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Assessment of Soil Vulnerability to Water Erosion Using GIS and Remote Sensing in the Watershed of Fergoug, North-West of Algeria

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ABSTRACT

The sub watershed is part of the Fergoug Macta basin is characterized by semi-arid climate. Erratic rains, usually in stormy character, combined with anthrop-zoogenic pressure (deforestation, urbanization, overgrazing) cause severe erosion. According to the National Agency of water resources, solid contributions (sediments from erosion) are estimated at 29 668 t / year, sediments contribute to siltation of dams. The objective of this study is to develop a methodology using geographical information systems (GIS) to map the zones presenting sensibility of water erosion. It aims to produce a sensibility map that can be used as a reference document for planners. The methodology presented consists of three factors that control erosion: the slope, the friability material and the land use, which were integrated into a GIS. The derived erosion sensibility map shows five areas of vulnerability to water erosion: No sensitivity to erosion (13.61%), Low (72%), medium (12.2%), high (1.34%), and very high (0.85%). Thus, this mapping study presents a tool of policy makers for better space management including water and soil resources and taking into account the expectations and needs of the rural population.
KEY WORDS: GIS, watershed of Fergoug, erosion, sensibility, Algeria

INTRODUCTION

Soil erosion is a natural process which is probably largely responsible for the current geomorphology. It is a process which usually does not cause any major problems. It becomes a problem when human activity causes it to occur much faster than under normal conditions [1]. In recent decades, natural environments have undergone significant degradation for various reasons, related to the natural processes of water dynamics and other development of agricultural activities [2]. In Algeria, about 6 million hectares are now exposed to active erosion. Annual losses of water in the dams are estimated at about 20 million m^3 due to siltation [3]. The sedimentation rate has changed in recent years due to the heavy erosion of watersheds, particularly in Western Algeria where erosion affects 47% of all land [4]. In the early eighties, about 120 million tons of sediment was ripped annually at the watershed of northern Algeria [5]. People's livelihood is increasingly threatened by soil loss. Despite its small size, the study area is perfectly representative of developments in watersheds in Algeria [6]. This study focuses on mapping the sensitivity to erosion of the Watershed of Fergoug, located in the North West of Algeria and controlling three dams in cascade Ouizert, Bouhanifia and Fergoug. Recent silting measures carried out by the national agency of dams and transfers reveals a low rate observed in the Ouizert and Bouhanifia dams (4%, 6%), a very high rate in the Fergoug dam (95%) [4]. The sensitivity to erosion deducted map allows detecting producing areas of sediments, with the aim of erosion control planning for the preservation of the three dams and the irrigation downstream [7]. In this work, we propose a mapping methodology for areas vulnerable to water erosion in the watershed of Fergoug using GIS and remote sensing. Developed GIS allowed us to overlay and analyze several factors such as slope, the nature of the exposed materials and vegetation.

MATERIALS AND METHODS

Area study

Sub watershed of Fergoug is located in North West part of Algeria (Fig. 1) and is part of the great basin of the Macta. The largest portion of the watershed feeds Bouhanifia dam and extends on attenuated the Macta in an area of reliefs where yet, energetic erosion dug deep valleys framed by witnesses who dominate the bottom of 200 to 300 m [7]. The climate of the region is semi-arid Mediterranean, with an average annual rainfall about 260 mm, poorly distributed along the year. The rainy season lasts from September to April. Over the period 1930-2002, the annual precipitation has decreased by about 26% on average [8]. The lithology of the watershed reflects a great diversity of surface formations with predominance of clay soils derived from marl formations [9].

