Morphometric analysis for predicting erosion dynamics in a Mediterranean environment. Case study of the Oued Djen-Djen watershed (Tebelout Dam), Jijel Wilaya (Northeast Algeria).

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Abstract

The morphometric characteristics of the Oued Djen Djen watershed are a crucial element that favors runoff and, consequently, water erosion. The objective of this research is to classify the sub-watersheds of oued, based on the morphometric indices indicators. For this purpose, the hydrographic network has been divided into six (6) sub-basins, based on reference documents such as the topographic map 1/25000. In order to accurately measure the influence of each morphometric index on water erosion, we used nine (09) indicative criteria. The various prioritization categories put in place result from the examination and processing of the averages of the morphometric indices, the hypsometric relief, as well as the size and shape, and finally the structuring of the hydrographic network. This study led to the classification of the sub-basins in question into three categories: classes with high awareness.

Keywords: Watershed, Oued Djen Djen , Tebellout, Morphometric index, Hierarchization, Erosion

Introduction :

The physical characteristics of the watershed and the climatic conditions that govern it impact the volume (in terms of water balance) and the temporal distribution (in terms of flow hydrograph) (Roche, M. 1963).

The morphological nature and the analysis of the hydrological functioning of the studied watersheds can be understood through three morphometric indices: hypsometric indices, form and size indices, and indices related to the organization of the hydrographic network.

The morphometric parameters, used to classify sub-basins (Bidwas, S et al., 1999), are constant indicators for assessing erosion risk.

These parameters also facilitate the classification and comparison of watersheds based on their suitability regarding current morphological processes.

A large number of formulas generally expressing observed statistical relationships between various morphological and physical attributes of river beds and basins have been established by American geomorphologists such as HORTON, LEOPOLD, MILLER, STRAHLER, SCHUMM, among others (Krimgold, D, B 1963; Hirsch, F, 1962).

All researchers indicate that the hydrological behavior of a watershed depends on hydrological mechanisms that are under the control of:

- The shape and organization of the watershed
- The lithological components of the study area.
- As well as the organization and architecture of the hydrographic network.

Our research aims to compare the sub-basins with each other, in order to detail and identify each sub-basin to better describe the unequal and extreme behavior of the sub-basins that are the object of our study.

The inequality of the morphometric properties at the level of the sub-watersheds reveals differences in the levels of runoff associated with a certain degree of erosion.

Research concerning erosion and solid transport processes reveals that these phenomena depend on various factors, the majority of which, such as morphometry, climate, and lithology, frequently generate distinct local impacts.

To illustrate this, we have established a specific in-depth study to measure the impact and severity of each of these morphometric parameters on erosion.

1. Presentation of the Study Area

1.1. Geographical Location of the Study Area.

The Oued Djen-Djen watershed is located 18 km south of the city of Jijel. It is supplied by the Oued Djen-Djen, which flows from west to east, and by the Oued Raha, which flows from east to west.

The Djen-djen Oued watershed is defined by a surface area of 264.19 km² and a perimeter of approximately 93.35 km. The aforementioned basin, which features an irregular and diverse topography, changes gradually from east to west, with elevations ranging from 220 m up to 1700 m.

