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Evaluating the Morphometric Characteristics and Water Flow Influences in the Boussaada Wadi Sub-Basin, Algeria: A GIS-Based Approach.

Évaluation des caractéristiques morphométriques et des influences de l'écoulement de l'eau dans le sous-bassin de l'oued Boussaada, Algérie : une approche basée sur le SIG.

Avaliação das características morfométricas e influências do fluxo de água na sub-bacia do Uádi Boussaada, Argélia: uma abordagem baseada em SIG.

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Abstract: The importance of water as a vital resource and development factor is well known all over the world, and its conservation has led to the assessment of morphometric parameters that play an important role in the flow of surface waters. This study emphasizes the morphological analysis of the Wadi Boussaada sub-basin in Algeria, leveraging Geographic Information Systems (GIS) to enhance the understanding of its hydrological dynamics. The watershed and its geomorphological and hydrometric characteristics were identified using a digital terrain model (DTM) derived from SRTM images with a 30-meter resolution. These data were utilized to generate detailed cartographic representations in GIS (ArcGIS), aiding in the development of morphometric databases (BD), geographic, and thematic models. The application of GIS facilitates the extraction of the hydrographic network and sub-watersheds, enabling the calculation of physical watershed characteristics such as shape, relief, and network structure. The study produces thematic maps—including slope, flow direction, and drainage maps—that aid in identifying potential hazard areas within the basin. This approach underscores the importance of morphological analysis while illustrating how GIS can enhance the evaluation process.

Keywords: Bousaada Sub-Basin; Hydrographic Network; Morphological Analysis; Thematic Mapping; GIS-Remote sensing.

Résumé: L'importance de l'eau en tant que ressource vitale et facteur de développement est bien reconnue dans le monde entier, et sa conservation a conduit à l'évaluation des paramètres morphométriques qui jouent un rôle crucial dans l'écoulement des eaux de surface. Cette étude met en lumière l'analyse morphologique du sous-bassin de l'Oued Boussaada en Algérie, en utilisant les Systèmes d'Information Géographique (SIG) pour améliorer la compréhension de ses dynamiques hydrologiques. Le bassin versant et ses caractéristiques géomorphologiques et hydrométriques ont été identifiés à l'aide d'un modèle numérique de terrain (MNT) dérivé d'images SRTM avec une résolution de 30 mètres. Ces données ont été utilisées pour générer des représentations cartographiques détaillées dans les SIG (Arc GIS), contribuant au développement de bases de données morphométriques (BD), géographiques et de modèles thématiques. L'application des SIG facilite l'extraction du réseau hydrographique et des sous-bassins, permettant le calcul des caractéristiques physiques du bassin versant telles que la forme, le relief et la structure du réseau. L'étude produit des cartes thématiques, y compris des cartes de pente, de direction d'écoulement et de drainage, qui aident à identifier les zones à risque potentiel au sein du bassin. Cette approche souligne l'importance de l'analyse morphologique tout en illustrant comment les SIG peuvent améliorer le processus d'évaluation.

Mots-clés : Sous-bassin de Boussaada, Réseau Hydrographique, Analyse Morphologique, Cartographie Thématique, SIG-Télédétection.

Resumo: A importância da água como recurso vital e fator de desenvolvimento é bem conhecida em todo o mundo, e sua conservação levou à avaliação de parâmetros morfométricos que desempenham um papel importante no fluxo das águas superficiais. Este estudo enfatiza a análise morfológica da sub-bacia do Wadi Boussaada na Argélia, aproveitando os Sistemas de Informação Geográfica (SIG) para melhorar a compreensão de suas dinâmicas hidrológicas. A bacia hidrográfica e suas características geomorfológicas e hidrométricas foram identificadas utilizando um modelo digital de terreno (MDT) derivado de imagens SRTM com uma resolução de 30 metros. Esses dados foram utilizados para gerar representações cartográficas detalhadas em SIG (ArcGIS), contribuindo para o desenvolvimento de bancos de dados morfométricos (BD), geográficos e modelos temáticos. A aplicação de SIG facilita a extração da rede hidrográfica e sub-bacias, permitindo o cálculo das características físicas da bacia hidrográfica, como forma, relevo e estrutura da rede. O estudo produz mapas temáticos, incluindo mapas de declividade, direção do fluxo e drenagem, que ajudam a identificar áreas de risco potencial dentro da bacia. Essa abordagem destaca a importância da análise morfológica, enquanto ilustra como os SIG podem aprimorar o processo de avaliação.

