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Study of Vulnerable and Water Erosion Risk Areas in Sareg Catchment (Central Tunisia) Using Remote Sensing, GIS and P.A.P/R.A.C. Qualitative Approach

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Study of Vulnerable and Water Erosion Risk Areas in Sareg Catchment (Central Tunisia) Using Remote Sensing, GIS and P.A.P/R.A.C. Qualitative Approach

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Abstract

The study of water erosion has always been a major concern for human societies. Efforts to reduce resulting forms of degradation and to understand their extent have not ceased. This article aims to identify vulnerable and water-erosion-prone areas in the study area. This is achieved through a predictive and descriptive approach leading to the integration of main physical parameters from various sources with direct observation data. The use of remote sensing, GIS and direct observation according to PAP/RAC guidelines has made it possible to prioritize areas at risk of erosion. The basin's lands show a general predisposition to water erosion, with 80% of them experiencing significant, high or very high erosion, including 20% for the last two categories. This situation is linked to a high erodibility of the geological outcrops of the basin (81%), with a low to very low degree of soil protection through vegetation cover (80% of the surface). The descriptive phase shows eroded surfaces of about 18%, a proliferation of ravines (12% of the surfaces) of which 6% are hierarchical ravines and bad lands. The integration phase, while confirming most of the previous data, provides an overview of the trend towards the extension of gullies observed during the descriptive phase to neighboring lands that were not initially subject to erosion. This study shows that a good integration of descriptive and predictive methods can lead to a good understanding of water erosion, which will facilitate solutions to control this phenomenon. It also shows the importance of GIS, remote sensing and their integration with direct field observation in order to produce a document that can be used, at a low cost, as a decision support tool.

Keywords: Erosion, PAP/RAC, GIS, Remote Sensing, Tunisia.

Introduction

Conservation of water and soil resources is one of the major challenges for all the world's nations. Faced to soil erosion and its losses to human communities, an effective and sustainable strategy is more than necessary. Catching runoff water and retaining its solid charges, which are the soils, must begin with a full understanding of erosion processes and with accurate and clear-sighted diagnoses. Water erosion is the main factor in soil degradation in Tunisia. The annual loss of useful land is well documented (Andersson 2010; Cormary et al.1964; Jebari 2009; Jebari et al. 2010; Masson 1971; Zante et al. 2003; Kaya et al., 2008). More recent work using modern assessment techniques confirms these trends (Gaubi et al. 2017). Central Tunisia has long experienced uncontrolled and continued erosion. Irregular rains and vegetation cover degradation, as well as crop management expansion and overgrazing, have only worsened the situation. Methods for assessing water erosion have recently been developed, increasing reliability and accuracy. This is mainly due to use of new methods such as GIS, remote sensing, numerical and empirical models. For this reason, we have used one of these methods in this work, which uses GIS and remote sensing among other sources and techniques to try an assessment of water erosion in the study area. PAP/RAC has the advantage of combining user-defined descriptive methods directly on field with predictive methods developed in a GIS environment (Grisbach et al. 1998). Since guidelines publication, several studies have tried to use them in different regions of the Mediterranean area (Sadiki et al. 2012; Boukrim et al. 2012; Faleh et al. 2014; Lima et al., 2014; Simav et al., 2015; Kaya & Gazioğlu, 2015; Mesrar et al. 2015; Gazioüğlu, 2018; Ülker et al., 2018; Ouallali et al. 2016; Lakhili et al. 2017; Ousmana et al. 2017; Fernandez et al. 2016 in Morocco, Portugal, etc.

Study Area

Study area corresponds to Sareg watershed, a northern tributary of the Leben Wadi. Vast of 157 km2 (15700 ha), this basin extends between 9°28' to 9°38' East and 34°42' to 34°52' North (Fig. *1*). Altitudes range from 215 to 742m (Fig. *2*). The catchment is bounded on west by the eastern end of Meloussi Mountain, on north by Boudinar, on east by Gouleb, Méhiri and Jebs. However, most of land corresponds to plain of Hachena in north and Remilia in south. While Meloussi and Bou Dinar reliefs are formed by dolomitic limestones of Cretaceous, those of Méhiri, Jebs and Gouleb are composed of Triassic or Eocene evaporite rocks (Fig. *3*). Foothills are composed of Miopliocene clays, silts and sands. Rest of land corresponds to alluvial and fine

Holocene-Present alluvial and aeolian deposits. Study area belongs to Upper Arid climatic stage. The nearest rainfall station, Meknassy, has an annual average of 198mm. Rainfall, although rare and irregular, often falls as heavy and brief thunderstorms that trigger sometimes violent and dissecting runoff. Reliefs surrounding the basin are covered with a degraded garrigue of Phoenicia juniper. While western foothills are covered by an Alfa steppe, gypsum soils of the East are covered with halophilic vegetation.

Materials and Methods

Erosion assessment methodology used here is that of PAP/RAC model (Priority Action Program of Regional Activity Centre 1998), which is part of Mediterranean Action Plan (MAP), which is itself part of United Nations Development Program (UNDP) (Grisbach et al., 1998, Fig. 5). PAP/RAC guidelines consist of three approaches:

- predictive approach:

It consists of integrating basic physical factors such as topography (slope), lithology, and vegetation (land use and density). In this step we used a 28m-resolution digital terrain model (DEM) (NASA) to produce slope map. Geological map at 1/50000 (Office national des Mines, 2005, Meloussi sheet n°: CIII), was used to digitalize lithofacies that were classified according to model categories. For land use map, we used a satellite images (Copernicus Open Access Hub). For vegetation density map, several authors have preferred to use NDVI index since it represents a modern, reliable and easy alternative (Fernandez et al. 2016) (Ousmana et al. 2017). We have also followed this choice. In this step we used classification categories given by guidelines (Table 1, 5, 7). Second step is to integrate, using integration matrices provided in guidelines, the four base maps two by two (Table 5, 11). It consists of integrating basic physical factors such as topography (slope), lithology, and vegetation (land use and density). In this step we used a 28m-resolution digital terrain model (DEM) (NASA) to produce slope map. Geological map at 1/50000 (Office national des Mines, 2005, Meloussi sheet n°: CIII), was used to digitalize lithofacies that were classified according to model categories. For land use map, we used a satellite images (COAH). For vegetation density map, several authors have preferred to use NDVI index since it represents a modern, reliable and easy alternative (Fernandez et al. 2016) (Ousmana et al. 2017). We have also followed this choice. In this step we used classification categories given by guidelines (Table 1, 3, 5, 7)

Second step is to integrate, using integration matrices provided in guidelines, the four base maps two by two (Table 5, 11, 13). The first two ones (slopes and lithofacies) produced soil erodibility map. The other two ones (land use and vegetation density) were used to obtain soil protection map. This integration was carried out using GIS software (ArcGIS) with the following steps (tools): Union - dissolves for each two polygon maps. Last step consists in integrating the two maps of second step to have final map of erosive states.