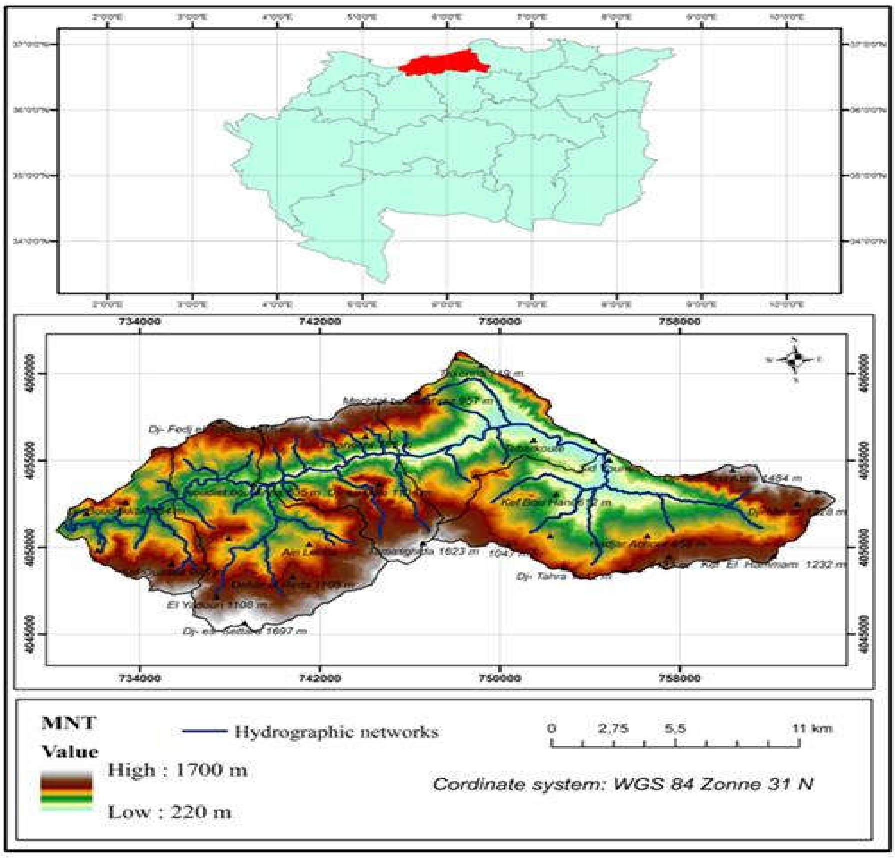

Figure 1 : Geographic location of the catchment area

1.2. Geologic, climatic and hydrological characteristics

From a geological perspective, several studies have been conducted in the Jijel region, including those by Bouillin (1971), D. Delga (1955), J. F. Raoult (1974), and H. Djellit (1987). These studies highlight the existence of two types of terrain: sedimentary and metamorphic.

In his work "Geological Study of the West of the Numidian Chain" (Étude géologique de l'Ouest de la chaîne numidique) published in 1955, Durand Delga identifies the Southern Numidian Chain and the Northern Numidian Chain as the two mountain ranges that delimit the upstream portion of the Djen-djen wadi.

In its initial section, the wadi conveys waters from the western extremity of the Numidian chains, where it forms deeply incised gorges that open out onto the plain under study.

Climatic factors play a significant role in the overall equation determining water erosion in watersheds.

The "water erosion" risk is strongly influenced by the substantial volumes of precipitation observed in the region in question.

Problems associated with water erosion in watersheds manifest during rainfall events (showers, thunderstorms, torrential rain) and/or during snow and ice melt.

Due to its location in North Africa, the study area lies at the intersection of polar and arctic air masses on one side, and tropical air masses on the other (Seltzer, P. 1946). According to Arabi, M. and Roose, E. (1989), high-intensity thunderstorm rainfall occurs particularly in autumn when vegetation is absent.

According to M. Côte (1998), the Djen-djen wadi watershed is classified within the humid bioclimatic category.

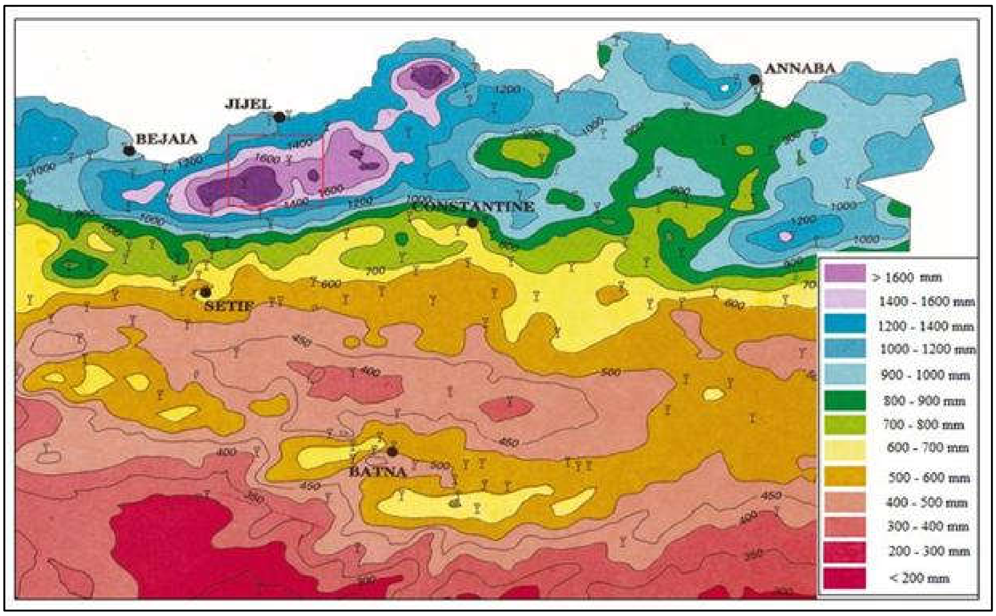

Figure 2 : Northeast Algeria: Annual Rainfall Depths 1965–2002 (ANRH)

