

THE ASSESSMENT OF EROSION IN AOULAI WATERSHED (CENTRAL RIF MOUNTAINS, MOROCCO) BASED ON THE  
PAP-RAC GUIDELINES APPLICATION\*

AVALIAÇÃO DA EROSÃO NA BACIA HIDROGRÁFICA AOULAI (MONTANHAS CENTRAIS DO RIF, MARROCOS) COM BASE  
NA APLICAÇÃO DAS DIRETRIZES DO PAP-RACON

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ABSTRACT

The land in the Aoulai watershed in the Rif mountain area of northern Morocco has been deteriorating continually due to several different forms of erosion. The Aoulai watershed is essentially characterized by the domination of weak resistance of the rocky formations and its sensitiveness to other major internal factors that result in a conspicuous impetus for both mass movements and water erosion.

Water erosion is seen as the most damaging phenomenon for nature in northern Morocco because it acts as an obstacle to the natural balances and seems to have greater effect on the slopes, through the influence of both human and natural factors.

To assess and examine the erosion phenomenon, we have chosen to conduct a qualitative assessment of water erosion in the Aoulai watershed using the PAP-RAC (Priority Actions Programme/Regional Activity Centre) Guidelines. This is the methodology that is most widely applied and implemented both for determining and identifying the areas at risk of erosion and for supporting projects to reduce the degradation that has become a major threat to hydraulic structures including dams, irrigation pipes and other infrastructure elements, which are damaged by the erosion phenomenon in the Central Rif mountains of northern Morocco.

**Keywords:** Erosion, assessment, Aoulai watershed, Rif mountains, PAP-RAC.

RESUMO

O solo da bacia de Aoulai, situada na área montanhosa do Rif, no norte de Marrocos, tem-se vindo a deteriorar continuamente devido à ação de diferentes formas de erosão. A bacia hidrográfica de Aoulai é essencialmente caracterizada pelo domínio de uma fraca resistência das formações rochosas e pela sensibilidade a outros grandes fatores internos, resultando numa proeminente dinâmica de movimentos de massa e de erosão hídrica.

A erosão hídrica é vista, no norte de Marrocos, como o fenómeno mais nefasto para a natureza, porque atua como um obstáculo aos equilíbrios naturais, parecendo ser mais efetiva nas encostas, tendo em conta a influência conjunta de fatores humanos e naturais.

Para conhecermos e avaliarmos o fenómeno da erosão, optámos por uma avaliação qualitativa da erosão hídrica na bacia de Aoulai através do modelo PAP-RAC (Priority Actions Programme/Regional Activity Centre), pois é a metodologia mais aplicada e implementada tanto na determinação e identificação de áreas de risco de erosão, como na promoção de projetos para reduzir a degradação, uma vez que constituiu uma grande ameaça para as estruturas hidráulicas, incluindo barragens, tubos de irrigação e demais infraestruturas que são afetadas pelos fenómenos de erosão nas montanhas do Rif Central no norte de Marrocos.

**Palavras-chave:** Erosão, avaliação, bacia hidrográfica de Aoulai, montanhas do Rif, PAP-RAC.

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Introduction

There has been growing interest in recent years about the problems associated with the deterioration of the soil and natural environment in general (Nachtergaele, 2005). The Aoulai watershed, in Northern Morocco, is considered as an obvious model for the Rif zones which are exposed to the problem of water erosion, causing serious environmental constraints reflected clearly on the environment. According to the World Food and Agriculture Organization study, 12,5% of the agricultural areas in Morocco are under the risk of water erosion (Bot *et al.*, 2000).

The Aoulai watershed is well known as a strong dynamic zone by hydraulic erosion due to several factors; among of which are common to a natural fragility, which is mainly characterized by heterogeneous facies, rugged mountains, fragile rocks, and weakly developed soil easily exposed to erosion (Heusch, 1970). Other factors are related to climate which is known by its Mediterranean system of irregular rainfall, autumn thunderstorms and a damaged vegetative cover by the old settlement in these areas.