- descriptive approach:
It consists in producing erosion forms map by direct observation via a satellite image navigator and field verification. Erosion categories of forms and symbols used are those provided by PAP/RAC guidelines. Erosion forms polygons were obtained by direct digitization and then transferred to GIS software.

- integration approach:
It consists of superimposing erosion forms map on erosion states map. It allows consolidation of erosion data by confirming or not the existence of areas subject to erosion.

Results and Discussions

Soil Erodibility
Lithofacies predispose lands to erosion:

Lithofacies map was made from geological map of Tunisia. It shows that most of land (78%) is in soft and loose rock category (fig. 6/ Table 2). Coherent and compact rocks represent only 22%. This predisposes basin land to water erosion.

Table 1 Lithofacies classes according to PAP/CAR guidelines

Lithofacies classes	**Material type**
(a)	Unaltered compact rocks, highly cemented conglomerates, crusts, outcrops sandstone ferruginous (massive limestones, soils highly rocky, igneous or eruptive rocks, locally encrusted soils).
(b)	Fractured or moderately altered cohesive rocks or soils.
(c)	Sedimentary rocks or soils slightly or moderately sedimentary compacted (slate, schist, marl, etc.).
(d)	Rocks and/or soils with low strength or strong/deeply altered (marl, gypsum, clay slate, etc.).
(e)	Sediment or loose soil, non-cohesive and detrital material.

Table 2 Distribution of lithofacies in the basin

Lithofacies Classes	Area (ha)	%
1 Compact and cohesive	1793	11,37
2 Cohesive slightly fractured or slightly altered	1048	6,64
3 Moderately compact	618	3,92
4 Slightly resistant, severely altered	893	5,66
5 Crumbly, detrital	11410	72,38