According to the map of annual precipitation exceeded on average once every ten years ("wet decadal" annual rainfall) for the period from 1965 to 2002, provided by the ANRH and based on average data spanning 37 years, it is observed that wet decadal precipitation for this period decreases from the coastline towards the interior of the country in Northeastern Algeria.

During this period, the study area is characterized by a prevalence of rainfall levels exceeding 1600 mm..

Understanding watershed hydrology is essential in the fields of hydraulic management and environmental sciences. It encompasses both the water flow processes in the natural system (watershed, industrial, or urbanized zones) and the design of hydraulic infrastructures necessary for the use and regulation of water.

It also offers a better understanding and simulation of the dynamic behavior of water in the regions where it flows, as well as a better grasp of the effects of hydraulic infrastructures on the environment (André Musy et al., 1998).

Morphometric indices, grouped into three categories, can provide insights into the morphological behavior and hydrological analysis of the studied watersheds. These indices include hypsometric relief indices, those related to morphometric size and shape, as well as those linked to the arrangement of the hydrographic network.

Stream ordering is a way of arranging and classifying the network of a watershed. Several different classifications have been established, including those by Schumm (1956) and Strahler (1957).

The classification carried out using Arc-GIS software is based on the method by Strahler (1957) (Figure 3). This method, in particular, is widely employed in hydrological research focusing on watersheds.

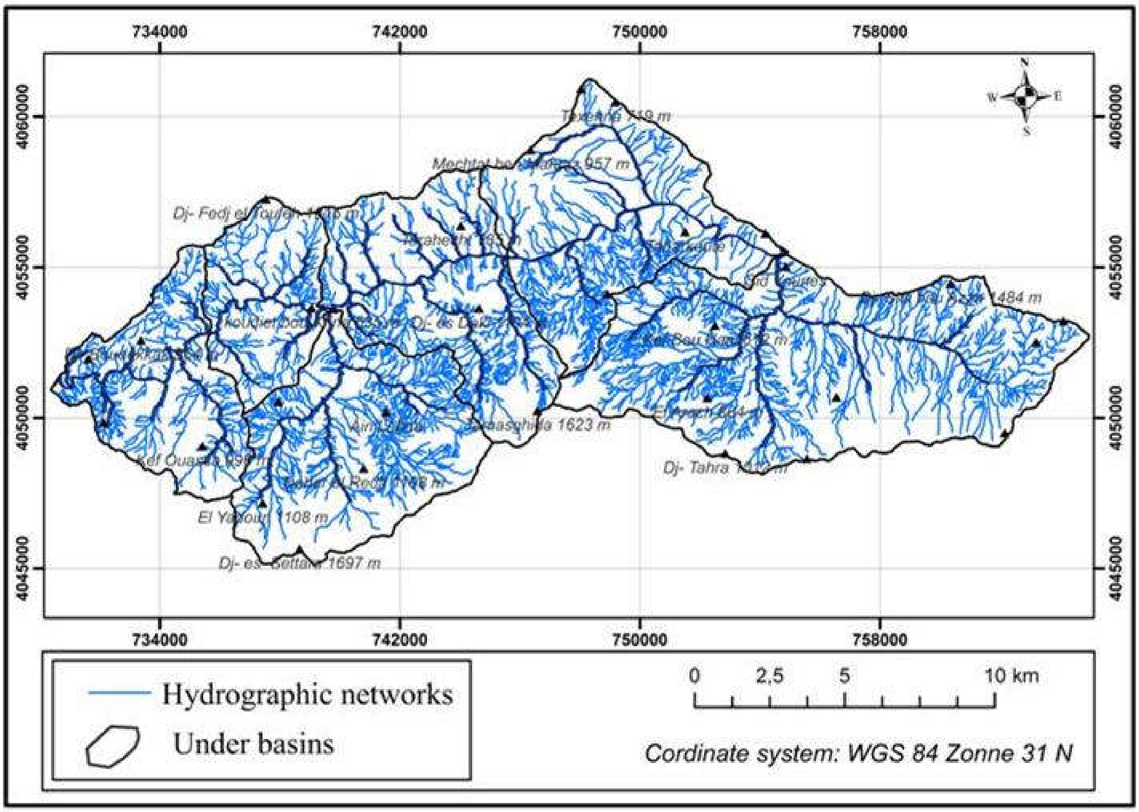

Figure 3: Oued Djen-djen Watershed: Hydrographic Network

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This classification is described as follows:

Strahler Classification 1957: A stream that has a source as its starting point is classified as first order (1). The confluence of two first-order streams results in a second-order stream (n+1). Similarly, the junction of a stream of any order with another stream of order (n+1) produces a stream that belongs to order (n+1). Thus, the order of the segment that reaches the outlet represents the maximum order of the basin (Benzougah, B et al 2016).

The hydrographic network (Figure 3.) was constructed based on the reference document: a topographic map at 1/25000 scale.

Table 1. Morphometric properties of the hydrographic network of the Oued Djen Djen sub-watersheds.

	watershed	Sub-watersheds					
		1	2	3	4	5	6
Total Number	3942	463	269	435	687	744	1344
Total Length (km)	1510,4	151,20	101,63	285,98	222,83	259,24	489,52
Length of the main thalweg (km)	33.34	8.05	6.64	9.07	7.22	11.44	10.72

Indeed, six (6) sub-watersheds were defined using a Digital Elevation Model (DEM). According to Table 1, it is noted that the majority of the sub-watersheds have a generally dense hydrographic network across the entire area of the sector, particularly sub-watersheds (3), (4), (5), and (6).

2. Materiel and method:

The objective of this study is to classify the sub-watersheds of Oued Lagreme and Oued Kissir, relying on indicative morphometric indices. Thus, the hydrographic network of the aforementioned watersheds was divided into six (6) sub-watersheds, delineated using reference documents such as the 1/25000 topographic map, which was modified from high-resolution satellite images using various software like ArcGIS and their extensions.

