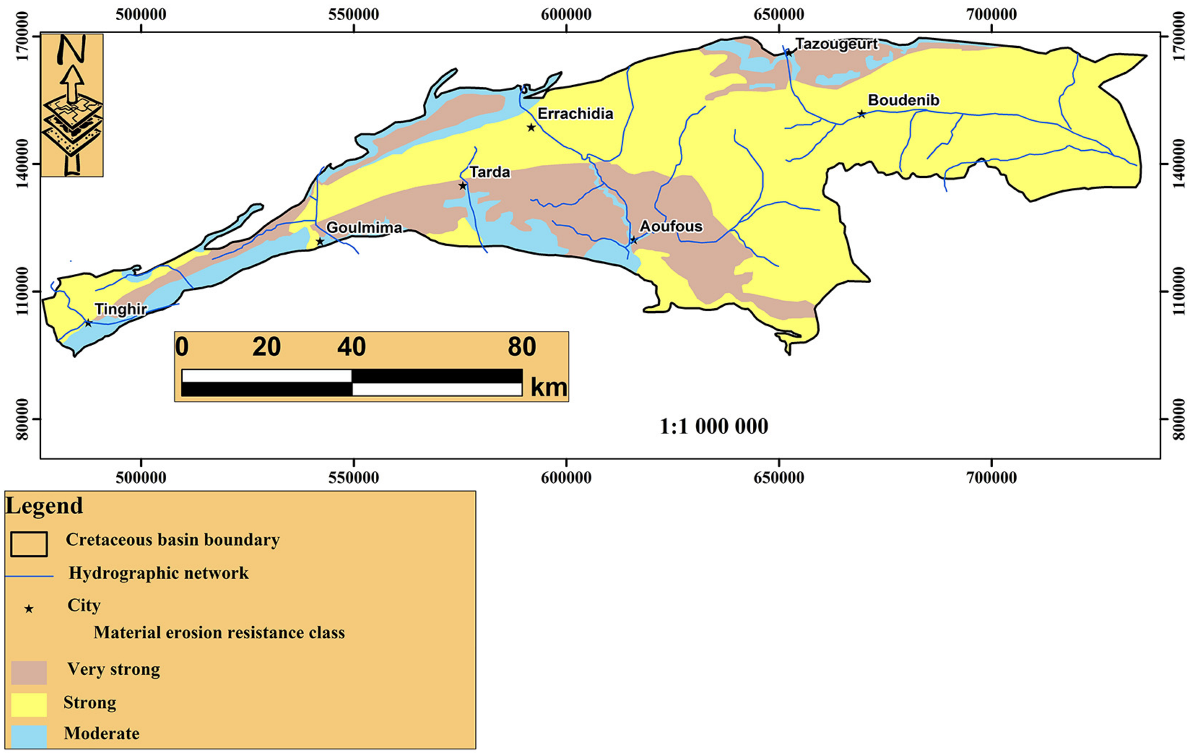

Figure 4. Lithofacies map of the study area (source ABH GZR modified)

Table 2. Lithofacies classes

Lithofacies classes	Type of equipment
1	Unweathered compact rocks, strongly cemented conglomerates, outcrops of limestone sandstones or igneous or eruptive rocks
2	Fractured or moderately weathered cohesive rocks or soils
	Sedimentary rocks or low to moderate soil
3	Compacted (marl, marl-limestone)
4	Rocks with low resistance and high weathering (gypsum, shale, tuffaceous crusts, molasses, etc.)
5	Loose, non-cohesive sediment or soil and detrital material

Table 3. Soil erodibility matrix

Slope classes	Lithofacies classes				
	1	2	3	4	5
1	1	1	1	1	2
2	1	1	2	3	3
3	2	2	3	4	4
4	3	3	4	5	5
5	4	4	5	5	5

Table 4. Degrees of erodibility

Class	Degrees of erodibility
1	Low
2	Moderate
3	Average
4	Strong
5	Extreme

According to the PAP/CAR approach, erodibility is obtained in the resulting polygons by applying the following matrix (Table 3).