The excessive human pressure, on natural resources and its ongoing expansion at the expense of forests in favour of conventional agriculture based on inappropriate tools and techniques, contribute in activating erosion. Recently, the integration of the cannabis cultivation into the Aoulai watershed, has changed a feature of the

agricultural view, and affected the economic and social behaviour, which has had a significant impact on the uses of soil (El Mazi *et al.*, 2017).

This paper aims at studying the water erosion in the Aoulai watershed in order to highlight the most important factors behind the phenomenon, as well as, quantifying the erosion through a cartographic approach seeks at identifying the potential erosion areas, and the areas exposed to the water erosion to reduce and mitigate the soil degradation risk

Study area

The Aoulai watershed in the Central Rif Mountains is located within Taounate and Chefchaoun territory (fig. 1). Geomorphologically characterized by a very diverse surface. It is composed of complex and young geological structure with fragile and weak rock formations characterized by it impermeable rock with the dominance of sandstone and marl clay-rich (Andrieux, 1971).

As far as the vegetative cover is concerned, the watershed contains planted and pristine forests: wild olives, cork oak, green oak and pine. Vegetation cover has been degraded due to multiple causes including forest fires, excessive cutting and overgrazing (El Mazi *et al.*, 2017). This deterioration is a result of the conjunction of the concentration and the quantity of the

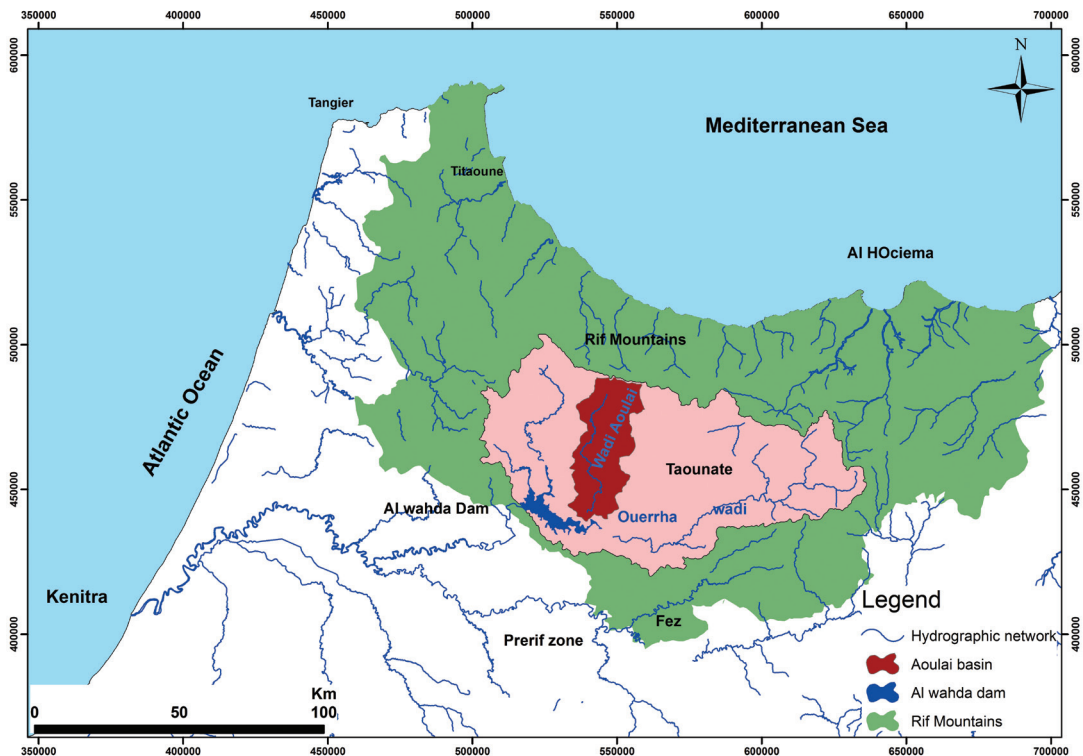


Fig. 1 - Location of Aoulai watershed in Ouerrha watershed in northern Morocco.

Fig. 1 - Localização da bacia hidrográfica de Aoulai na bacia de Ouerrha, no norte de Marrocos.

heavy rain which exceeds 1,400 mm in Oudka mountain. The drainage is served by a dense hydrographic network into Aoulai Wadi. The thermal contrast of the study area reaches more than 20 °C/month plays a key role in exacerbating the phenomenon. These factors contribute in activating the process of water erosion.