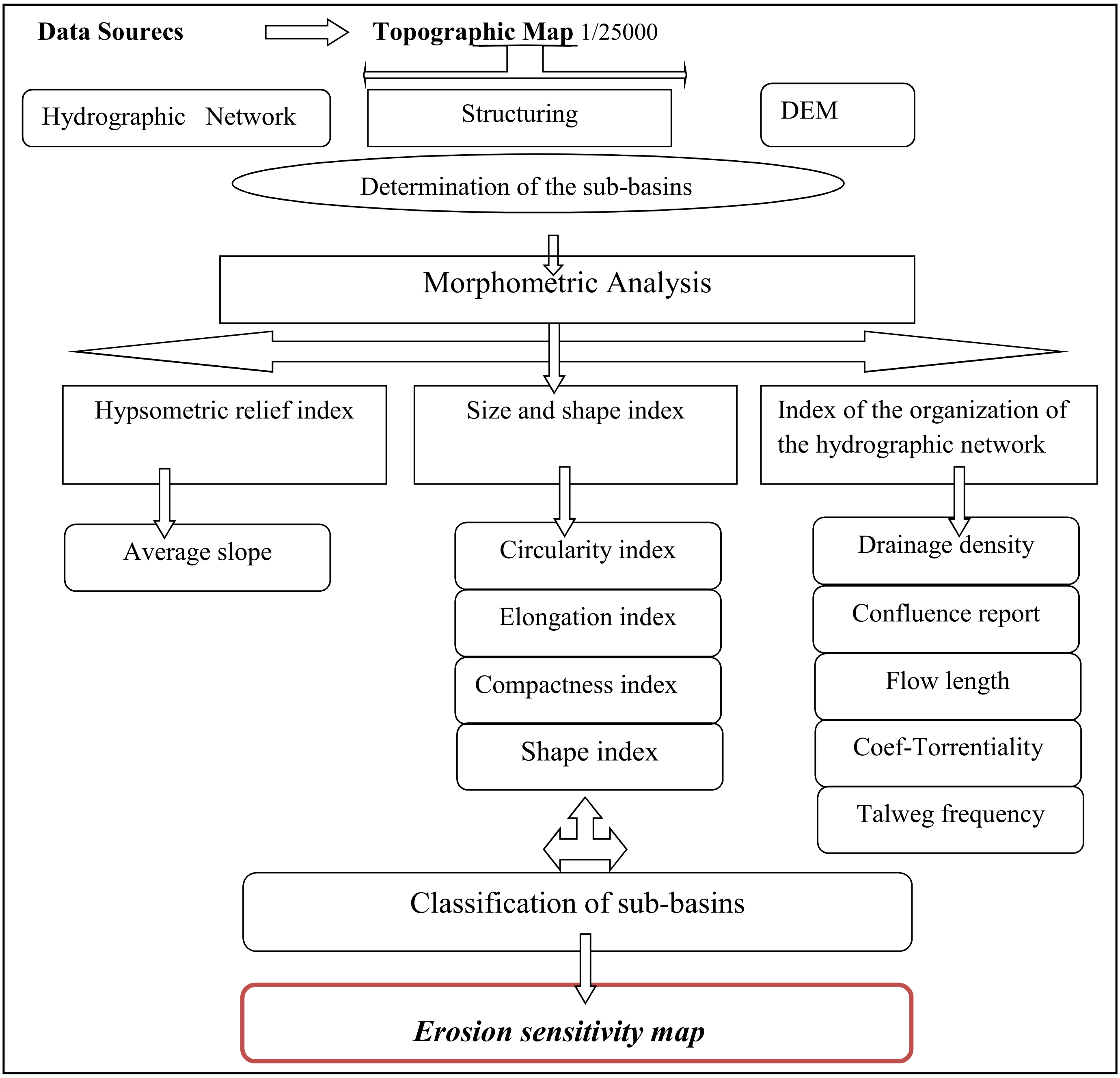

Figure 4: Organizational chart of the adopted methodology

In order to accurately measure the effect of each morphometric indicator on water erosion, we used nine (09) indicator criteria. The various categories of prioritization developed later result from the examination and processing of averages of various morphometric indices, hypsometric reliefs, as well as dimension and shape, and finally the arrangement of the hydrographic network.

This study uses the following method (figure 4.):

The development of the hydrographic network for the watershed was carried out based on the topographic maps of the study region (scale 1/25000).

A high-resolution Digital Terrain Model (DTM) was created based on the topographic map.

In order to perceive the risk factors for water erosion in the study area, our approach is based on the evaluation of the weight of the morphometric indicator parameters of the concerned basin.

In this work, the hydrographic network was validated and then divided into six (6) sub-basins. In order to accurately measure the influence of each morphometric parameter on water erosion, we used nine (09) separate indicators.
The various categories of prioritization that have been implemented are the result of examining and processing averages of various morphometric indices, hypsometric reliefs, dimension and configuration, and finally, the arrangement of the hydrographic network.
Morphometric parameters are perceived as criteria for assessing erosion risk and were used to prioritize sub-basins (Bidwas et al., 1999)
In the end, the approach adopted made it possible to establish a classification of the sub-basins of the Odi Djen Djen, based on nine (09) morphometric indicators. The prioritization criteria considered later result from an analysis and study of the averages of various morphometric parameters:

2.1. Establishment of indicative parameters for the classification of sub-basins

The inequality of morphometric attributes at the sub-watershed scale reveals variations in runoff intensities, which are related to an associated level of erosion.

Table 2. Oued Djen Djen watershed: Morphometric characteristics of subbasins

	watershed	S/b n°1	S/b n°2	S/b n°3	S/b n°4	S/b n°5	S/b n°6
Area (km2)	264.19	28.89	21.38	45.00	41.09	46.40	81.43
Perimeter (km)	93.35	27.15	20.72	31.17	32.78	34.70	46.43

The study of watersheds greatly benefits from these two indicators, the area and the perimeter. The nature of the relationship between flow and time is influenced by their factors (Ahmed Laabidi et al., 2016).

The hypsogram and hypsometric curve define the distribution of elevations in the watershed and facilitate the identification of the dominant elevation, or the elevation covering the largest elemental area between two consecutive contour lines.

2.2. The hypsometric indices indicating relief:

Physical elements such as relief hypsometric indices, mean slope (Pmoy), basin relief (Rb) and relative relief index (Rr) are crucial for the functioning of the watershed.

The meteorological conditions that govern the functioning of the watershed, as well as its physical properties, affect the volume and the temporal distribution (Roche ; 1963).