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Fig1. Location map of the study area

Acquisition and processing of data

Data acquisition required a bibliographic approach, field investigations and cartographic support. After treatment, it was possible to achieve a multi-source combination in a GIS. The material used is composed of the satellite image Shuttle Radar Topography Mission (SRTM) of UTM zone 31 coordinates WGS 84 (World Geodetic System), obtained from the space Advanced thermal sensor terminal Emission and reflection radiometer (ASTER) Global Digital elevation model (GDEM) version 2, in October 2011, with a spatial resolution of 30 m. Distributed from the Ministry of Economy, Trade and Industry (METI) Earth Remote Sensing Data Analysis Center (ERSDAC) in Japan and the National Aeronautics and Space Administration (NASA). Exploited cartographic sketch are lithological and land cover map, northwest Algeria. Data processing was performed using MapInfo 7.0 software, ENVI 4.3 (this treatment has established a digital elevation model (DEM) to map the slopes. After this treatment, a base physical data of the study area was set up to create layers and mapping multifactor soil vulnerability to water erosion.

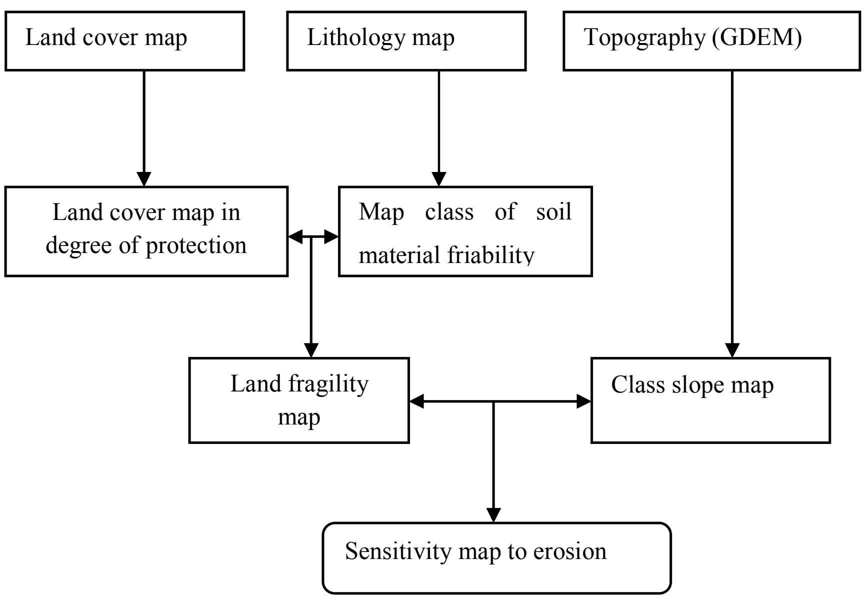

Fig. 2. Diagramme of methodology; source: [3]

Methodological approach

Soil erodibility is an estimate of the capacity of soil to resist erosion based on the physical characteristics of each floor. soil structure influences the ease with which it can be eroded. In general, soils with good water infiltration, high levels of organic matter and a structure favorable to agriculture are resistant to erosion [10]. On the other hand soils with medium to fine texture, low organic matter content, and weak structural development are most easily eroded. Typically these soils have low water infiltration rates and, therefore, are subject to high rates of water erosion and the soil particles are easily displaced by wind energy [15].

The methodology is very simple, we used the topographic, the land use and lithological maps. After processing and production of each map, we obtained the slope map in order of influence in four classes (Fig. 4) from the topographic map. The land cover map (Fig.3) was transformed in different class and the map class of soil material friability was obtained from the lithological map. The croisement of the land cover map in degree of protection and Map class of soil material friability give us the land fragility map. This last croised with Class slope map give us the sensitivity map to erosion of area study.

RESULTS

Mapping of land cover

The land use map is obtained from the map digitalization by the National Office of Economic and Rural Development in 2010. The map reflects the effects of cropping and management practices on soil erosion rates in agricultural lands and the effects of vegetation canopy and ground covers on reducing the soil erosion in forests regions [11]. For each class a degree of protection against water erosion has been assigned (Tab. 1):
Level 0: not protective (Water body),
Level 1: not protective,
Level 2: little protective,
Level 3: moderately protective,
Level 4: highly protective.