The resulting map is then analyzed and the erodibility classes are subdivided according to the PAP/CAR guidelines summarized in Table 4.

Table 5. Land use class

Class	Land use
1	Dryland or bare land cultivation
2	Arboriculture and Reforestation
3	Intensive cultivation in the vicinity of housing
4	Natural forest
5	Dense canopy matorral
6	Open canopy matorral

Soil protection

Soil protection by vegetation cover depends on the nature of the land use and the density of cover. The soil protection map overlaps the land use map and the canopy cover density map.

The land use map

This map was drawn up using "Erdas Imagine 9.2" and then "google earth". It was completed in the field and then digitized in GIS. Several types of land use coexist in the Cretaceous basin. The land cover and land cover classes according to the PAP/CAR guidelines are shown in Table 5.

The degree of vegetation cover map

Vegetation cover depends on the growth and development of vegetation in relation to the variation in erosivity of the climate. This factor plays a key role in maintaining soil resilience because regardless of the soil, slope, and climate, a complete vegetation cover allows for better soil and water conservation. Thus, according to the PAP/CAR Directive, each degree of vegetation cover is assigned a code from 1 to 4 (Table 6).

The map of predictive erosive states

The erosive state map is the final product of the prediction phase, resulting from the overlay of the erodibility map and the soil protection map. The overlay is done by applying the matrix presented in Table 7.

Table 6. Classes of the degree of vegetation cover

PAP/CAR classes	Degree of vegetation cover
1	Less than 25%
2	25–50%
3	50–75%
4	More than 75%.

RESULTS AND DISCUSSION

Predictive approach

Slope map

The map shows that the study area is characterized by a generally moderate slope of the landforms (3–12%) (Figure 5).

Erodibility map

The map resulting from the superposition of the slope map and the lithofacies map (Figure 6) indicates that erodibility is dominated by the two very extreme and strong classes, while the medium, moderate and weak erodibility classes are the results of areas with slopes above 20%.

Soil protection map

Map of the degree of vegetation cover

The degree of vegetation cover map developed shows two vegetation classes (Figure 7): sparse vegetation (less than 25%) and medium density vegetation (25–50%), each class is assigned a value between 1 and 2; the class with the least cover is assigned the number 1 and the class with medium cover the number 2. The map indicates that the degree of vegetation cover in the study area is negligible.

Land use map

The analysis of satellite data in the Errachidia-Boudenib Cretaceous Basin has identified five main land use classes, as follows (Figure 8):

Table 7. Matrix of soil erosion conditions

Degree of soil protection	Degree of erodibility				
	1	2	3	4	5
1	1	1	1	2	2
2	1	1	2	3	4
3	1	2	3	4	4
4	2	3	3	5	5
5	2	3	4	5	5