#### This study aims:

- To know, to what extent the morphodynamical actions and other factors of erosion can affect the soil of the Aoulai watershed, through mapping of the erosion forms using satellite images and field work carried out through several missions;
- To demonstrate the seriousness of the erosion problem in the Aoulai basin, that was chosen because it is well known by a highly unstable morphodynamical balance, associated with water erosion and mass movements which are clearly seen along the banks of the Aoulai wadi. This is related to the water which comes out from heavy rainfalls during raining seasons. The weak rock formation which the area is based, and degradation of the vegetative cover, in addition to the human intervention into the watershed is regarded as the main erosion factors affect erosion rates and high erosion rates have a negative impact on the hydraulic equipment's of the Al Wahda dam;
- To highlight the natural resources degradation in the Aoulai watershed through the most important dynamic forms (water erosion and mass movements types), identifying the generator factors that contribute in distribution of these forms and the assessment of the erosion using the PAP-RAC approach.

#### Problems and adopted methodology

The problem of water erosion in the Aoulai watershed has a negative impact on agricultural lands and water

equipment which have economic and social importance. The solid load produced caused a huge damage on the hydraulic structures of the Al Wahda dam. A significant quantity of sediments from the top of slopes are accumulated and contribute to its siltation.

The phenomenon of erosion in the Aoulai watershed is related essentially to many factors resulting from lithology formation, rough terrain and the rate of degradation of vegetation cover (El-fengour, 2009). The erosion is also a human act; it develops with the increasing demographic pressure on natural resources on the one hand, and the multiplicity of human activities on the other hand, the expansion of agriculture at the expense of natural vegetation, grazing and the development of emerging urban centres is a major factor in accelerating man-made erosion in a manner that is far more invasive than natural erosion. The precipitation is the main factor causing soil degradation due to the intensity of heavy rain showers and the strength of rainfall in very brief period of the year (Gartet, 1994), and thermal fluctuations have a direct impact on erosion. To analyse these aspects and evolution of the erosion process, the methodology is comprised of three stages:

- Present the current situation of the Aoulai watershed through a collection and analysing of thematic maps based on spatial and statistical analysis using GIS, this method allows to detect potential erosion areas to highlight key factors contributing to the erosion in the studied environment by identifying the stable and degraded zones;
- The assessment of erosion is based on PAP-RAC guidelines using GIS. The factors maps (lithology, slope, land use and vegetation) are the elements of this approach (fig. 2);
- Compare the results obtained through the PAP-RAC approach with the reality in Aoulai watershed (Faleh and Maktite, 2014), in order to recognize the erosion forms.

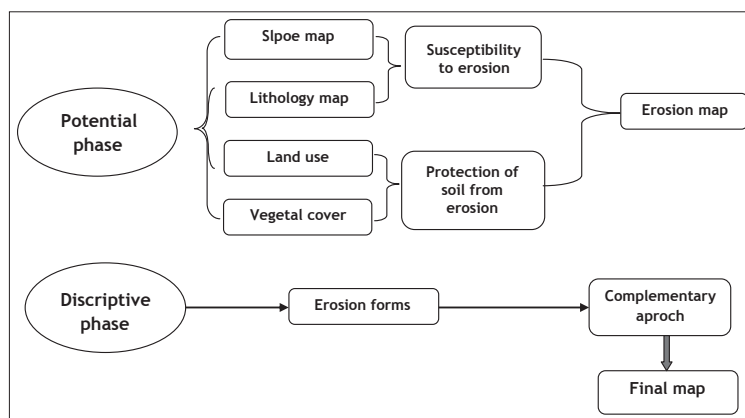


Fig. 2 - Approach used to assess the water erosion, according to the PAP-RAC model.

Fig. 2 - Esquema da abordagem usada para avaliar a erosão hídrica, de acordo com o modelo PAP-RAC.

Results

The PAP-RAC approach to obtain thematic maps, used by FAO (Griesbach *et al.*, 1997), was chosen because it is the most widely used model in the qualitative evaluation of water erosion.