Palavras-chave : Sub-Bacia de Boussaada, Rede Hidrográfica, Análise Morfológica, Mapeamento Temático, GIS-Sensoriamento remoto.

Introduction

Algeria, like other North African countries, faces significant erosion challenges (Probest & Suchet, 1992, p. 145). Given water's pivotal role in sustaining life and driving development, its quantification and management are universally acknowledged necessities. Consequently, the development of management and decision support tools becomes imperative for accurately estimating future developments in the studied region (Ould Ahmed, 2008, p. 78). Morphometric analysis serves as a vital approach for prioritizing watersheds, independent of soil mapping (Biswas et al., 1999, p. 112). A watershed represents an area where all water converges towards a single point, typically its outlet, directing every drop within its natural boundaries towards rivers or tributaries and eventually downstream.

Traditional techniques for studying watershed complexities have predominantly relied on manual methods, often yielding inaccurate results. However, the advent of GIS and remote sensing technologies has simplified the determination of shape, relief, and typology parameters of hydrographic networks, meeting the demands for surface water utilization and flood risk prevention (Benzougagh, 2016, p. 58).

The utilization of GIS software aligns with a broader process of information collection, management, and dissemination, empowering stakeholders to make informed decisions promptly. Serving as a tool for representing reality, understanding phenomena, and simulating alternatives and their repercussions (Achour, 2013, p. 203), GIS facilitates comprehensive assessments.

The present paper aims to provide a thorough evaluation of how morphometric characteristics affect water flow within the Boussaada Wadi sub-basin. By focusing on detailed morphometric analysis, the research seeks to enhance our understanding of how these characteristics—such as basin shape, relief, and hydrographic network—interact to influence hydrological processes. The study employs Geographic Information Systems (GIS) as a methodological tool to accurately assess and visualize these morphometric features. GIS facilitates the creation of detailed cartographic representations and thematic models, which are essential for analysing the spatial and temporal variations in water flow across the sub-basin.

Furthermore, the study seeks to optimize the interpretation of cartographic data through advanced GIS techniques. By leveraging GIS for precise mapping and spatial analysis, the research aims to improve the accuracy of hydrological assessments and provide valuable insights into the watershed's physical characteristics. Mastering computer-aided mapping techniques will enable the development of comprehensive morphometric databases and thematic maps, such as slope, flow direction, and drainage maps. These tools will aid in identifying potential hazard areas and contribute to better water management practices within the sub-basin.

Materials and methods

Study Area:

The study area is part of the arid and semi-arid regions, which present the greatest biodiversity in Algeria also the greatest loss of soil by water and wind erosion, by its climatic, physiographic, geomorphological characteristics, hydrological, pedological, historical, and current uses of the soil-vegetation system. Located on the southern part of the Province of M'sila, in the southeast of northern Algeria, between latitudes 34 ° 40 '0" in the North and 35 ° 20' 0 " in the South and between longitudes 3 ° 20 '0" West and 4 ° 30 '0" East (Figure 1).