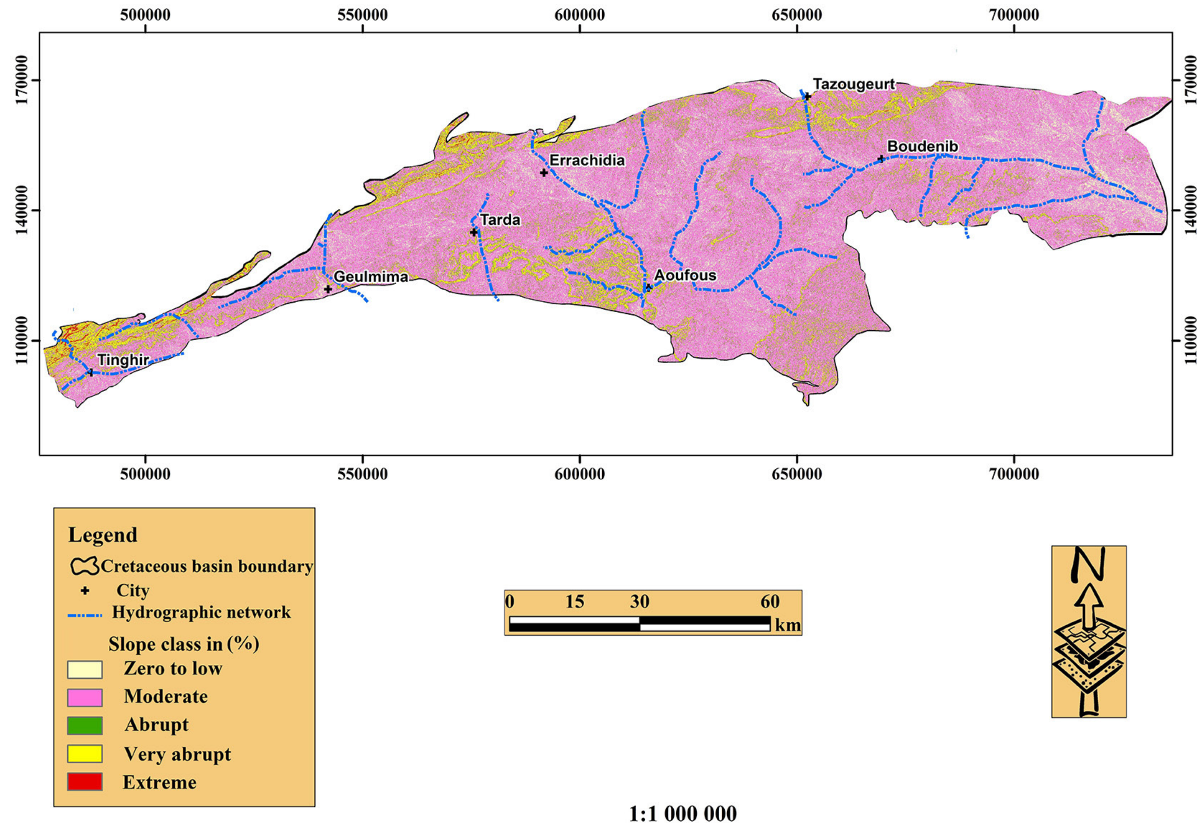

Figure 5. Map of the slopes of the Cretaceous basin

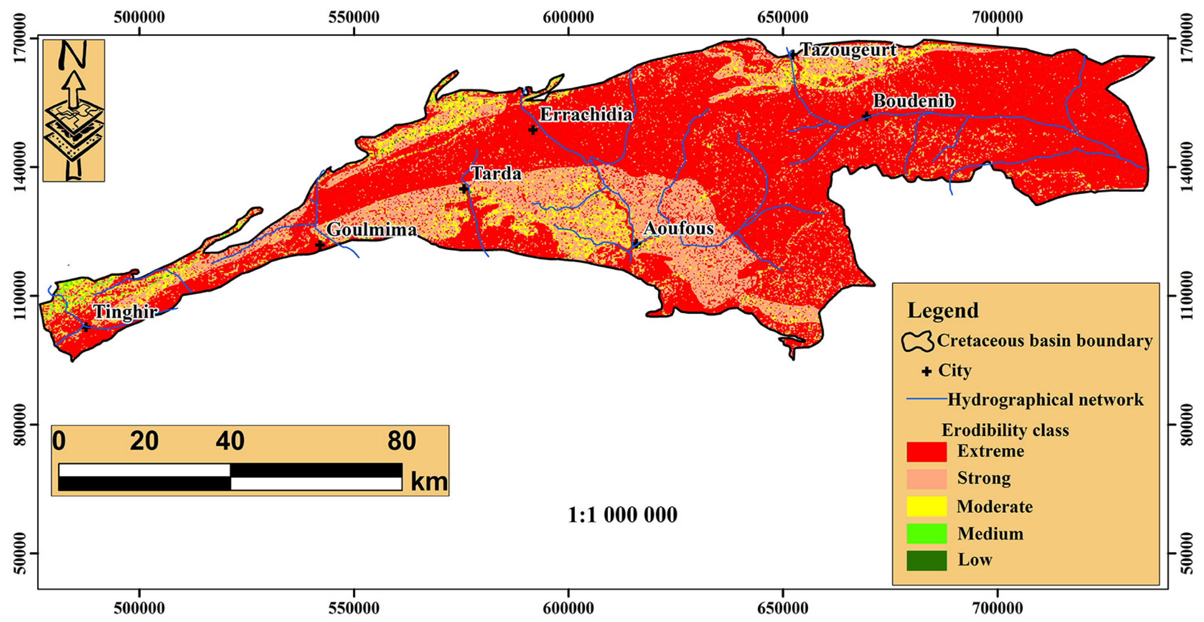

Figure 6. Erodibility map of the Cretaceous basin materials

- bare land (rangeland or uncultivated): generally, dominates the entire basin;
- sandy areas: the sandy areas are mainly located in the central part of the basin (from the east and south-east to the west), probably due to its lower altitudes compared to the northern parts, and also due to the dominant winds in the Ziz, Rheris and Guir basins, especially the chergui winds, which blow from the south-east to the north-west, and consequently, the sandy particles take the direction of the west since this area is in the form of a corridor bounded