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The maps of the susceptibility to the erosion, and the forms of the erosion derived from frequent field visits and using satellite images, demonstrated that the Aoulai watershed is known by a strong morphodynamical action, through the associated forms, from sheet erosion, rill erosion, gully erosion till bad lands (photo 1).



Photo 1 - Different forms of water erosion in Aoulai watershed area, situation in December 2016.

Fot. 1 - Diferentes formas de erosão hídrica na bacia hidrográfica de Aoulai, situação em dezembro de 2016.

The forms and the highly eroded slopes show the combination between environmental factors; fragile lithology, concentrated runoff in time and space and steep slopes, and the exploitation of slopes by human activities unsuited to the nature of the surface. The repercussions of this strong erosion, the loss and destruction of the soil and the threat of infrastructure and environmental problems reflected in the socio-economic skills of the settlers, due to the decline of land use, soil fertility and sustainability of the agricultural system for future generations, and the threat to human facilities and equipment (such as roads and irrigation channels).

Among the factors contributing to the activity of this phenomenon can be summarized as follows:

- Natural conditions: refer to the characteristics of the surface and climate changes that occurred during different periods of time, which played a key role in the deterioration of the natural environment. The violent and sudden rainfalls concentrated in time and space, is the main engine of water erosion, resulting in an important water flow leading to extract and transform the surface of soil to deposit on the valleys and the banks of the wadis (Gartet (Houari), 2010). This is related to the weak vegetation cover of the surface (El Mazi *et al.*, 2017), steep slopes and friable materials of the Aoulai watershed;

- Human activities: The human factor is strongly related to the deterioration of the soil of the Aoulai watershed. This is due to the old settlement of these mountainous areas (Daïde, 2005), rapid demographic growth and high population density, accompanied by an increase in consumption and a consequent increase in demand for food needs, associated to the technological development achieved to improve social and economic conditions.

This fact has pushed the population to a greater exploitation of natural resources, at the expense of fragile areas with an unstable ecosystem and without taking into account environmental balances.

The human interventions are also crucial to the erosion dynamics due to its misuse of the study area, either through reform or activities in the provision of food needs, such as overgrazing, exploitation of bare and steep slopes, roads and roadways without regard to the negative effects behind these operations (Gartet (Houari) *et al.*, 2005).

The areas of the Aoulai watershed are also known to have been clearly degraded by erosion (fig. 3) resulting from rain, directly affecting the fragile rocky surface.

Degradation is a result of the combination of many factors and gives the key elements for the interpretation

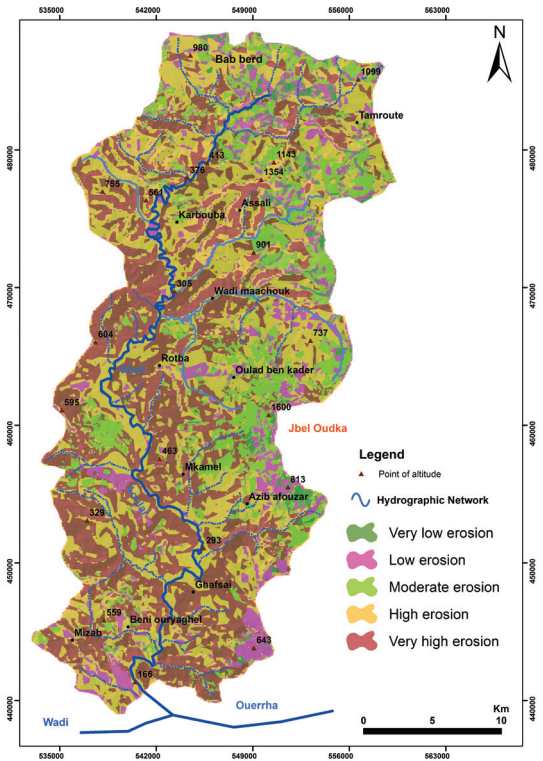


Fig. 3 - Erosion susceptibility in Aoulai watershed based on PAP-RAC approach.