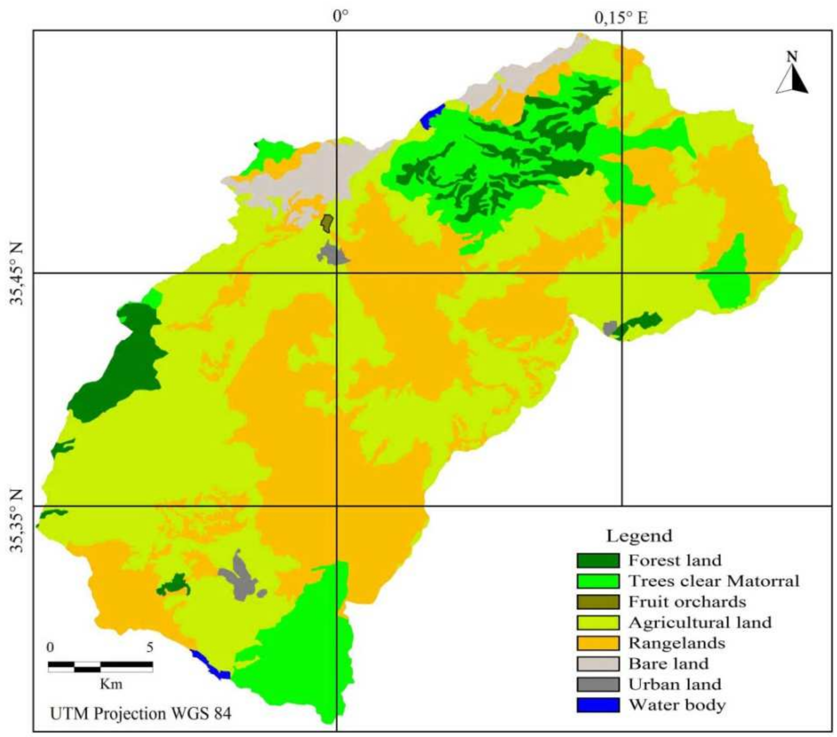

Fig. 3. Land cover map of area study

- The permanent cover includes:
Forest land: facies *Tetraclinis articulate* 5.14%, trees clear Matorral: facies *Tetraclinis articulate, Quercus ilex* and *Oleo lentiscus* 12.48%.
- The temporary canopy includes:
Annual crops Cereals, extensive agriculture and semi intensive and cropland occupied 43.78%.
- The incomplete vegetation cover includes:
Rangelands concern much degraded with 34.63% (Tab. 1). Vegetation significantly reduces the erosion rate by intercepting raindrops [12]. The allocated degree of protection against erosion allowed the development of a new map of land use.

Table1. Sensitivity classes of vegetation

Vegetation cover	Degree of protection	Area (ha)	Percentage
Forest land	4	2963	5.14
Trees clear Matorral	4	7193	12.48
Fruit orchards	4	35	0.06
Agricultural land	3	25235	43.78
Rangelands	2	19960	34.63
Bare land	1	1793	3.11
Urban land	1	346	0.60
Water body	0	115	0.20

Mapping slope classes
The slope map is generated from the digital elevation model (DEM), for each slope class a number is assigned between 1 and 4 (Tab. 2). It was subdivided into four classes: 0-5%; 5 to 15%; 15 to 25% and upper to 25%. First class of 0-5% is a relief of plains, alluvial terraces and structural ledges that are found in the mountainous area. Second class of 5-15% is the piedmont area, glazes terrain and hills. The third class of 15-25% is a mixed area which includes the high foothills and mountains and the fourth class greater than 25% is moderately hilly terrain to hilly with rocky escarpments.