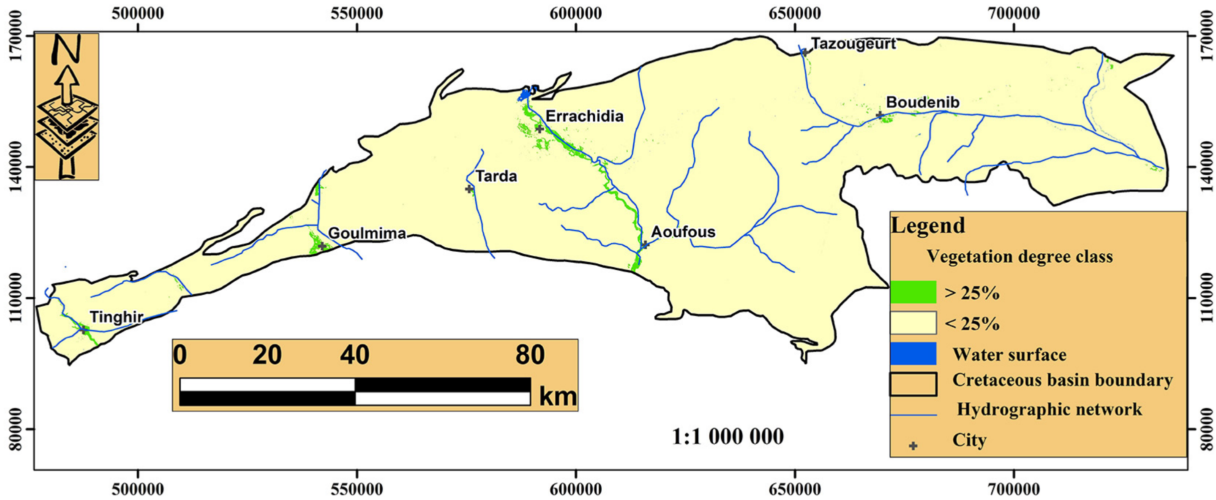

Figure 7. Degree of vegetation cover map

by the High Atlas and the Anti Atlas, which makes it possible to consider it as a shelter for these sandy particles;

- vegetation cover: represented by the oases located along the main wadis, such as the palm groves of Goulmima, Todgha (Tinghir), Ziz, and Guir dominated by date palms and cereal crops;
- built-up areas: are generally represented by the main population Centers in the basin;
- water bodies: the Cretaceous basin has one large hydraulic dam, the Hassan Adakhil dam, small dams, and diversion dams.

Soil protection map

The resulting map (Figure 9) shows a very low degree of protection in the entire study area.