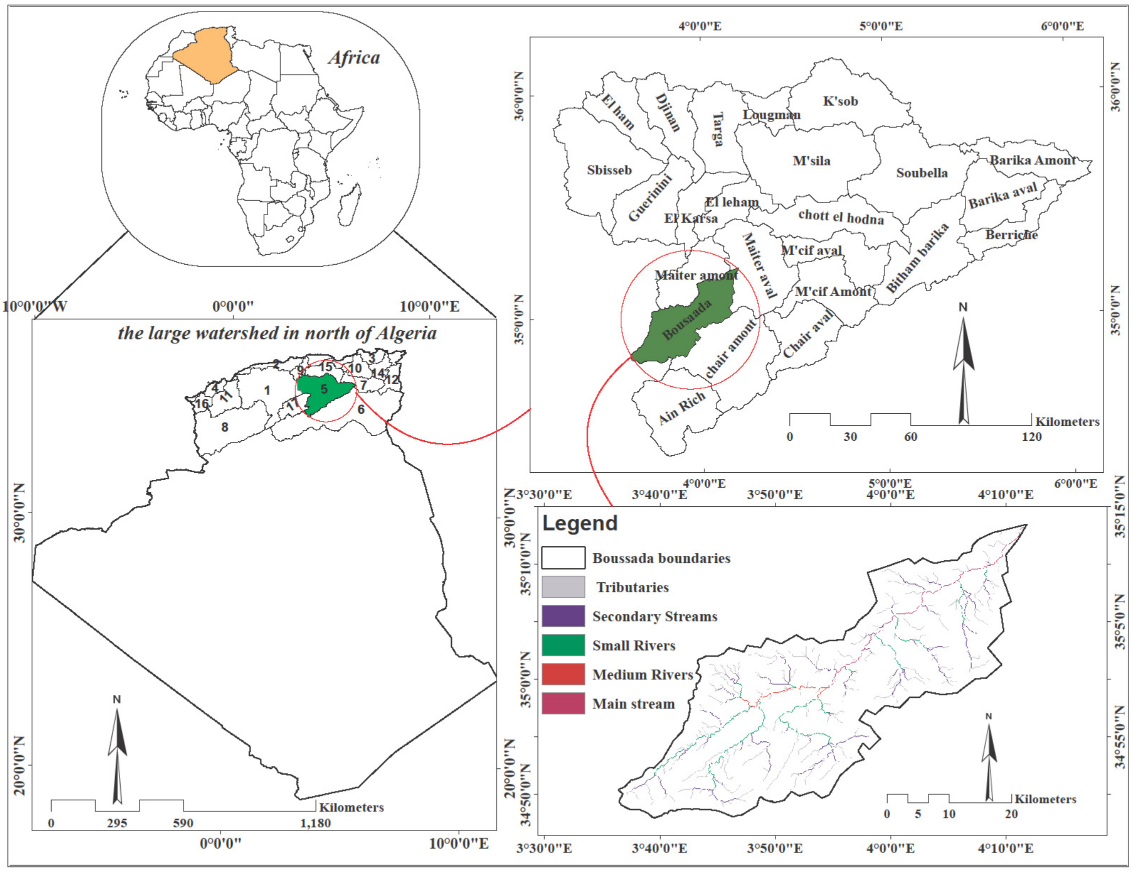

Figure 1- Situation of the study area

This area is part of the Maiterwadi watershed, which belongs to the large endorheic basin of Hodna. It is bordered by significant sub-basins as shown in Figure 1:

- Sub-basin of Wadi Maiter Upstream in the North.
- Sub-basin of Wadi Maiter Downstream in the North - East and East.
- Sub-basin of Wadi Chair Upstream in the South -East and South.
- Sub-basin of Wadi Daiet Mefiag in the West.
- Sub-basin of Wadi Medjadel in the North West.

Climate and Soil

The watershed is characterized by significant phytocenotic diversity, with limestone accumulations that reduce the depth of usable soil. This results in low vegetation cover and minimal organic matter content, making the area highly susceptible to degradation and erosion. The situation is exacerbated by intense rainfall events, which increase water erosion in sloping areas. Additionally, escalating and uncontrolled human activities pose a direct threat to the renewal of biological resources and the ecological balance of the region, significantly raising the risk of desertification.

