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Vulnerability of soils in the watershed of Wadi El Hammam to water erosion (Algeria)

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Abstract

Located in the north west of Algeria, the watershed of Wadi El Hammam is threatened by water erosion that has resulted the silting of reservoirs at cascade: Ouizert, Bouhanifia and Fergoug. The objective of this study is to develop a methodology using remote sensing and geographical information systems (GIS) to map the zones presenting sensibility of water erosion in this watershed. 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 three areas of vulnerability to water erosion: low, medium and high. The area of high vulnerability corresponds to sub-basin of Fergoug.

Key words: *GIS, remote sensing, Wadi El Hammam, water erosion, watershed*

INTRODUCTION

The erosion of soil by rain and runoff is a phenomenon widely distributed in the different countries [BANASIK *et al.* 2001, 2012; BĄK, DĄBKOWSKI 2013; PANAGOSET *et al.* 2015; WALLING, WEBB 1996]. In Algeria, about 6 million hectares are exposed to active erosion, an average of 120 million tons of sediment are washed away each year [HEDDADJ 1997]. The slopes of Algerian Northwest which represent a great potential for agricultural production are affected for a century by a degradation of vegetable cover and land dynamics [MORSLI *et al.* 2004]. The annual losses of capacity of storage of water in dams are estimated about 20 million m^3 and are due to siltation [REMINI, HALLOUCHE 2005].

Remote sensing and geographic information systems (GIS) are increasingly used for the study of surface phenomena and form tools essential in interactive decision support systems operational for risk management operations [BOUKHEIR *et al.* 2006]. The implementation of effective measures for the conservation of soil must be preceded by an assessment of the erosion risk in the space [MOUSSA *et al.* 2002; SOUCHÈRE *et al.* 2005].

This study focuses on mapping the sensitivity to erosion of the basin side of the Wadi El Hammam, 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 (ANBT) reveals a low rate observed in the Ouizert and Bouhanifia dams (4%, 6%), a very high rate in the Fergoug dam (95%).

In this work, we propose a mapping methodology for areas vulnerable to erosion that the source of solid materials extracted and transported by water based on field, remote sensing and topographic data. Developed GIS allowed us to overlay and analyze several factors such as slope, the nature of the exposed materials and vegetation. 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.

STUDY AREA

Watershed Wadi El Hammam is located in North West part of Algeria and is part of the great basin of the Macta. It includes three sub-basins: Ouizert, Bouhanifia and Fergoug (Fig. 1). At the Fergoug dam, Wadi El Hammam has a watershed of 8251 km^2, corresponding to the strongest reliefs and downstream Bouhanifia part and constitutes the own dam impluvium: these are the mountains of Benichougrane which dominates 850 m Mohammadia plain. The largest portion of the watershed feeds Bouhanifia dam and extends on attenuated the Oran Meseta in an area of reliefs where yet, energetic erosion dug deep valleys framed by witnesses who dominate the bottom of 200 to 300 m [BENCHETRIT1972].

The climate of the region is semi-arid Mediterranean, with an average annual rainfall of about 260 mm (average for the period 1995–2010), 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 [MEDDI *et al*. 2009]. The lithology of the watershed reflects a great diversity of surface formations with predominance of clay soils derived from marl formations [BOUCHETATA *et al*. 2006]. Grain and vegetable crops dominate the southern part of the basin. These cultures cover the soil seasonally and leave it the rest of the year. To the North, forest cover deteriorated by the anthropogenic action and recent fire, occupies the steep slopes of the watershed of Wadi Fergoug. It should be noted that subsistence agriculture prevals with over exploitation of soils, a permanent clearing and intensive overgrazing. Faced with this situation, the erosion found its scope of development due to the lack of protective vegetation, low resistance of the land and their slopes.