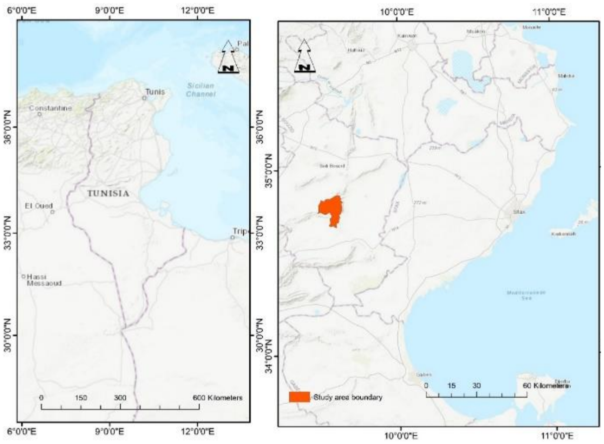

Fig. 1 Location map

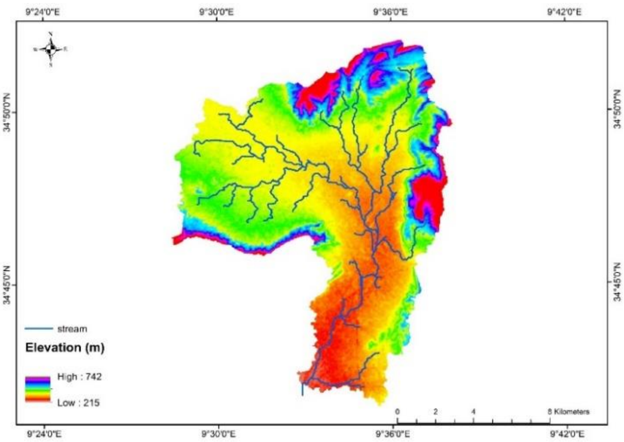

Fig. 2 Digital elevation mod

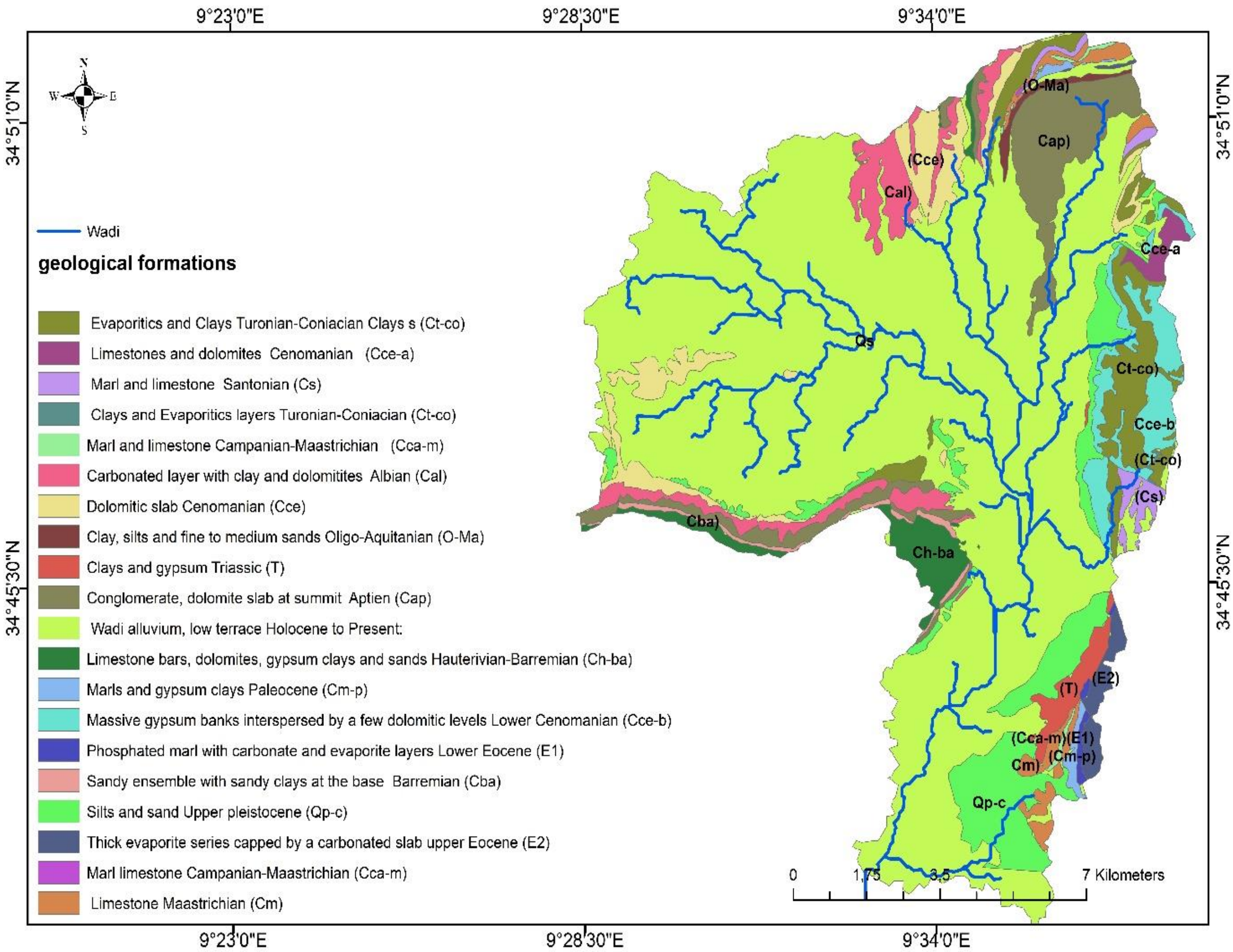

Fig. 1 Geological map

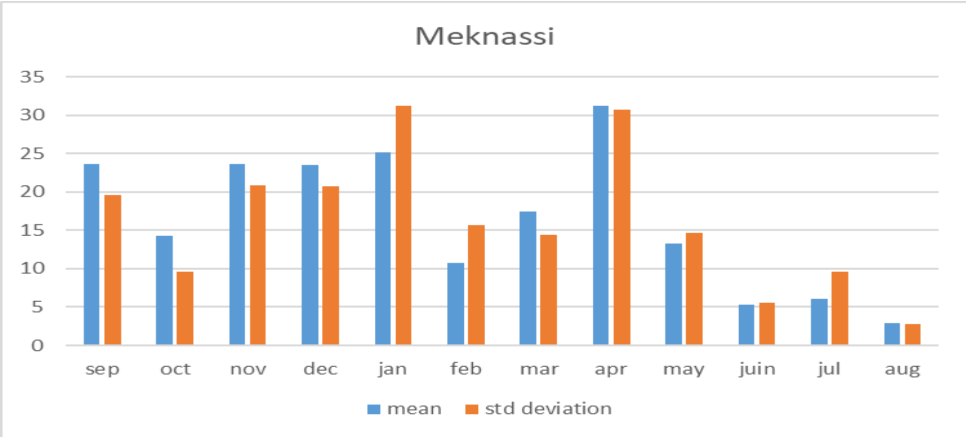

Fig. 2 Monthly average rainfall in Meknassy station between 2002 and 2011

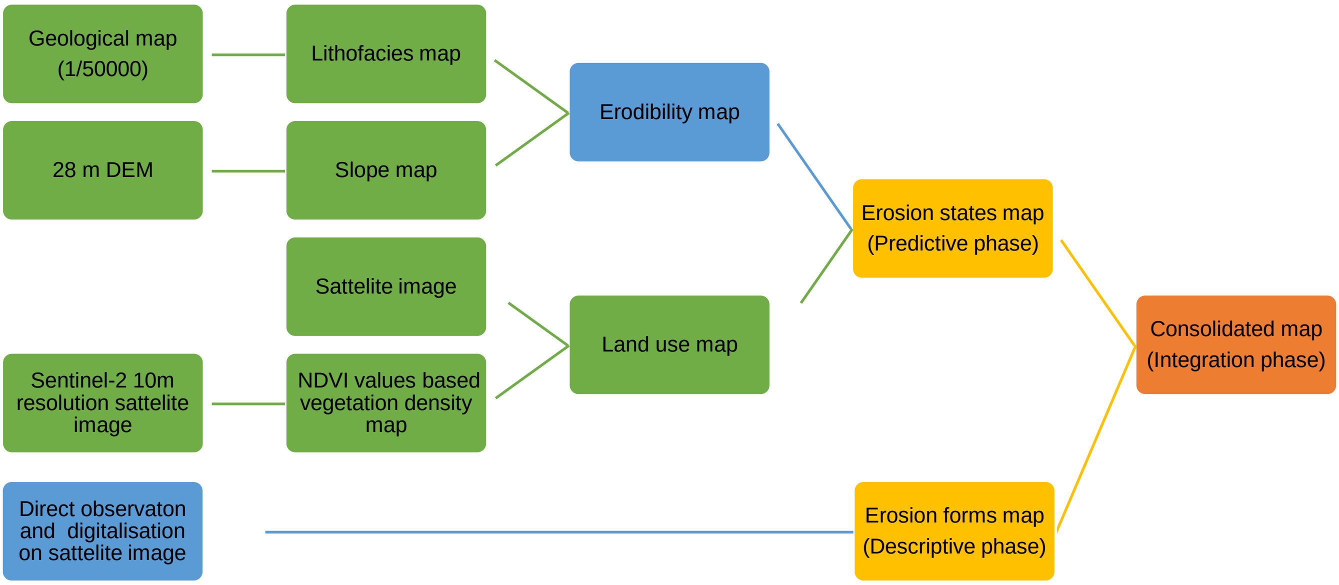

Fig. 3 Methodology flowchart

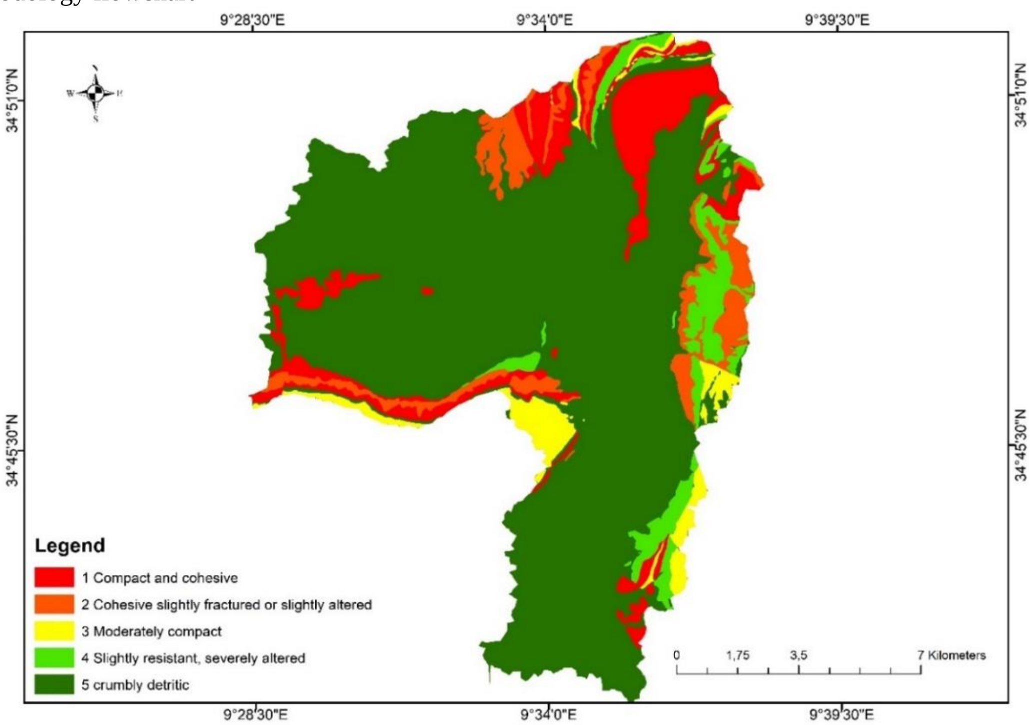

Fig. 4 Lithofacies map

Steep slopes characterize a significant part of the basin:

Slope map was based on a digital elevation model (DEM). It shows that steep, very steep and extreme slopes represent 30% of the total and are confined to the mountainous areas bordering the catchment (Fig. *5*) (Table *4*). Moderate slopes represent 58% and low slopes 8%. They also represent most of land in basin.

Table 3 Slope classes according to PAP/RAC guidelines.

Class	**Slope type**
1.	Null to low (0-3%)
2.	Moderate (3%-12%)
3.	Abrupt (12%-20%)
4.	Very steep (20%-35%)
5.	Extreme (> 35%)

Table 4 Distribution of slope classes in the basin

Slope classes	**Area (ha)**	**%**
0-3	1369	8,67
3-12	9274	58,79
12-20	2096	13,28
20-35	1574	9,97
➢ 35	1214	7,69

Erodibility map confirms high soil vulnerability:

Soil erodibility map is the result of lithofacies and slopes combination. Its examination shows that 81% have a medium, high or very high erodibility (Fig. 8) (Table 6). Only 19% have moderate or low soil erodibility. As expected, spatial distribution situates highly erodible terrain in soft rocks located on steep slopes of mountainous areas. It also shows that majority of the basin's low-slope terrain with moderate to moderate erodibility often correspond to quaternary and Neogene deposits occupying the largest part of surface area.

Table 5 Slope-lithofacies matrix according to PAP/RAC guidelines.

Slope class	Lithofacies class				
	1(a)	2(b)	3(c)	4(d)	5(e)