According to the Emberger pluvial thermal climagram, the Boussaada region is located in the upper Saharan bioclimatic stage with a warm winter. The lithological formations consist of very resistant limestone substrate rocks, sometimes alternated with puffins, occupying the northern and northeastern parts of the study area. These formations can be distinguished into three types: zoogenic, sub-reef, and dolomitic limestone. High resistance, indicating low permeability (Figure 2), characterizes them.

Gypsum marls, which consist of gypsum with limestone and sandstone infillings, are found in the northern and western parts of the study area. These lands generally have low permeability. Additionally, the region features alluvial deposits, including both recent and older Quaternary deposits, composed of pebbles, gravel, and predominantly clay soils. These clay soils are prevalent throughout most of the study area and are impervious to water flow.

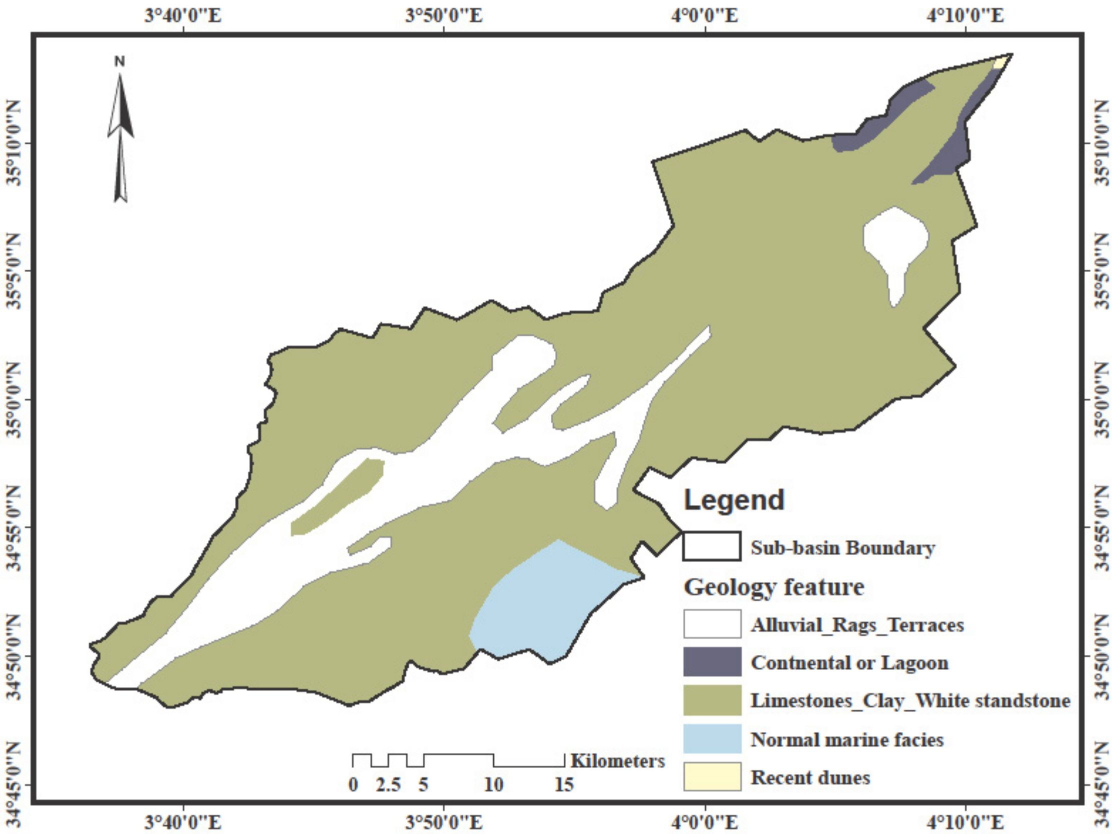

Figure 2- Geology of Boussaada Wadi watershed.

River System

A high density of the river system (Figure 3) which is justified by the existence of stronger slopes and less permeable surface formation, increasing the large exports of land that are linked to run-off.

Morphometric factors are very favorable for surface flow, lithological factors are favorable for water infiltration, vegetation is favorable for run-off and therefore for erosion and solid transport.