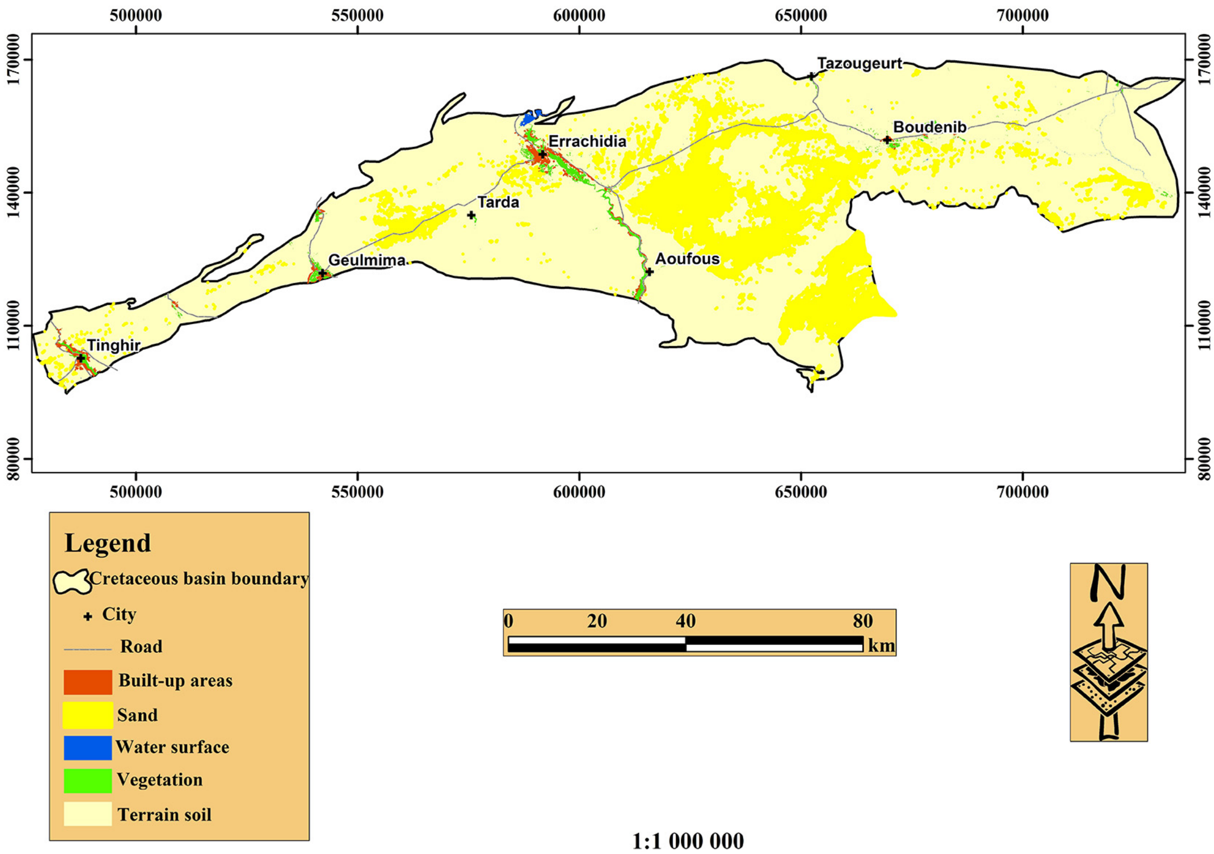

Figure 8. Land use map of the Errachidia-Boudenib Cretaceous basin (April 2016)