Average slope (Pmoy): it is expressed by the formula below.

$$p'(m-km) = \frac{Hmax\,(m) - hmin\,(m)}{\sqrt{A}\,(km2)} x100$$

From where: Hmax (m): maximum altitude of the watershed in meters

Hmin(m): minimum altitude of the basin in meters

A(km2): area of the drainage basin in km2.

2.3. The indicators indices of size and shape:

The size and shape indicator parameters such as the shape index (IF), elongation index (E), and compactness index (Ic) are inversely proportional to the strength of soil erosion (Benzougah.B, et al 2016).

Circularity index (ICr): The circularity index (ICr) is the ratio of the surface area of a basin to the area of a circle having the same circumference as the perimeter of the basin (Miller 1953).

ICr= $\frac{A}{SCn}$, hence:

A= area of the watershed (Km 2).

SCn= area of a circle having a perimeter Pcn=P, with:

Pcn: Perimeter of the circle in Km.

P = perimeter of the watershed in (Km).

Elongation index (E): According to Schumm.1956, the elongation index is defined as the ratio of the diameter of the circle with the same surface area as the drainage basin to the maximum length of the basin.

The elongation index is represented by the following formula:

$$E = \frac{DCr\ (km)}{Lmax\ (km)}$$ from where

DCr: diameter of a circle having an area (SCr) equivalent to the area of the watershed object of study.

Lmax: maximum horizontal length of the watershed in (km).

Compactness index (IC): Thus, in 1914, Gravelius (Germany) proposed the compactness coefficient, defined as the ratio of the perimeter of the basin to that of a circle of the same area.

The index to which it is most commonly referred is the so-called Graviluis compactness index. It is defined as the ratio of the perimeter of the studied watershed to that of a circle with the same surface area (Bendjoudi H; Hubert .P, 2002).

If the perimeter of the basin object of study is noted (P) and its surface (A), the compactness index is expressed by: $Kc = 0.28\,\frac{P}{\sqrt{A}}$

Shape index (IF): the shape index is defined as the ratio of the total surface area of the watershed and the length of the basin (Horton, 1932).

For a perfectly circular watershed, the value of (IF) generally greater than 0.8.

$$IF = \frac{S(km^2)}{[Lmax\ (Km]^2}$$

With:

S (km 2) : area of the watershed

Lmax (km): maximum horizontal length of the watersched

2.3. The indicator indices of the organization of the hydrographic network

Drainage density (Dd):

• The drainage density, defined by Horton (1934), is the ratio of total length of tributaries per unit area of a watershed. It is controlled by several factors, notably the geological nature of the land, the infiltration capacity of the soil and subsoil, the climatic conditions and the vegetation cover of the watershed, Humbert, 1990).

The flow length index (l_0): it is determined by the following formula:

$(l_0) = ½ \, Dd$ **,** with

Dd: drainage density of watershed

(l_0): flow length index (l_0)

The flow length index (l_0) is inversely proportional to the average slope of the channel (Shiva and Dharanirajan, 2014).

Torrentiality coefficient (Ct):

The torrentiality index indicates the level of dissection of the relief by first-order watercourses, and thus the significance of the thalweg. It reveals the intensity of the hydrographic network and offers a concrete representation of the subdivision of basins (Dermmak, 1982).

The torrentiality coefficient, which is an indicator, turns out to be more significant than other parameters in the organization of the hydrographic network of a watershed. It is formulated as follows:

$$Ct = Dd. N1/S$$

With:
Ct: torrentiality coefficient
Dd: drainage density of the watershed
N1: number of thalweg order 1
S: total area drained by the order thalweg

Thalweg frequency: the frequency of the Talwagons of a watershed is defined by the formula below:

$$Fq = \frac{N(talwegs)}{S(km^2)}$$

With
N: total number of drains in the watershed.
S: area of the watershed.

2.4. Method for classifying and coding sub-watersheds according to the degree of impact of morphometric indices on erosion

According to Benzougah, B et al. (2016), the indicator parameters concerning the hyphometric relief and the structure of the hydrographic network of a catchment area directly and proportionally influence the erodibility of soils; their value is more important, the more the erodibility of the soils is great. While size and shape indicators are inversely proportional to erosion, in other words, the lower these values are, the greater the soil's erodibility.

Thus, we have taken this measure as a regulation for the classification and coding of various indicators (hypsometric relief indices, size and shape, and finally the organization of the hydrographic network) for the sub-basins of the Oued Djen_djen.