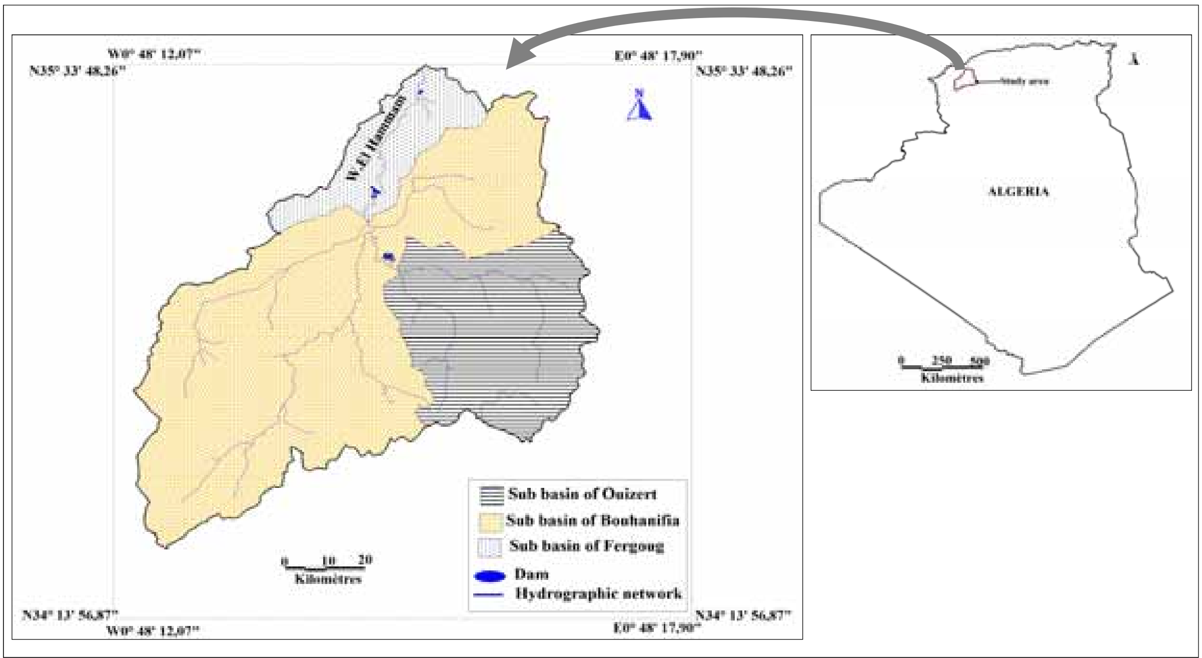

Fig. 1. Watershed of Wadi El Hammam; source: own elaboration

MATERIALS AND METHODS

The methodology used in this study is based on satellite data, topographic, lithological and of ground observations. These data are then integrated and analyzed in a GIS environment for restitution and mapping of areas proned to water erosion (Fig. 2). The input data cover:
– a slope map,
– a lithologic map digitalized and georeferenced,
– a land cover map digitalized and georeferenced.

Map of land use

The classification is led by the method of maximum likelihood. It is based on direct observation of the categories of land use allowed obtaining a map of land tenure. Eleven classes of vegetation cover appear. Each class has been assigned a degree of protection against water erosion (Tab. 1):
Level 1: not protective,
Level 2: little protective,
Level 3: moderately protective,
Level 4: highly protective.

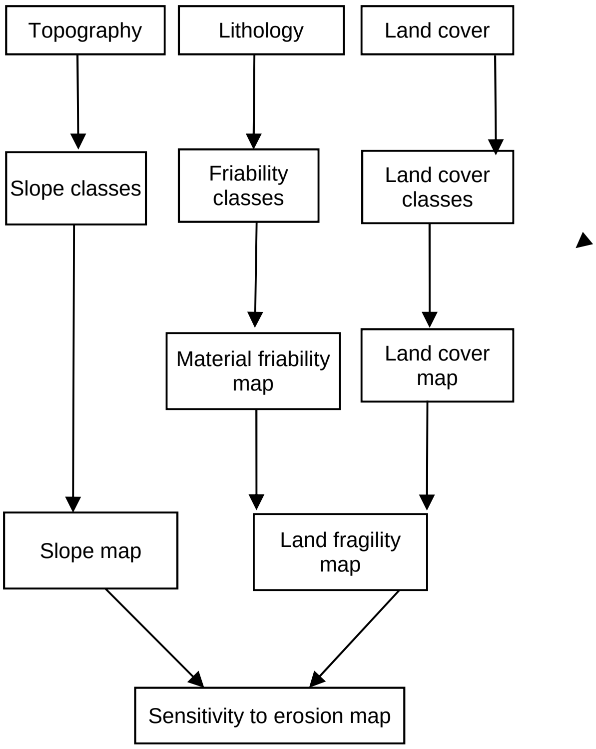

Fig. 2. Diagramme of methodology; source: own elaboration

Table 1. Sensitivity classes of vegetation

Vegetation cover	Degree of protection
Bare soils	1
Highly degraded path	2
Rangelands	2
Cropland	3
Semi-intensive farming	3
Cereals	3
Extensive agriculture	3
Trees Clear Matorral: facies *Tetraclinis articulata* and *Oleo lentisque*	4
Dense wooded Matorral: facies *Tetraclinis articulata*	4
Trees Clear Matorral: facies *Tetraclinis aticulata* and *Quercus ilex*	4
Vine	4

Source: elaborated acc. to BOUCHETATA *et al*. [2006].