1.	1(EN)	1(EN)	1(EN)	1(EN)	2(EB)
2.	1(EN)	1(EN)	2(EB)	3(EM)	3(EM)
3.	2(EB)	2(EB)	3(EM)	4(EA)	4(EA)
4.	3(EM)	3(EM)	4(EA)	5(EX)	5(EX)
5.	4(EA)	4(EA)	5(EX)	5(EX)	5(EX)

Legend: 1: Low (EN°, 2: Moderate (EB), 3: Average ‘EM), 4: High (EA), 5: Extreme (EX)

Table 6 Distribution of erodibility classes in the basin

Erodibility classes	**Area (ha)**	**%**
Low (EN)	864	5,56
Moderate (EB)	1997	12,85
Notable (EM)	9206	59,26
High (EA)	2215	14,25
Very High (EX)	1251	8,05

Table 7 Land use classes according to PAP/CAR guidelines.

class	**Land use**
1.	Dry farming (herbaceous)
2.	In-line cropping (olive trees, almond trees, fruit trees, vineyards)
3.	Irrigation
4.	Forests
5.	Dense shrubs
6.	Sparse shrubs, pastures

Table 8 Distribution of land use classes in the basin

Land use classes	Area (ha)	%
Bare soil, bare rock	10055	63,82
Olive and fruit trees	2771	17,59
Irrigated and intensive crops	2907	18,45

Soil Protection:

Land cover is limited to irrigated crops in the western part:

Land cover map was produced from Sentinel-2 10m resolution satellite image classification and interpretation. It shows that most of land in the basin (63%) is bare soil or bare rock (Fig. 6) (Table 8). Fruit trees, particularly olive trees planted in rows, represent 17.5% of total, while irrigated crops represent the same percentage (18%).

Low density of vegetation cover except in intensive areas:

Land cover map was produced from Sentinel-2 10m resolution satellite image classification and interpretation. It shows that most of land in the basin (63%) is bare soil or bare rock (Fig 8/Table 8). Fruit trees, particularly olive trees planted in rows, represent 17.5% of total, while irrigated crops represent the same percentage (18%).

Table 9 Land cover density classes according to PAP/RAC guidelines.

Classes	Degree of vegetation cover
1.	Below 25%.
2.	25% – 50%
3.	50% – 75%
4.	More than 75%.