Fig. 3 - Suscetibilidade à erosão na bacia hidrográfica de Aoulai com base na abordagem PAP-RAC.



of the contribution of each element. The steep slopes cover nearly 75% of the entire watershed, which explains the importance of a precipitous element in accelerating erosion processes and the aspects forms, and its direct impact on the behaviour of water flow along the watershed due to the rugged mountain terrain.

The thematic maps combined can be considered as documents that assist those responsible for the areas of damage to find solutions for mitigation the erosion problem. Based on these maps, the area's most sensitive to water erosion are targeted to guide interventions aimed at protecting the natural and territorial resources in the Aoulai watershed, especially because that watershed is in a stage requiring urgent intervention to reduce the aggravation of the problem that disrupt the environmental balance in the concerned zone.

The erosion susceptibility map highlights the factors of the erosion through examining and determining the slopes, lithology formation, vegetative cover and land use (fig. 3). The matrix correlation (Griesbach *et al.*, 1997), shows the main factors engaged into the process of erosion susceptibility in the Aoulai watershed; over 60 % of the strong correlations is clearly related to the soil exposed to erosion with the rate of  $r=0,76$ . The soil preservation up to  $r=0,62$ , the slope up to  $r=0,65$ , and up to 0,60 of the vegetative cover (TABLE I).

Based on the correlation coefficient for erosion susceptibility, we have drawn to the outcome that both the slopes and vegetative cover are considered as the most influential factors for the morphodynamical and the activation of water erosion in the Aoulai watershed. According to the PAR-RAC assessment (MAP, 1989), the surficial formations formations and the land use have less impact on the natural environment of the Aoulai watershed since the correlation coefficient remains stagnated at  $r$  for both the slopes and the vegetative cover in the study area, respectively 38% and 73%.

The weak correlations lesser than 40% are associated with the lithological formations and the land uses respectively with the rate of  $r=0,37$  and  $r=0,32$  with the equivalent rate of 9% of the land utilization and 16% for lithology. To summarize, all descriptive aspects of the factors for the predicative study have not reached since the human intervention in the watershed remains as the main factor for the dynamics and activation of the erosion process and forms (fig. 4).

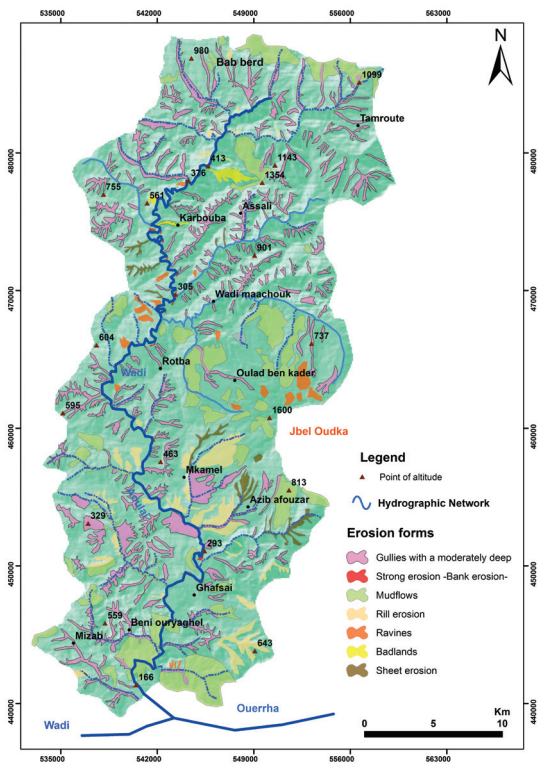


Fig. 4 - The forms of water erosion in Aoulai watershed in Central Rif mountains.

Fig. 4 - Formas de erosão hídrica na bacia hidrográfica de Aoulai, nas montanhas de Rif Central.

TABLE I - The correlation matrix for erosion susceptibility in Aoulai watershed.

TABELA I - Matriz de correlação para avaliar a suscetibilidade à erosão na bacia hidrográfica de Aoulai.