Table 3. Prioritization of the hypsometric Parameters indicating the relief of the sub-basins Oued Djen-djen

		Hypsometric relief indicator parameters	
		P(moy)	class
B/V		-	-
S/B	1	18,62	4
	2	19,48	2
	3	18,63	3
	4	20,28	1
	5	17,33	5
	6	15,28	6

The parameters indicating the size and shape

Indicator parameters are inversely related to soil erodibility: the lower their values, the higher the soil erodibility.

According to Benzougah, B et al (2016), the indicator of size and shape (Table 4) in particular the shape index (IF), is inversely related to the intensity of soil erosion.

Table 4. Prioritization of parameters indicating the size and shape of sub-basins Oued Djen-djen

-		Size and shape indicator parameters							
		ICr	class	E	class	IC	class	IF	class
B/V		-	-	-	-	-	-	-	-
S/B	1	0,492	4	0,71	2	1,42	3	0,40	2
	2	0,630	6	0,72	3	1,26	1	0,41	3
	3	0,583	5	0,90	6	1,30	2	0,63	6
	4	0,481	2	0,77	5	1,43	4	0,47	5
	5	0,484	3	0,72	3	1,43	4	0,42	4
	6	0,475	1	0,51	1	1,44	6	0,25	1

The indicator parameters of the organization of the hydrographic network

Table 5. Prioritization of indicator parameters of the organization of the hydrographic network of the sub-basins Oued Djen-djen

		Indicator parameters of the organization of the hydrographic network							
		Dd	class	L_0	class	Ct	class	Fq	class
B/V		-	-	-	-	-	-	-	-
S/B	1	5,23	5	2,62	4	63,54	4	16,02	4
	2	4,75	6	1,19	6	43,45	5	12,58	5
	3	6,35	1	1,59	5	35,14	6	9,66	6
	4	5,42	4	2,71	3	68,85	2	16,32	2
	5	5,59	3	2,80	2	67,95	3	16,03	3
	5	6,01	2	3,005	1	75,28	6	16,51	1

3. Result and discussion

The various categories of prioritization developed (table 6.) come from a study and processing of previously obtained means of various morphometric parameters, hypsometric relief index, size and shape indices, as well as organization indices of the hydrographic network.

Table 6. Results of analysis and codification of all the morphometric parameters used in the sub-basins Oued Djen-djen

sub-basins	Codification of morphometric parameters										
	1	2	3	4	5	6	7	8	9		
	p_{moy}	ICr	E	IC	IF	Dd	l_o	CT	Fq	Moy	Final Class
1	4	4	2	3	2	5	4	4	4	3,555	Average
2	2	6	3	1	3	6	6	5	5	4,111	Low
3	3	5	6	2	6	1	5	6	6	4,444	Low
4	1	2	5	4	5	4	3	2	2	3,111	High
5	5	3	3	4	4	3	2	3	3	3,333	Average
6	6	1	1	6	1	2	1	1	1	2,222	High

The final distribution of the sub-catchments of the Oued Djen-djen led to the identification of key morphometric parameters that are at the origin of this classification.
The classification of the studied sub-basins was carried out based on the range of values of the parameters defined previously.

- Values of 2.222 to 3.111 soil erodibility classes high
- Values from 3.333 to 3.555 average erodibility classes
- Values from 4.111 to 4.444 classes of low erodilbility

This study led to the classification of the sub-basins of Oued Djen-djen into three distinct categories (figure 5).

High awareness classes (red color): under basins (4), and (6), this class corresponds to the area most exposed to erosion risks
Average awareness classes (yellow color): under basin (1), and (5) .
Low awareness classes (green color): under basin (2), and (3)