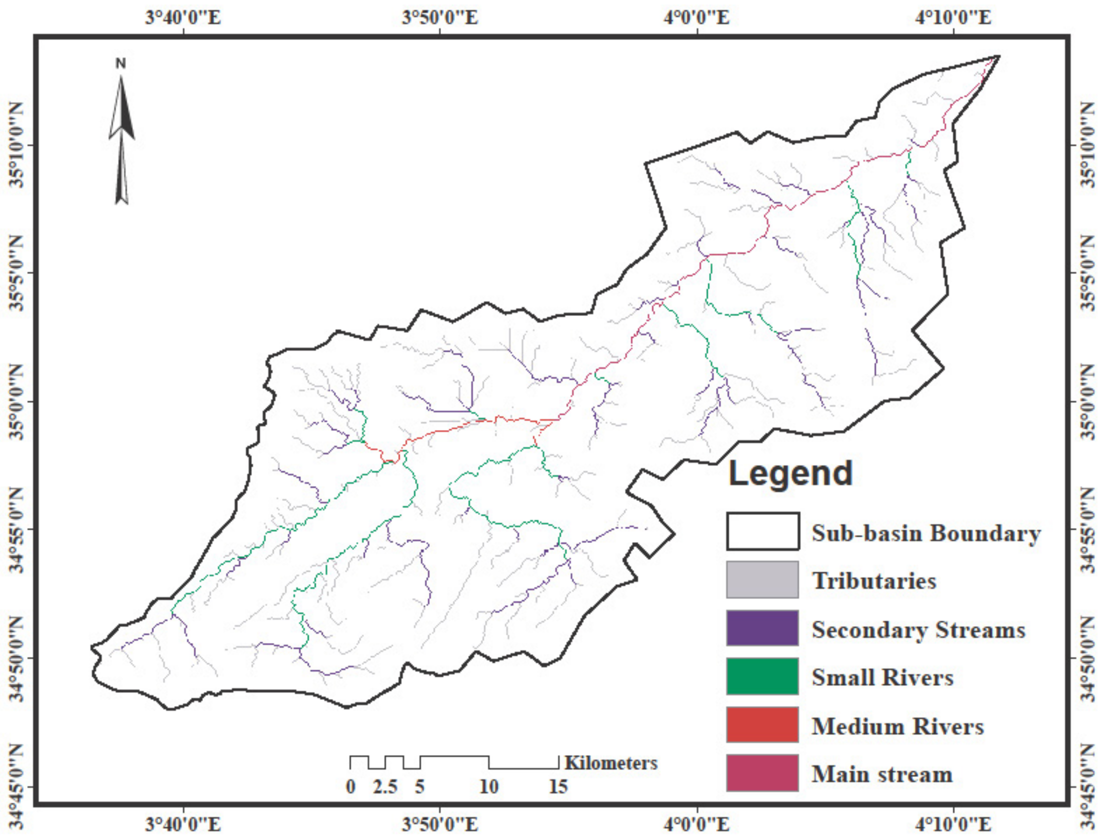

Figure 3- Study Area River System Map

Materials used

The use of The Shuttle Radar Topography Mission (SRTM) is valuable for delineating the study catchment area and automatically extracting the physical characteristics of the area under investigation. (Morphological characteristics, relief parameters, morphometric characteristics) (Benzougagh et *al*., 2019, p. 34).

The materials and data required for this study are summarized in Table 1.