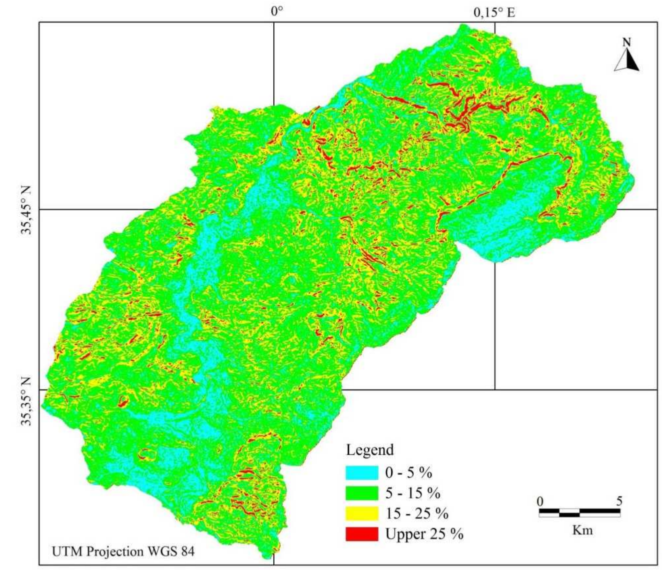

Fig. 4. Slope map of area study

The slope map (Fig. 4) show that over 80% of the basin area have an average slope, strong to extreme (Tab. 2). In the northeastern part erodibility is strong to extreme. When the slope is more important and the soil resistance is low the erodibility is strong.

Table 2. Classes slope and assigned index

Slope (%)	Index assigned	Area (ha)	Percentage
0 - 5	1	8588,36	14.9
5 - 15	2	34007,6	59
15 - 25	3	13026,64	22.6
> 25	4	2017,4	3.5

Map class of soil material friability
Lithologic map of the watershed of Fergoug reveals a great diversity of surface formations with predominance of marl formations and very vulnerable material with 48, 5% of the area. For each type of soil, sensitivity classes are assigned from our field knowledge, describing the nature of rocks on the geological map and their sensitivity to smearing and cracking [3]. One can thus distinguish four classes of materials resistant (Fig. 5, Tab. 3).

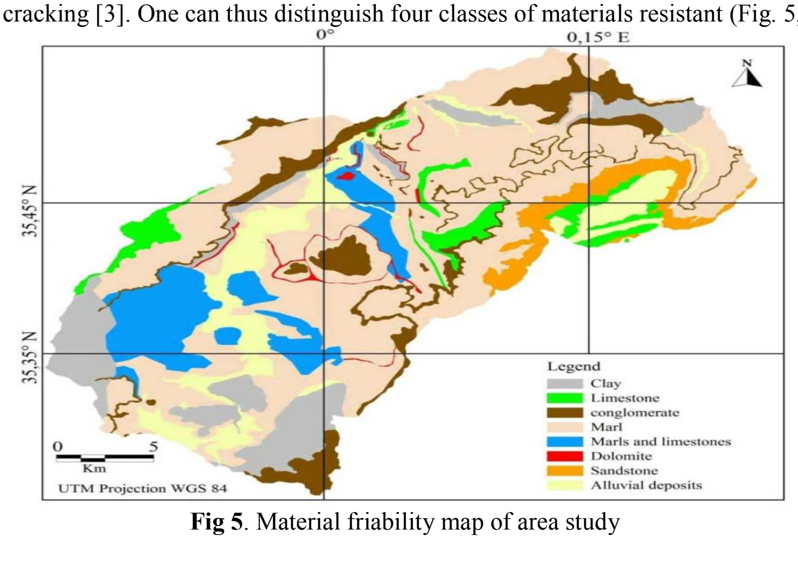

Fig 5. Material friability map of area study

Table 3. Friability classes of materials and assigned index

Geologic Facies	Litho-logic Facies	Friability of materials	Index assigned	Area (ha)	Percentage
Miocene	Clay	very vulnerable material	1	6744	11.7
Miocene	Limestone	moderately resistant materials	3	2507	4.35
Oligocène	conglomerate	moderately resistant materials	3	5908	10.25
Oligocène	Marl	very vulnerable material	1	27955	48.5
Cénomanien	Marl and limestone	vulnerable materials	2	5678	9.85
Aptien	Dolomite	resistant materials	4	403	0.7
Barrémien	Sandstone	resistant materials	4	2306	4
Quaternaire	Alluvial deposits	very vulnerable material	1	6139	10.65

Establishment of the vulnerability map for soil erosion

The methodology developed in this study uses qualitative rules, assessments and a hierarchy of parameters involved in water erosion: land cover map (Fig. 3), degree of slope (Fig. 4) and material friability map of the watershed area (Fig. 5).