Table 10 Distribution of vegetation density classes in the basin

NDVI Classes	Area (ha)	%
< 25%	32	0,20
25-50%	14893	94,54
50-75%	552	3,50
> 75%	276	1,75

A Very limited protection by vegetation cover:

Soil protection map is the result of the land use combined with the vegetation density map. Its examination shows that 80% of land has low or very low soil protection (Fig. 9). Only 20% therefore have high or very high protection. The relatively protected areas are those where islands of natural vegetation still cover the ground, but they are mainly linked to intensive, particularly irrigated, crops that effectively occupy soil surface. Major part of the basin remains without significant protection.

Table 11 Land use- vegetation density matrix according to PAP/CAR guidelines.

Land use	Vegetation cover			
	1	2	3	4
1	5(MB)	5(MB)	4(B)	4(B)
2	5(MB)	5(MB)	4(B)	3(M)
3	3(M)	2(A)	1(MA)	1(MA)
4	4(B)	3(M)	2(A)	1(MA)
5	5(MB)	4(B)	3(M)	2(A)
6	5(MB)	4(B)	3(M)	2(A)

Legend: 1: Very high (MA), 2: High (A), 3. Average (M), 4. Low (B), 5. Very low (MB)

Table 12 Distribution of soil protection classes in the basin

Soil protection classes	Area (ha)	%
1. Very high (MA)	324	2,06
2. High (A)	2578	16,39
3. Moderate (M)	102	0,64
4. Low (B)	405	2,57
5. Very low (MB)	12312	78,31

Result is Lands Highly Exposed to Water Erosion

Integration of physical parameters output:

Final result of qualitative study is erosive states map. The latter shows that 80% of basin's land suffers from significant to very high erosion, with 66% of land suffering from high to very high erosion (Fig. 14) (Table 14). (20%) suffer from low to very low erosion. Spatial distribution shows location of lands highly prone to erosion in areas of steep to very steep slopes (between 12 and 35%) on mountain hillsides surrounding the basin. They correspond mainly to tender outcrops of Triassic, Miocene and marl-clayey-sandish intercalation of Cretaceous. Lands experiencing significant erosion are more widespread in basin where Miopliocene and Quaternary unconsolidated formations outcrop in surface. Low and very low erosion areas are characteristic of sectors protected by natural vegetation or intensively cultivated (irrigated), often located on gentle slopes or hard rocks that minimize erosion and loss of material.

Table 13 Soil erodibility- soil protection matrix according to PAP/CAR guidelines.

Degree of soil protection	Degree of erodibility				
	1(EN)	2(EB)	3(EM)	4(EA)	5(EX)
1(MA)	1	1	1	2	2
2(A)	1	1	2	3	4
3(M)	1	2	3	4	4
4(B)	2	3	3	5	5
5(MB)	2	3	4	5	5

Legend: 5. Very high, 4. High, 3. Significant, 2. Low, 1. Very low.

Table 14 Distribution of erosion classes in the basin

Erosion classes	Area (ha)	%
1. Very low	500	3,17
2. Low	2021	12,82
3. Notable	2457	15,59
4. High	7615	48,33
5. Very high	2655	16,85

Table 15 Distribution of erosion forms in the basin

Erosion forms	Area (ha)	%
(C1) Individualized gullies	381	2,42
(C2) Localized gully networks	557	3,54
(C3) predominant gullies	201	1,28
(C4) Bad lands	733	4,65
(L3) Generalized sheet erosion with soil stripping	965	6,13
Eroded surfaces	2837	18,01
(06) Stabilized environments by physical and mechanical installations	986	6,26
(W2) Flooded and/or periodically alluviated areas / hydromorphic areas	847	5,38
(W1) Periodically flooded areas and/or alluviated	1026	6,51
Stable or alluviated	2859	18,15

Direct observation reveals lands invaded by gullying:
Erosion form map represents field observations that are therefore current and observable facts of land degradation and have been mapped using satellite images. (Fig. 12-13, Table 15). Table 15. It emerges that gully forms represent the most notable phenomenon among the observed erosion forms. Gullying of different densities represents 13% of basin, more than 4% of which is in badlands. The gully mainly characterizes the clay-marly outcrops of the eastern and north-eastern mountainous areas. Sheet erosion represents 6% and mainly characterizes foothills with a slight slope, often without gullies. The total area of eroded land represents 2837 ha or 18% of the basin. Some areas have been stabilized by using benches (6%). Others periodically experience alluvial landings (6%) or are occasionally flooded (6.5%). Stable or alluvial soils represent 18 of totals. It shows that about 1/5 of basin's land is subject to erosion, which is sometimes very serious or even irreversible. These lands are not subject to any type of conservation or protection. Flooded or alluvium land prevents any agricultural activity and can be considered as sterilized in its current state