Table 1. Materials used

<table>
<tr><td colspan="4">Documents</td><td>Software</td></tr>
<tr><td rowspan="2">Image data</td><td colspan="3">The Shuttle Radar Topography Mission (SRTM) provides topographic data with a resolution of 30 meters.</td><td rowspan="6">• Arcgis 10.7
• Q gis
• Global Mapper 18.
• GEE</td></tr>
<tr><td colspan="3">Sentinel-2 A on March 2020 (with a swath width of 290 km and a spatial resolution of 10 m)</td></tr>
<tr><td rowspan="2">Map data</td><td>Title</td><td>Scale</td><td>Support</td></tr>
<tr><td>• Map of Northen Algerian watershed.
• Land use map of Hodna region.
• Lithologie map of Hodna region.
• Topographic map of Biskra.
• Geologic map of Hodna region.
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<tr><td>Other data</td><td colspan="3">Rainfall recorded between 2010 and 2020 (Meteorological station of M'sila and Bou Saada)</td></tr>
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Metodology

The methodology of this work involves representing cartographic and descriptive information for various factors and parameters related to shape, relief, and typology of a hydrographic network, which can be analysed using a Geographic Information System (GIS) platform (Figure 4).

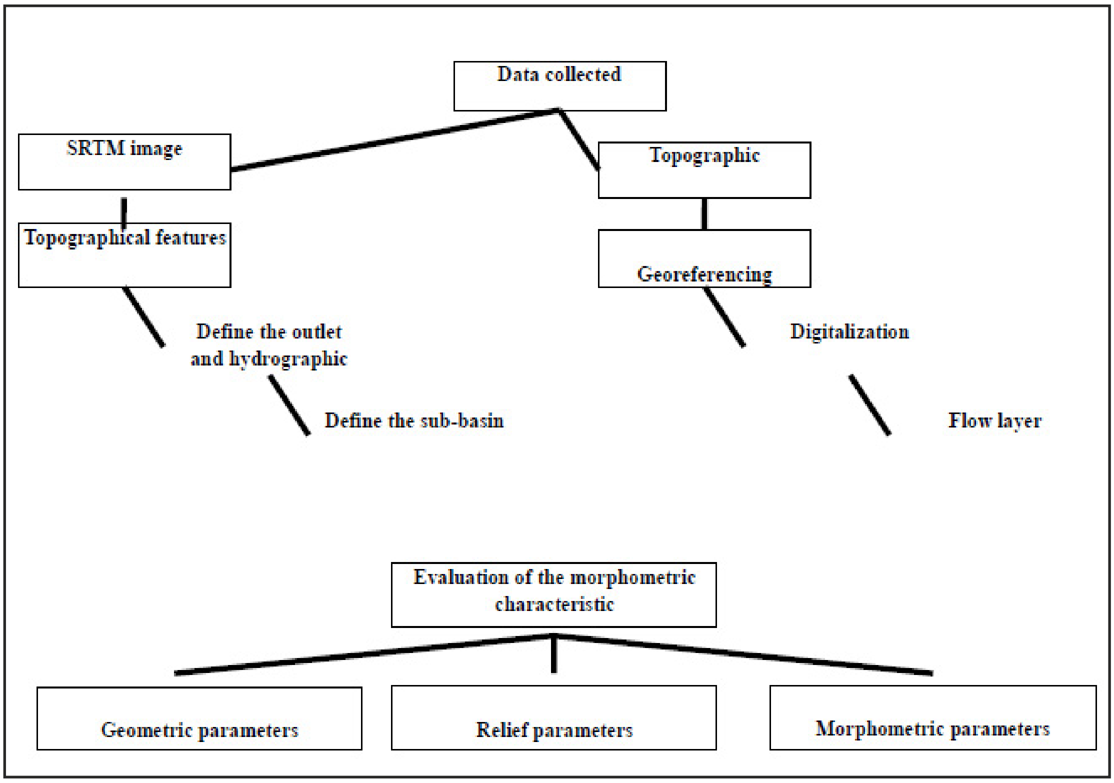

Figure 4- Methodology adopted for the work

The methodology also involved identifying and analyzing the parameters of relevant factors influencing the phenomenon, including the topographic index, rainfall erosivity, soil characteristics, and the NDVI index.

Results and Discussion

Results

In order to evaluate the morphometric characteristics of a watershed and its influence on the surface flow of water, the determination of the morphometric parameters is essential. In this study, we have used the automatic techniques that facilitate the extraction of these indices.

Geometric characteristics

The physical characteristics of a watershed influence the flow regime during flood or low water periods (Talatizi, 2014, p. 89).