The classification of ROOSE [1977] has served us to identify an appropriate classification. Roose classified plant canopies into three groups:
– permanent cover,
– temporary vegetation cover,
– incomplete vegetation cover.

This mode of classification was detailed by subdividing the plant covered group incomplete in two groups: grazing and bare floors

a) The permanent cover includes:
– Canopy:
Trees Clear Matorral: facies *Tetraclinis articulata* and *Oleo lentiscus*
Dense wooded Matorral: facies *Tetraclinis articulata*
Trees Clear Matorral: facies *Tetraclinis aticulata* and *Quercus ilex*
Forest reforestation
– Perennial crops:
Wine plantation and orcharding

b) The temporary canopy includes:
– Annual crops
Cereals, extensive agriculture and semi intensive and cropland.

c) The incomplete vegetation cover includes:
– Pasture concern much degraded and the less degraded rangeland
– Bare floors: it's completely bare and uncultivated soils

The plants cover classification and the allocated degree of protection against erosion allowed the development of a new map of land use.

Map of slopes

The digital terrain model DTM (with a resolution of 30 m by shuttle radar topography mission SRTM) was used to produce the map of slopes. It was subdivided into four classes: 0–5%; 5–15%; 15–25% and upper to 25%. Each class is assigned an index ranging between 1 and 4 (Tab. 2), 1 assigned to the low slopes (<5%), 4 to the steep slopes (>15%).

Table 2. Classes of slope and assigned index

Slope, %	Index assigned
0–5	1
5–15	2
15–25	3
>25	4

Source: own study.

Map of friability

Lithologic map of the Wadi El Hammam watershed reveals a great diversity of surface formations with predominance of clay soils derived from marl formations. 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. One can thus distinguish four classes of materials (Tab. 3): resistant,

Table 3. Friability classes of materials and assigned index

Facies	Friability of materials	Index assigned
Marl and sandstones	very vulnerable material	1
Alluvial deposits	vulnerable materials	2
Marls and limestones	vulnerable materials	2
Clays and shales	moderately resistant materials	3
Limestone dolomite and dolomite	moderately resistant materials	3
Lacustrine limestones of the Pliocene	resistant materials	4
Sandstone and miocene sands	resistant materials	4
Sandstones	resistant materials	4

Source: own study.

moderately resistant, vulnerable, and very vulnerable. Each class is assigned an index ranging from 1 and 4. Index 1 is assigned to material exposed to erosion and index 4 assigned for less erosion-proned materials.

RESULTS

The methodology developed in this study uses qualitative rules, assessments, and a hierarchy of parameters involved in water erosion: occupation of land (Fig. 3), friability of the material (Fig. 4) and degree of slope (Fig. 5). All of these data are integrated in a GIS for a better management of information. The combination of these maps following the rule of decision mentioned on Table 4, has allowed producing a thematic map called map of fragile lands (Fig. 6). It includes four classes: very fragile (0.33%), fragile (35.43%), moderately fragile (58.90%) and little fragile (5.34%), very fragile and fragile lands represent 35.76% of the watershed area.