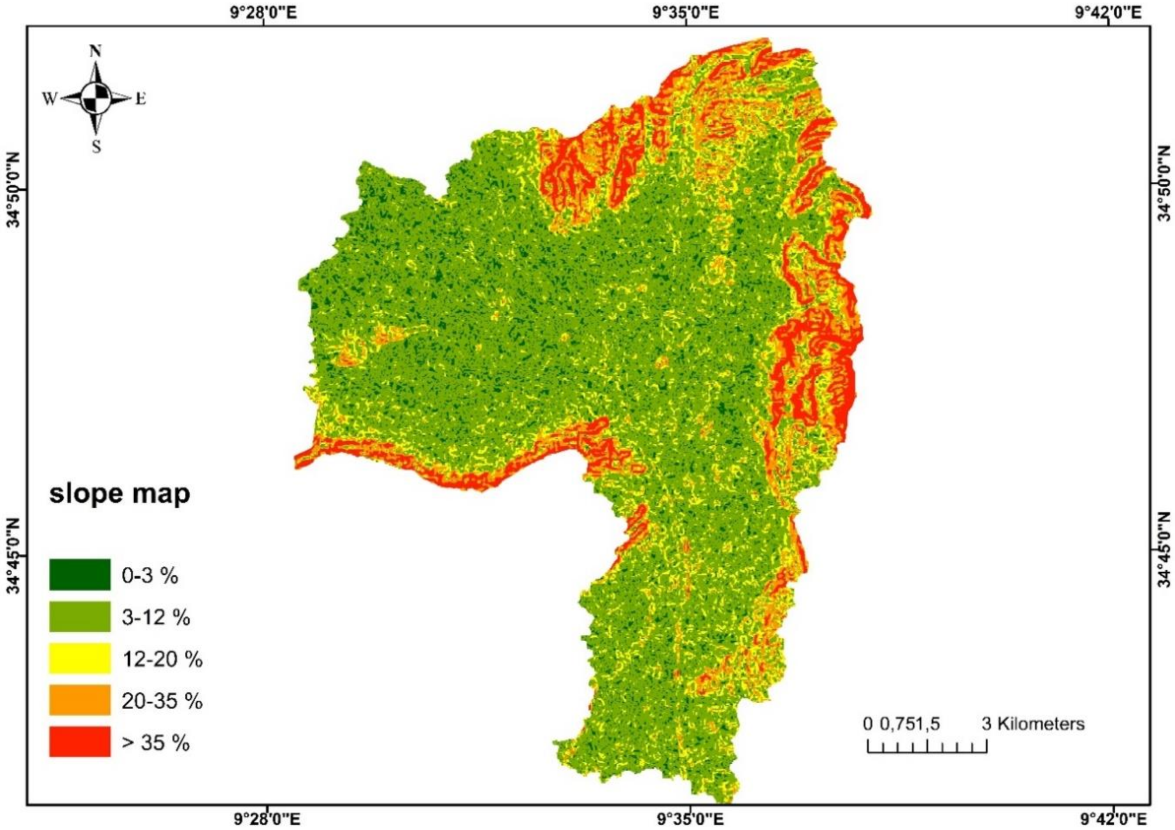

Fig. 5 Slope map.

Integration of qualitative and descriptive data confirms trends towards gully expansion:
This is an integration map of map of erosive states and map of erosion forms. Superimposition of the two maps allows to confirm or not erosive state suggested by the final PAP/RAC map (Fig. 14). Badland areas have invaded lands that were initially not prone to intense erosion, as shown on erosive states map. This indicates a trend of expansion and a contagion effect and proliferation of gullies in these areas to irreversible state. Sheet erosion areas are almost always sectors of significant erosion, high to very high. They therefore confirm their status as erosion sectors by stripping soil. Stabilized areas are located in red areas of high vulnerability. They explain interventions that have been made to prevent erosion. Dominant gully zones dangerously surround Bad Lands, indicating a contagion and multiplication of ravines on clay slopes in absence of a protective plant cover or a water and soil conservation measure. On silty or clayey foothills, individualized ravines frequently appear, especially on those north of Meloussi Mountain, whose head retreat has reached areas that are not very vulnerable to erosion. This informs us of trend to expansion of these gullies in absence of a control strategy. Frequently alluviated or flooded areas of the northwestern plain of the basin correspond to areas of significant to very high erosion. They appear on the field as lands representing a vast bed of undecided riverbed and without clear borders. Gullies are almost always absent and crops are impossible because of significant and frequent alluvial inputs that disturb vegetation. This part of the basin is an accumulation zone that may experience a loss of materials if the flow of water exceptionally increases.

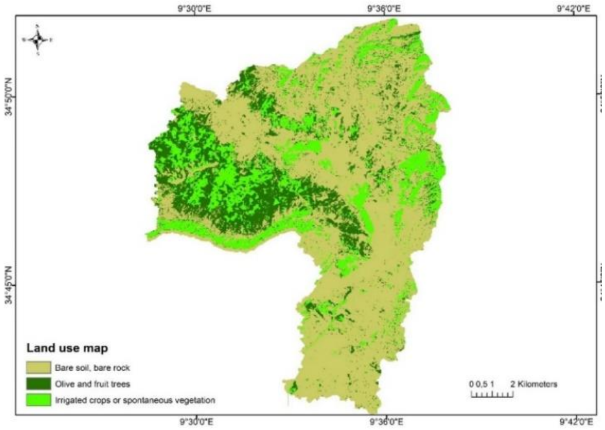

Fig. 6 Land use map.

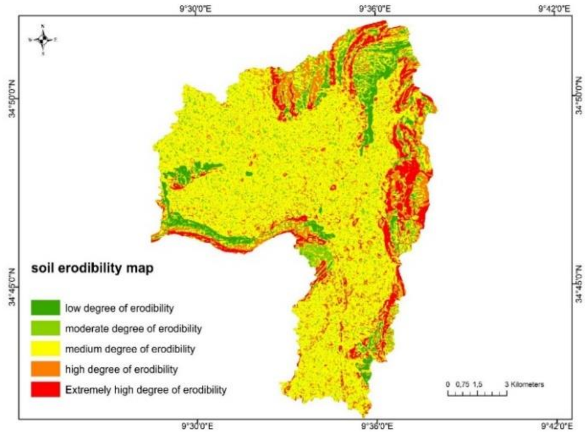

Fig. 8 Soil erodibility map

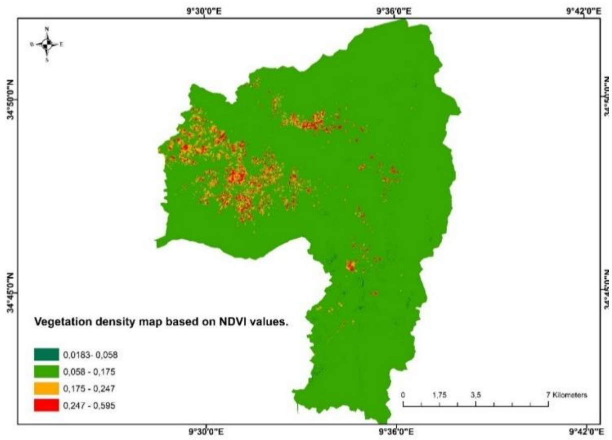

Fig. 7 Vegetation density map

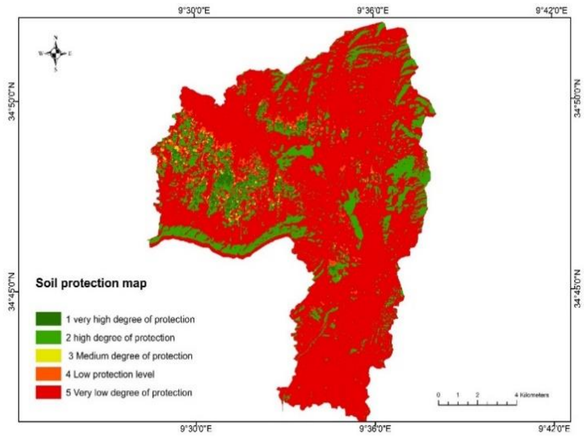

Fig. 9 Soil protection map.