Morphometric is concerned with the study of several indices (area, perimeter, shape, etc.) that are more or less relevant (André & Christophe, 2003, p. 56).

Form characteristics

Area and perimeter

For this study, the digitalization of the DEM of the Boussaada region allowed us to obtain an area (**A**) of 1035.47 Km^2 in a perimeter (**P**) of 195.50 Km.

The form

The Gravelius (1914) K**G** compactness index is defined as the ratio of the perimeter of the basin to the perimeter of the circle having the same area according to the relation (1):

$$KG = \frac{P}{2\sqrt{\pi . A}} \approx 0.28 \frac{P}{\sqrt{A}} \quad (1)$$

Where:

KG**:** Gravelius compactness coefficient,

P: Perimeter of the watershed in Km,

A: Area of the watershed in Km^2 and π: 3.14

If this coefficient is close to 1, the watershed is perfectly circular and therefore better drained. If **KG** is greater than 1, the watershed has an elongated shape and is therefore poorly drained. Based on a geographical query, the Gravelius compactness index (KG) is 1.69. The index is greater than 1, which characterizes a rather elongated basin, allowing linear and regressive erosion.

The equivalent rectangle

The concept of equivalent rectangle or Gravelius rectangle, introduced by (Roche, 1963, p. 45). The level curves becoming straight lines parallel to the small coasts and the outlets of the watershed being assimilated to one of these small sides of the rectangle (Ould Ahmed, 2008, p. 32). To compare the basins in terms of the effect of their geometric properties on the flow, the following two relationships were utilized: where L and I are the length and the width of the rectangle, and P and A are the perimeter and area of the watershed. Equations (2) and (3):

$$\left.\begin{array}{l} A = L \times l \\ P = (L + l)x2 \end{array}\right\} \tag{2}$$

$$L = \frac{KG}{1.12}\left[1 + \sqrt{1 - \left(\frac{1.12}{KG}\right)^2}\right] \& \; l = \frac{KG}{1.12}\left[1 - \sqrt{1 - \left(\frac{1.12}{KG}\right)^2}\right] \tag{3}$$

For the Boussaada Wadi sub-basin, we obtain a length (L) of 85.45 km for a width (l) of 11.72 km. The length being 7 times greater than the width. Which reflects the elongation of the sub-basin, this form in duct low peak flood flows.

Relief

The influence of the relief on the run off is easily understood, because many hydro meteorological parameters (precipitation, temperatures, etc.) vary with the altitude and the morphology of the sub-basin. In addition, the slope influences the flow velocity. The relief is also determined by means of the following indices or characteristics:

The hypsometric map

The hypsometric map illustrates the distribution of elevations throughout a landscape. It shows the areas between contour lines, offering insights into how different elevations affects the basin's surface. Additionally, it provides information on the slope and the rate at which the terrain's relief changes across the basin.

The hypsometric curve provides a synthetic view of the slope of the basin. It is established by planning the areas corresponding to the definition of the ordinate for each of the level curves (Eskenazi, 1991, p. 112). It makes it possible to judge the age and degree of erosion of the watersheds (Amil, 1992, p. 78).

After reclassifying a portion of the sub-watershed using the DEM, we obtain both the elevation data and the hypsometric map for the various altitude levels. (Figure 5).