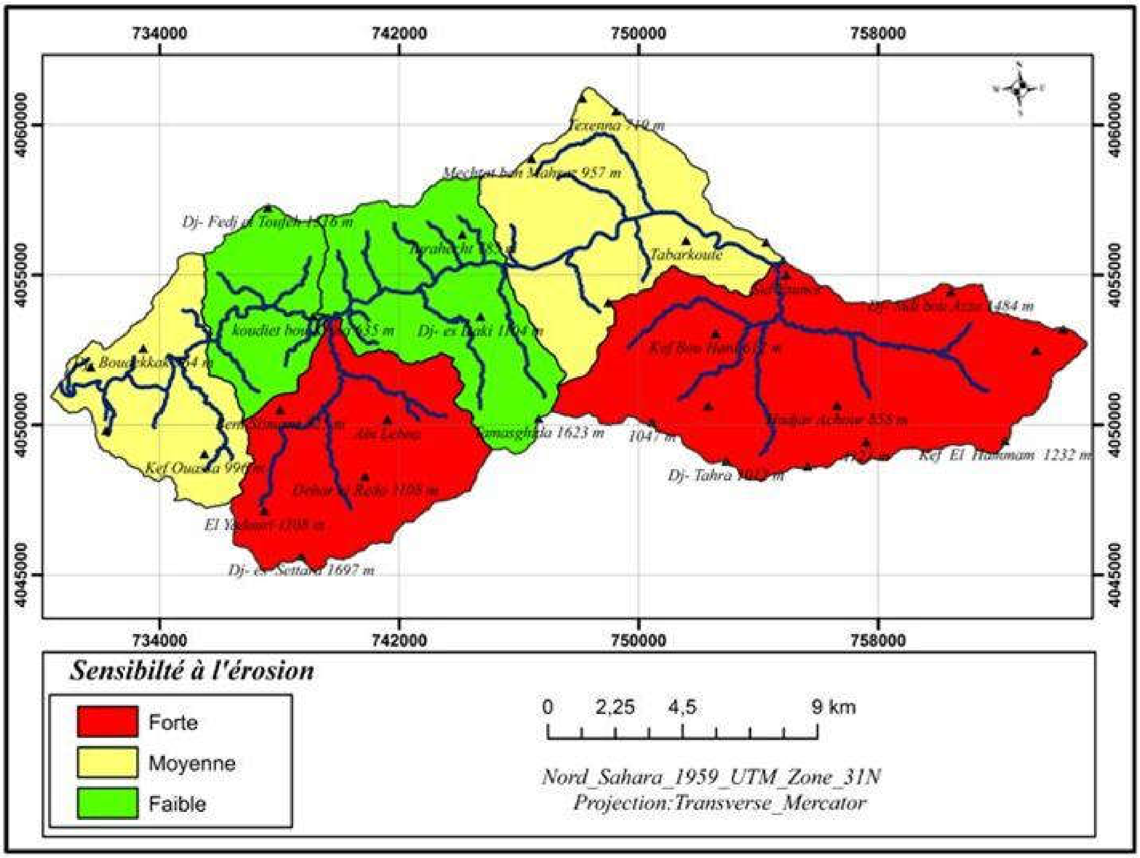

Figure 5. Map of sensitivity of the erosion of subwatersheds Oued Djen-djen

Conclusion:

This study successfully employed a comprehensive morphometric analysis of the Oued Djen-Djen watershed (Tebelout Dam) to assess and predict erosion dynamics within this complex Mediterranean environment in Northeast Algeria. By integrating indices related to basin shape, relief, and drainage network organization, this research provides a quantitative framework for understanding the factors driving high susceptibility to erosion.
The analysis highlighted that the watershed exhibits high relief and steep slopes (as indicated by the Mean Slope and Hypsometric Index), coupled with a dense and highly ramified drainage network (high Drainage Density and Stream Frequency), which significantly contribute to rapid runoff and intense erosive processes. Furthermore, specific sub-basins identified through the Torrentiality Coefficient and other shape indices were confirmed to be the most critically vulnerable zones, demanding prioritized intervention.

The various attributes of classification and ranking are the result of the analysis and processing of averages of several morphometric indices, hypsometrics, as well as size and shape, not to mention the organization of the hydrographic network.

Sub-basins (4) and (6) are highly sensitive to water erosion, while sub-basins (1), (5), (2) and (3) show moderate to low vulnerability.

In conclusion, the morphometric indices served as powerful and reliable proxies for identifying areas with an intrinsic physical predisposition to erosion. The resulting Erosion Susceptibility Map is a crucial decision-making tool for local authorities and water management bodies (like the Tebelout Dam operators). It directly supports the formulation of targeted, cost-effective soil conservation strategies, including reforestation programs, gully correction, and optimized land-use planning.

Future research should focus on integrating these morphometric findings with dynamic variables, such as land use changes, rainfall intensity data, and sediment yield measurements, to develop a fully predictive erosion model for sustainable management of the Oued Djen-Djen watershed's vital water resources.

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