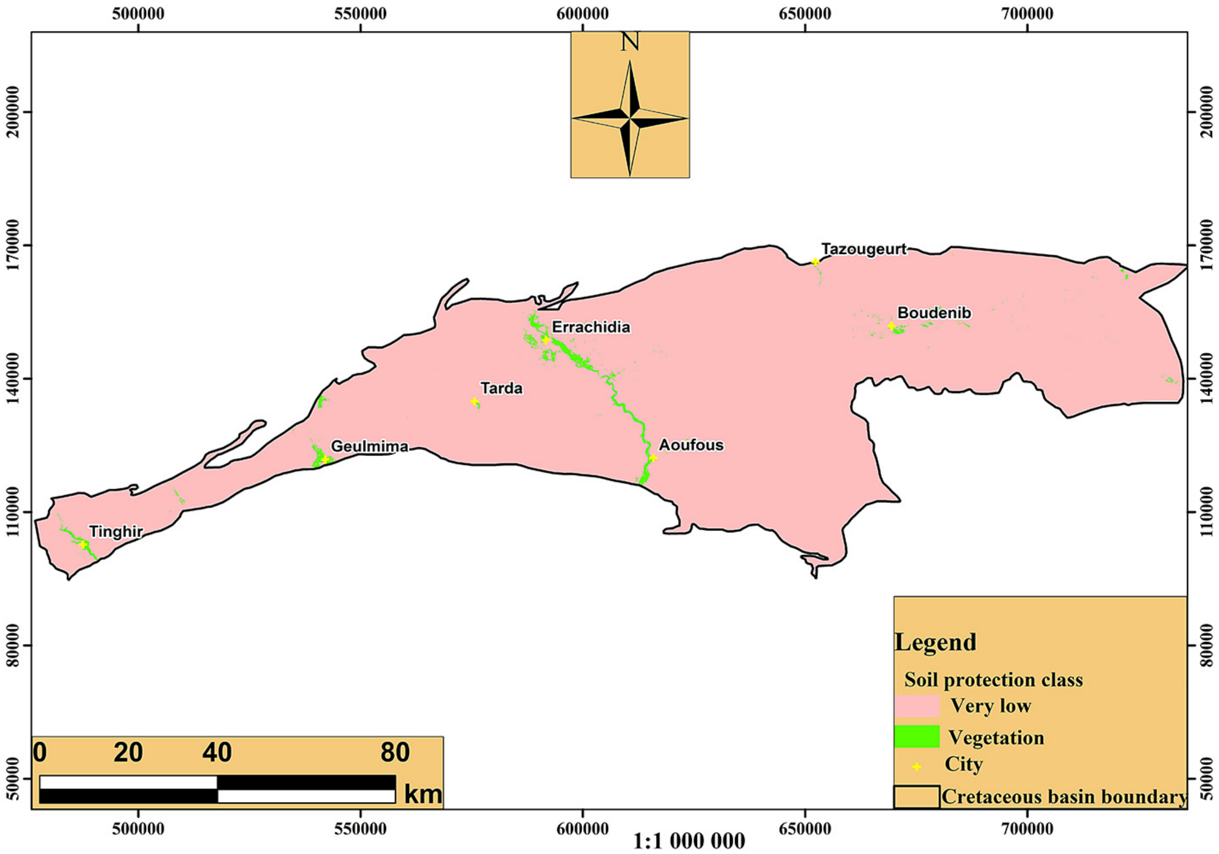

Figure 9. Soil protection map of the Errachidia-Boudenib Cretaceous basin

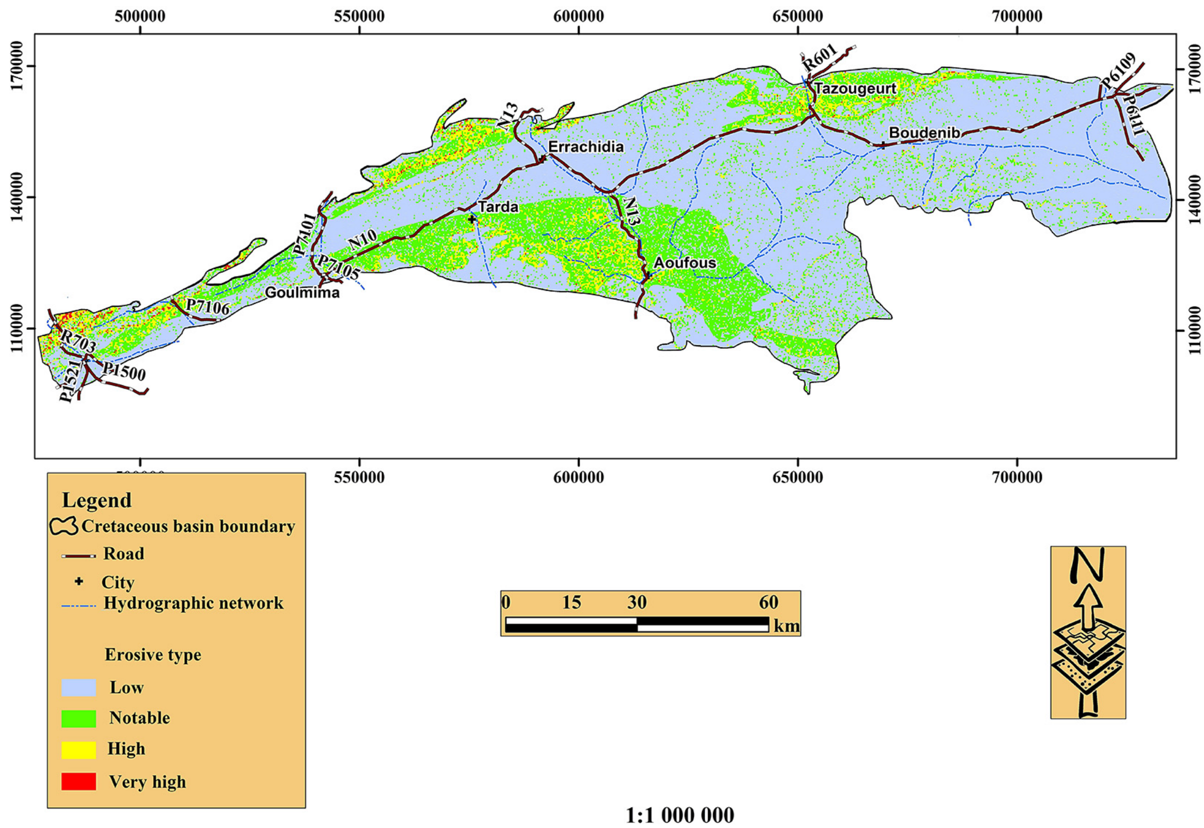

Figure 10. Map of erosive conditions in the Cretaceous basin

Predictive erosive state map

The final map (Figure 10) represents the different states of water erosion in the study area. Thus, it can be seen that the most dominant class is the low erosive state class, while the very high class characterizes the high-altitude areas.

CONCLUSIONS

The qualitative study of potential erosion using the PAP/CAR method, based on natural factors (slope, lithology, vegetation cover, and land use), has enabled the analysis and understanding of the problem of the study area in terms of erosion risk. It has shown its importance as an efficient tool to carry out, simply and quickly, a general diagnosis of the potential risk of water erosion at the scale of the Cretaceous basin.

This work has enabled the creation of a multi-source database on the study region and has shown the importance and contribution of geographic information systems and remote sensing to the mapping of areas at risk of water erosion. The predictive phase provided information on the current state of soil degradation based on the degree of influence of the different factors controlling water erosion. From the erosive state map, it can be seen that the erosion rate is very high due to heavy rainfall and deposited on extreme slopes (>35%) on the alluvial plains where a strong alteration of the parent rock will result in the accumulation of clays. These results are similar to those of authors (Donfack et al., 1988) who established that degradation is very high in clayey or marly soils. Add to this that erosion is stronger at the level of the reliefs (limit between the Cretaceous basin and the High Atlas) because of the increase in erosion and transport of the upper parts of the soils which are not very evolved types and the increase in precipitations generally of the stormy type which characterize the climate of the region. Other authors (Ouallali et al., 2016; Ousmanaet al., 2017; Mesrar, 2016; Ait Yacine, 2019) have found that water erosion depends on the morphology of the land and thus on the effect of the slope. Indeed, the final map shows that 70% of the studied catchment area has low erodibility and 22% notable, while only 8% characterizes high to very high erodibility. Indeed, this study has allowed us to locate certain sectors and roads that may be contaminated by this type of erosion, namely the mountainous areas of the High Atlas and roads number R13, R601, R 703, and P7106.

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