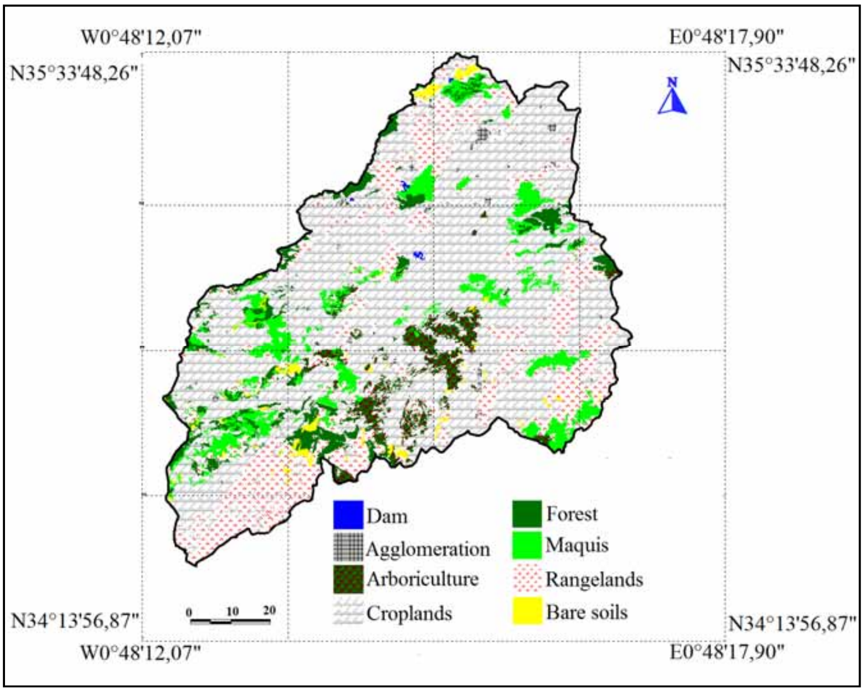

Fig. 3. Land cover map; source: own elaboration

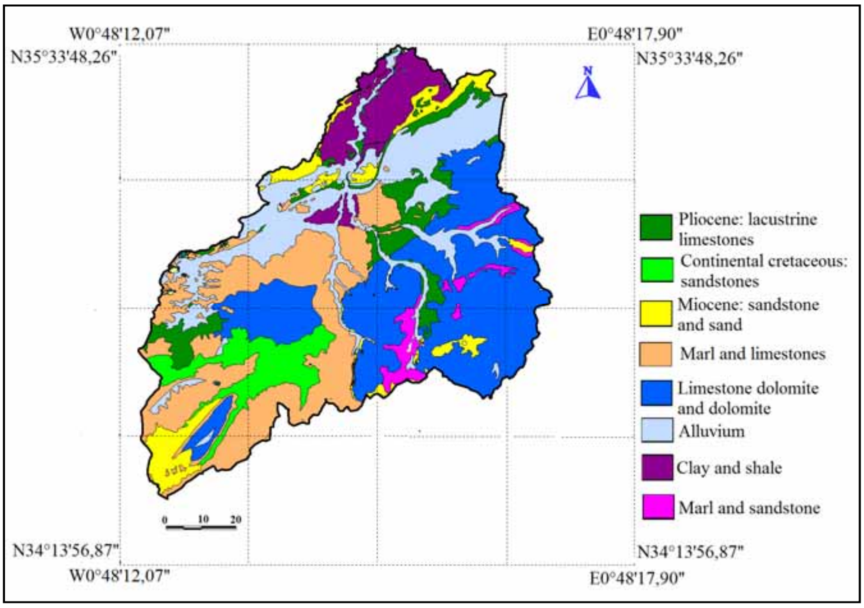

Fig. 4. Material friability map; source: own elaboration

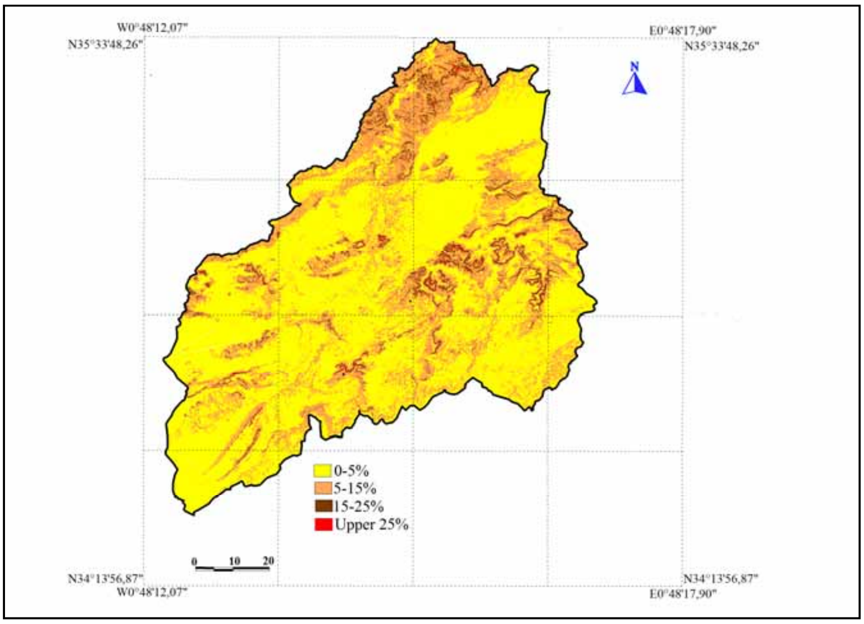

Fig. 5. Slope map; source: own elaboration

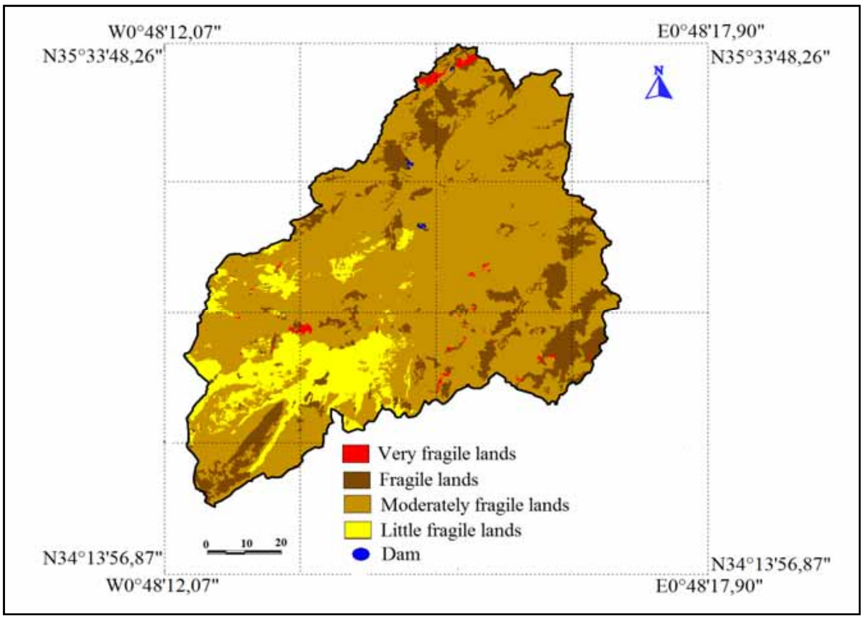

Fig. 6. Land fragility map; source: own elaboration

Table 4. Rules of decision for land fragility

Occupation of lands	Fragility of lands depending on friability of materials			
	very vulnerable	vulnerable	moderately vulnerable	resistant
Not protective	very fragile	very fragile	very fragile	fragile
Little protective	very fragile	very fragile	moderately fragile	moderately fragile
Moderately protective	fragile	moderately fragile	little fragile	little fragile
Highly protective	moderately fragile	little fragile	little fragile	little fragile

Source: own study.

The map of sensitivity to erosion (Fig. 7) has been developed by the interaction between the fragility of land and the degree of slope; using the rule of decision in Table 5. Three classes are bounded: low (65.18%), medium (26.18%) and high (8.64%).

The thematic maps of fragile land and sensitivity to erosion show that moderately fragile land areas have low sensitivity to erosion and occupy 65.18% of the study area. These areas are scattered throughout the region, mainly on land with a low slope to medium (<15%) covered of culture and matorral. Sensitivity medium to high affect Ouizert and Bouhanifia sub basin with a predominance for the Fergoug sub-basin, where we meet Marly terrain steep (>15%) and a cover nearly absent.