The result is a land fragility map of the watershed area with five classes: very fragile (41.09%), fragile (5.06%), moderately fragile (30.58%), little fragile (22.97%) and reservoir (0.3%) of the watershed area (Fig. 6, Tab. 4).

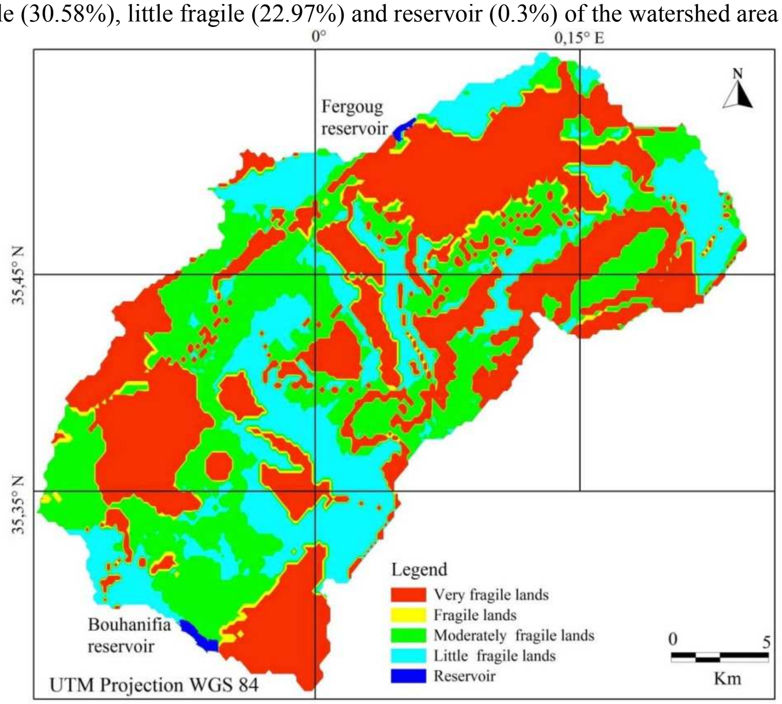

Fig 6. Land fragility map of the watershed area

Table 4. Land fragility map of area study

Land fragility	Index assigned	Area (ha)	Percentage
Very fragile lands	4	23682	41.09
Fragile lands	3	2919	5.06
Moderately fragile lands	2	17626	30.58
Little fragile lands	1	13239	22.97
Reservoir	0	174	0.3

Mapping of soil sensitivity to water erosion

The map of sensitivity to erosion (Fig. 7) has been developed by the interaction between land fragility map and the degree of slope map. Five classes are bounded in the study area: no sensitivity to erosion (13.61%), low (72%), medium (12.2%), high (1.34%) and very high (0.85%) (Tab. 5). These areas are scattered Throughout the Region, Mainly on land with a slope to medium low (<15%) of covered cultivation and scrub. Sensitivity to medium high affect Ouizert Bouhanifia sub basin with a predominance for the Fergoug sub-basin, where we meet Marly steep terrain (> 15%) and a cover missing Nearly [3,4].