Conclusion

The purpose of this study was to assess water erosion in the Sareg catchment. This was done using a multi-source predictive approach, a descriptive approach and an integration phase for the two previous ones. The result is that majority of basin land is soft and/or loose (78%), that steep slopes are frequent (30%) or moderate (58%) that most of surfaces are bare (63%). Integration of soil erodibility parameters reveals that 82% of land has moderate, high or very high erodibility with 20 for the last two categories. Similarly, soil degree of protection by vegetation cover is also significant with 80% of the surfaces having a low to very low level of protection. Erosion map shows a general predisposition of land to significant, high or very high erosion (80%), of which 20% for the last two categories. Descriptive phase shows eroded surfaces of about 18%, a proliferation of gullies (12% of surfaces) including 6% for hierarchical gullies and Bad Lands. These are located at steep slopes of mountainous reliefs taking advantage of clay-marly intercalations but which extend dangerously on surrounding slopes. Localized gullies often dot foothills. Similarly, 12% of land area has often been flooded or alluviated, making it unusable for farming. Finally, integration phase, while confirming most of previous data, gives ideas mainly on trend towards gullies extension observed during descriptive phase to neighboring lands that were not initially predisposed to erosion.

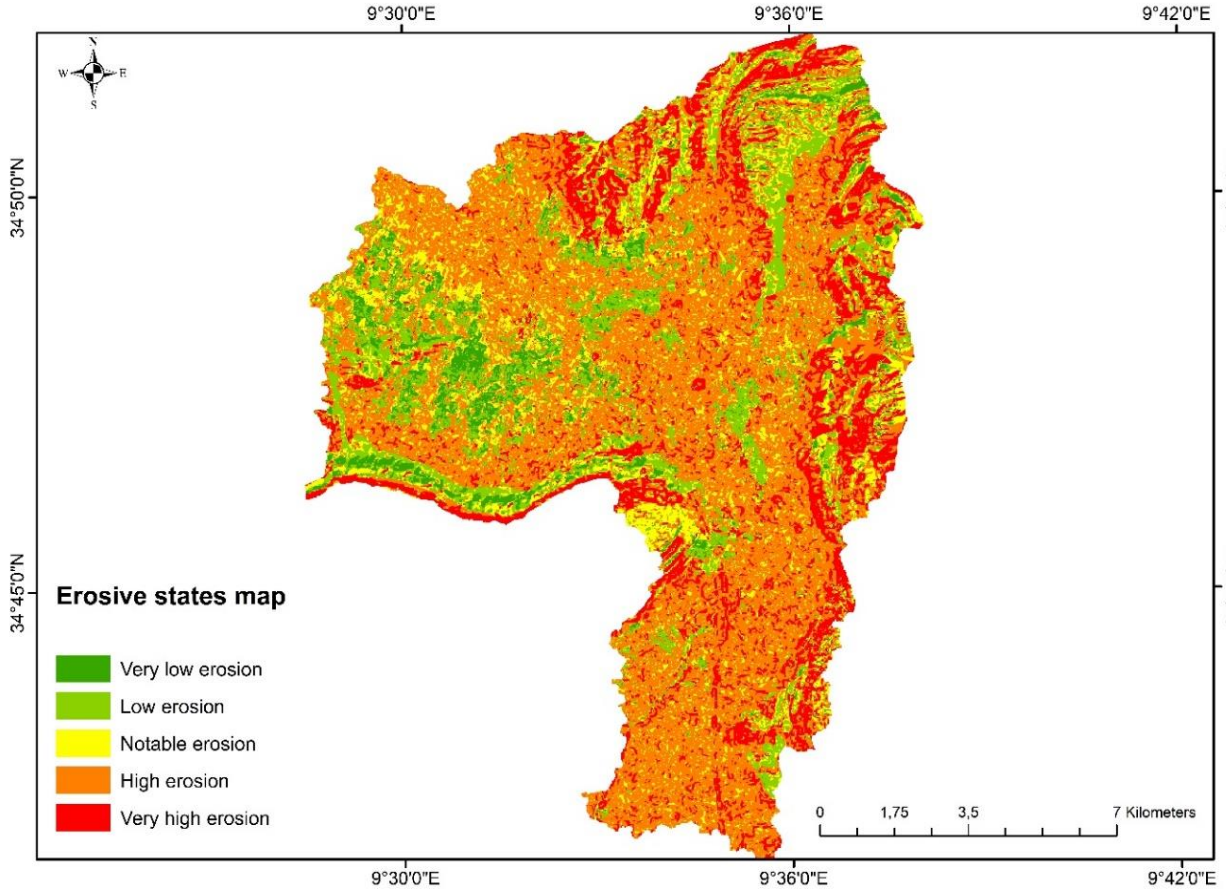

Fig. 10 Erosive states map

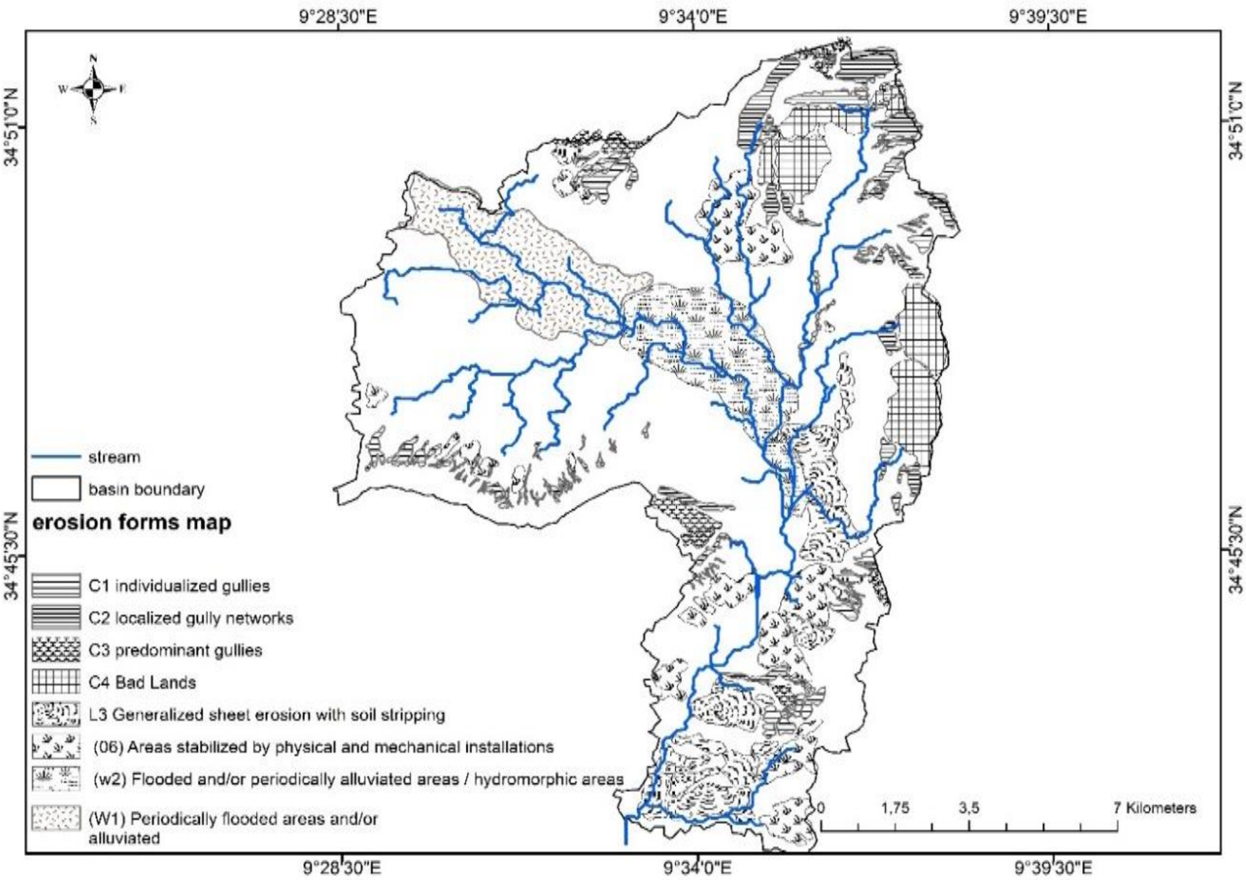

Fig. 11 Erosion forms map

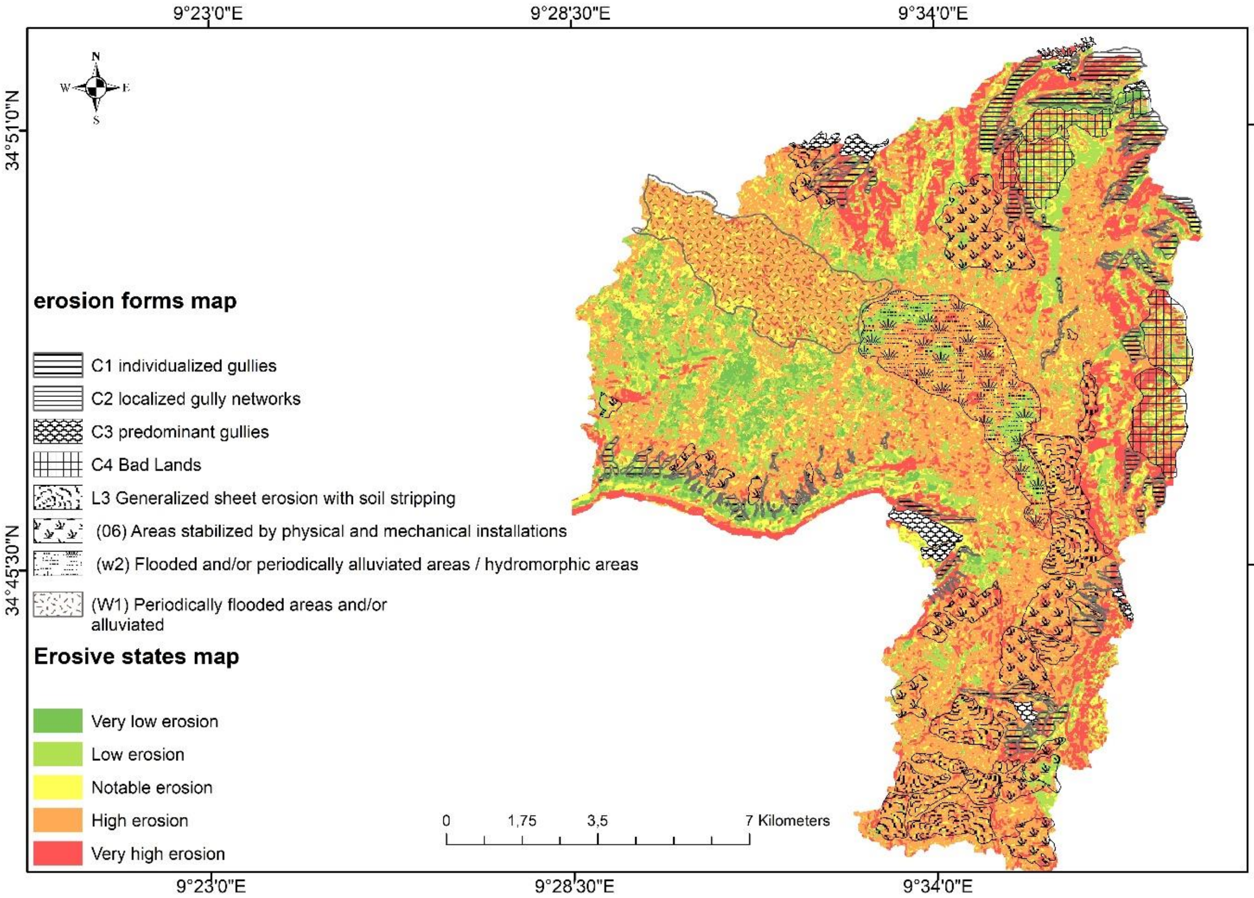

Fig. 12 Consolidated map

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