	Land use	Vegetation cover	Slope	Lithology	Soil protection	Soil erosion susceptibility	Potential erosion
Land use	1	-0,15	-0,26	-0,02	0,2	0,24	0,32
Vegetation cover		1	0,05	-0,03	-0,99	0,04	-0,62
Slope			1	0,01	-0,06	0,85	0,65
Lithology				1	0,05	0,49	0,37
Soil protection					1	-0,03	0,62
Soil Erosion susceptibility						1	0,76
Potential Erosion							1

Through our analysis of the map of erosion susceptibility in the Aoulai watershed, we can distinguish between three main categories of erosion:

- Strong and very strong erosion zones: this covers the bare and semi bare areas, and the annual cultivation of the shale and clay slopes that belong to the Jurassic era and are marked with steep slopes as well as weak resistance. These areas cover about 588 km<sup>2</sup> of the watershed area (72%) which are clearly located along the watershed and are particularly in upstream on the slopes look over in the Aoulai Wadi, where the ravines and meanders are clearly expanded (photo 2);
- Medium erosion zones: these areas cover about 118 km<sup>2</sup> (14%) clearly appeared at the foothills of the watershed Mountains such as Oudka and some rocky outcrop along the watershed;
- Weak and very weak erosion zones: these areas contain 14% of the watershed surface; 110 km<sup>2</sup>. In terms of spatial distributions are concentrated in the mountainous areas of Oudka, Zazou and Tiklyan located in the upper part of the watershed with very important vegetative cover and non-residential areas.

According to the descriptive analysis and the maps of the erosion forms in the Aoulai watershed, we notice a great diversity of the water erosion forms in the concerned watershed. This is entirely interconnected with the peculiarities of its natural environment where the upper part of the soil surface, is violently removed and eventually becomes less fertile because of the lack of the organic substances (Roose, 2004). This can affect negatively on the main source of people living known as the third classic activity (agriculture, animal husbandry and forest exploitations). On other hand, these areas are considered to be a source of sediments exportation into the valley bottoms (Gartet, 2001), contributing to the siltation of water installations in Al Wahda dam which is viewed as one of the indicators of environmental degradation in the Ouerrha watershed.

Although the complicated problem, there is no clear strategic vision of the government to integrate these areas into the process of sustainable programs of the state. Consequently, this leads to an increasingly complicated situation by the bank erosion of wadis and the morphodynamical steep slopes contributing to the unbalance of ecosystem of the region. The effects of water erosion can be summarized as follows:

- Degradation of the agricultural lands with loss of its productivity, the emergence of ravines and rill erosion resulting from diffused streaming which impede the possibility of using modern tools for agriculture because of the water erosion changes the state of the surface;
- Elevation of the base level of the Aoulai Wadi and Al Wahda dam is caused by the sediment resulting from the erosion of the fertile soils and superficial



**Photo 2** - Active erosion and deposition in upstream sector of Aoulai watershed in Bab berd and Tamroute areas, situation in December 2016.

*Fot. 2 - Aspeto da erosão ativa e da deposição num sector de montante da bacia de Aoulai, situado nas zonas de Bab berd e Tamroute, situação em Dezembro de 2016.*

formations which affect the quality of the soil by weakening the organic substance and making it inappropriate for agriculture. This is directly reflected on the economic and social levels of the population by making the area unsuitable for human stability,

- Protruding tree roots due to strong erosion in the presence of fragile lithological formation where they can be easily transported through water erosion or wind and affects directly the life expectancy of the Al Wahda downstream of the Aoulai basin.

## Conclusion

The assessment of water erosion in the Aoulai Watershed shows the importance of GIS and the PAP-RAC methodology in the diagnosing of the dynamics of water erosion and its distribution in the basin. The factors involved in controlling it including rocks and relief. This problem has a clear impact on the soil heritage of the Aoulai basin, where the different types of erosion affect the impoverishment of the soil and turn it into Badlands which actually makes the lands unsuitable for agriculture and favor the appearance of Cannabis cultivation into the basin making even worse the standards of social life.

The current morphodynamic in the Aoulai basin is controlled by a set of variable factors which can be generally summed up as follow:

- The fragility of the natural environment which is mainly dominated by marl formation;
- The relief favors the dynamics through the dominance of the steep slopes along the basin;
- The excessive exploitation of vegetative cover by the local population leads to the degradation of the natural ecosystem in Aoulai watershed.

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