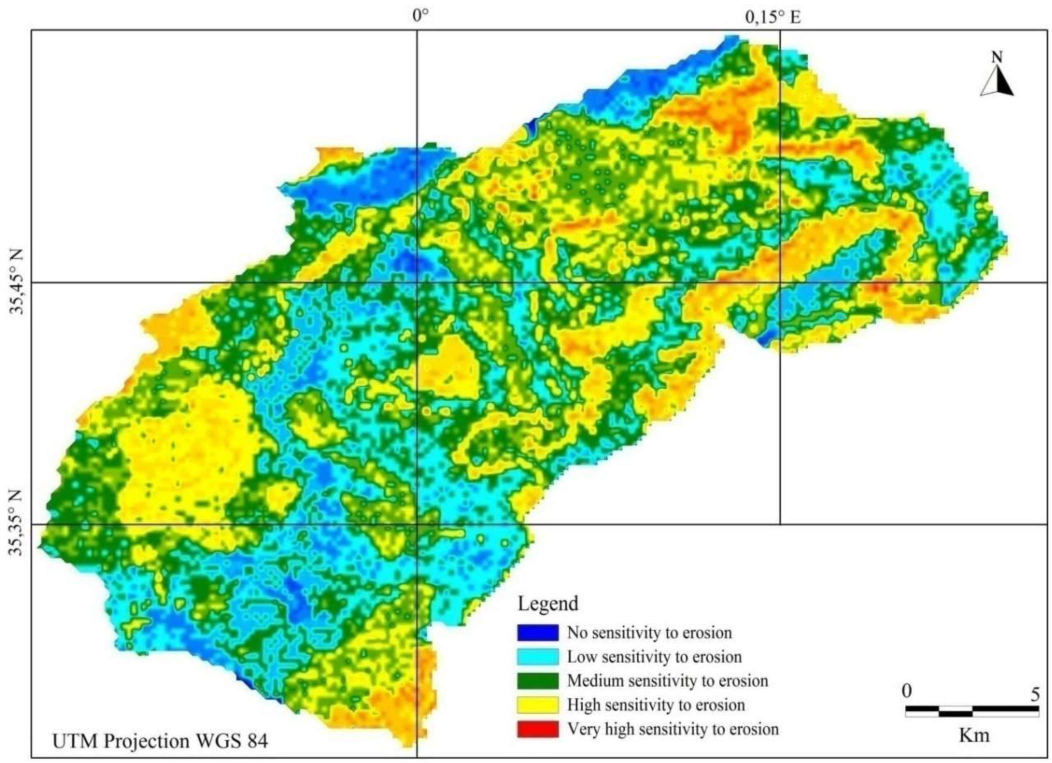

Fig 7. Sensitivity to erosion map of area study

Table 5. Sensitivity to erosion of area study

Sensitivity to erosion	Area (ha)	Percentage
No sensitivity to erosion	7845	13.61
Low sensitivity to erosion	41500	72
Medium sensitivity to erosion	7032	12.2
High sensitivity to erosion	773	1.34
Very high sensitivity to erosion	490	0.85

DISCUSSION

The map of soil sensitivity erosion in study area has 12.2% moderate, 72% low, and 1.34% high sensitivity erosion levels. The description and discussion of the card class sensitivity to erosion requires a parallel reading maps of the physical parameter (slope) and natural (lithology and land use) of the entire study area. In the north-east of the basin, we find a concentration of class sensitivity to severe erosion 0.85% (Table 5), coinciding with a very steep area. The cover of the soil by the perennial vegetation and the very low slope protect the soil against the phenomenon of erosion. Indeed, 72% of the soils of the study area have a low susceptibility to erosion. Perennial vegetation consists mainly of forest land, trees clear Matorral. The importance of plant cover in controlling water erosion is widely accepted. In the short term, vegetation influences erosion mainly by intercepting rainfall and protecting the soil surface against the impact of rainfall drops [13].Other authors [14] have concluded that typical Mediterranean shrubland vegetation is efficient in reducing water erosion, even under extreme torrential simulated rainfalls. . However, the spatial distribution of class erosion sensitivity does not coincide perfectly with the card class of fragile soils since they have found more than 41% of fragile ties soil (Table 4), this can be explained by heterogeneity in land use and topographic and lithological variation in the study area.

CONCLUSIONS

The map of sensitivity to erosion of potential soil loss help us in assessing the erosion impact of various cropping system and conservation support practices. This study demonstrates that GIS and remote sensing are valuable tools for assessing soil erosion risk in the spatial domain. The adopted approach was based on mapping procedures, such as conversion of categorical into numerical polygons, interpolation, map algebra and raster map.

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