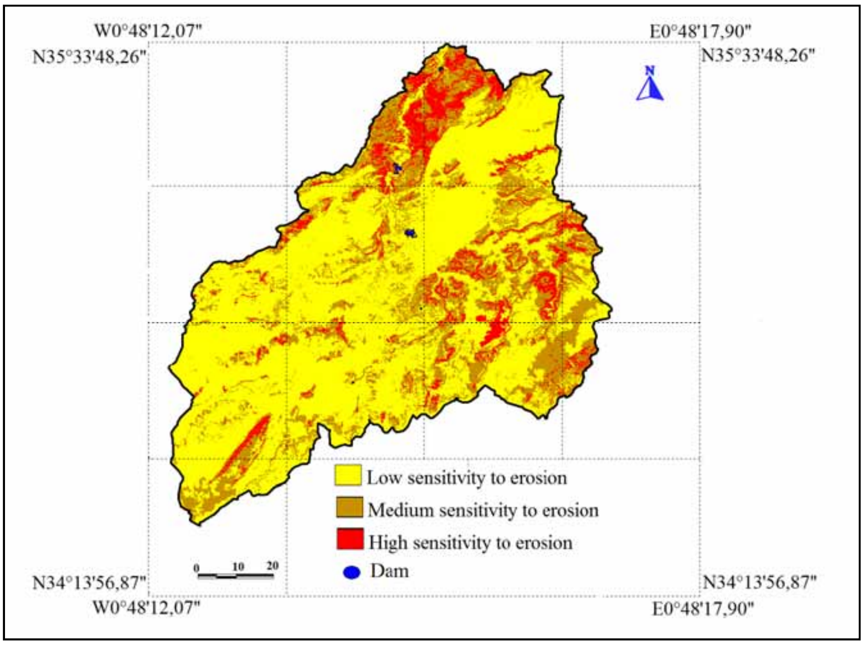

Fig. 7. Sensitivity to erosion map; source: own elaboration

Table 5. Rules of decision for sensitivity to erosion

Slope, %	Sensitivity to erosion depending on fragility of land			
	very fragile	fragile	moderately fragile	little fragile
0–5	medium	low	low	low
5–15	high	high	medium	low
15–25	high	high	high	medium
>25	high	high	high	high

Source: own study.

DISCUSSION

The dominant classes of the sensitivity to erosion correspond to low and middle levels. These affect 91% of the study field. These areas correspond to areas of low to medium slopes, which also represent 69.68% of the total area of the watershed of Wadi El Hammam. This result shows that the sensitivity to erosion of the study area is mainly controlled by the degree of slope and the vegetable cover density.

The fragility of the erosion is triggered by human action caused agricultural practices on steep terrain. This is the case of the Sub basin of Fergoug where the slopes greater than 25% represent 35.31% of the surface of the Sub basin and 61.53% for those greater than 12.5% [BOUCHETATA *et al*. 2006]; these areas mainly marl and clay intended for pastures and intensive food crops, helps produce fragile lands to very fragile and therefore a strong sensitivity to erosion.

CONCLUSION

Items in topographic, lithological and land use maps were crossed in a geographic information system. Analysis and spatial modelling of the fragility of the lithological substratum, of cover plant and the degree of slope permitted to have a clear idea about the management basin watershed of Wadi El Hammam and therefore produce a project more in harmony with the need to protect the dams, located downstream, against siltation.

In this catchment, the low to moderate slopes dominate South, South West and central, from the Ouizert sub-basin to the boundary of Bouhanifia. These areas represent 69.68% of surface, the rest, which is 30.32% of area is reserved for the steep slopes scattered in various parts and highly concentrated at the sub basin of Fergoug.

The mapping areas to water erosion in the watershed of Wadi El Hammam has made it possible to distinguish three sensitivity classes. Interested in the low class to average 91.36% of the total area. These levels of sensitivity are due to the low to medium slopes above the basin studied and are relevant to the Ouizert and Bouhanifia sub-basin. The class of highly erodible soils also affects these two sub-basins and especially the sub watershed Fergoug.

To avoid repeating the scenario of Fergoug dam, the Ouizert and Bouhanifia dams currently having a low sedimentation rate, would be condemned to siltation in the medium to long term if we do not make an adjustment of risk areas erosion by the prohibition of agricultural practices on steep slopes, the forest protection, reforestation of denuded areas, installation of retaining walls and terracing that preserve land for agriculture. Map of sensitivity to erosion resulting from this work, draft that it be improved by extensive research on soil erodibility, and the rainfall erosivity, allows policymakers to better target their preventive intervention strategies to reduce siltation of dams downstream.

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Podatność gleb w zlewni Wadi El Hammam na erozję wodną (Algieria)

STRESZCZENIE

Słowa kluczowe: *erozja wodna, GIS, metodologia teledetekcji, Wadi El Hammam, zamulanie zbiorników, zlewnia rzeczna*

Położona w północno-zachodniej Algierii zlewnia rzeki Wadi El Hammam charakteryzuje się dużą podatnością na procesy erozji wodnej, które prowadzą do zamulenia zbiorników w kaskadzie: Ouizert, Bouhanifia i Fergoug. Celem badań było opracowanie metodologii wyznaczania stref w zlewni o różnej podatności na erozję z wykorzystaniem teledetekcji i geograficznych systemów informacyjnych (GIS) oraz stworzenie mapy wrażliwości gleb na erozję, która może być wykorzystana jako dokument referencyjny dla planistów. Przedstawiona metodologia polega na integracji w GIS trzech czynników warunkujących procesy erozji, tj.: nachylenia stoków, struktury gleb i użytkowania terenu. Na opracowanej mapie wyróżniono trzy klasy charakteryzujące: małą, średnią i dużą podatność zlewni na procesy erozji wodnej. Dużą podatność na erozję wykazują głównie obszary na terenie zlewni zbiornika Fergoug.