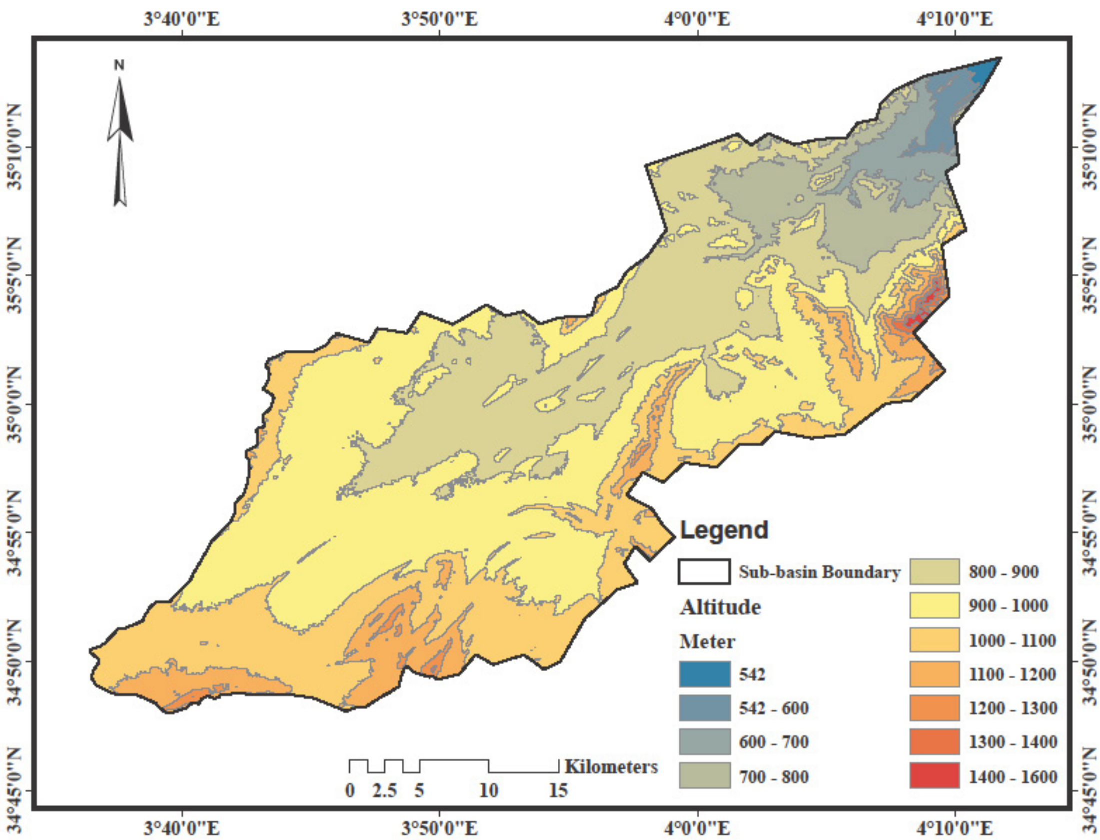

Figure 5 - Hypsometric map and altitude classes repartition.

The hypsometric curve of the sub-watershed is presented on figure 5, concave in form; it indicates that the basin is in a state of maturity. The maximum altitude represents the highest point of the basin while the minimum altitude considers the lowest point, generally at the outlet. For our study area, the maximum altitude (H) Max is 1618 m, the minimum altitude (H) Min is 554 m, with 1100 m for the median altitude. The median altitude corresponds to the altitude read at the ordinate point 50% of the total area of the basin (H50) on the hypsometric curve (Dubreuil, Guiscafre, 1972, p. 45).

The slope of the sub-basin

The slope has a great influence since it provides its erosive energy to water. Slope inclination directly affects the speed of run-off, accelerating solid transport downward; thereby increasing the impact of the ablation of detrital materials (Dumas, 2004, p. 67). The topographic index will therefore be the parameter to be considered for this factor. The numerical model of altitude (DEM) of the study area allowed establishing an altitude map (hypsometric) and a map of slope classes (Figure 6), aspects, concavities and convexities. The number of classes was chosen based on our knowledge of the field (Table 2).

Table 2: Slope characteristics in the study area.

Class (%)	Area(Km²)	Percentage (%)	Slope class
0 -3	474.27	45.84	Very low
3 - 6	332.49	32.14	Moderate
6 - 12	134.52	13	Faily low
12 - 25	72.06	6.97	High
> 25	21.22	2.05	Very high
Total	**1035.47**	**100 %**	

The slope is a key factor in determining the travel time of direct runoff, which impacts the concentration time and directly affects the peak flow during a storm.

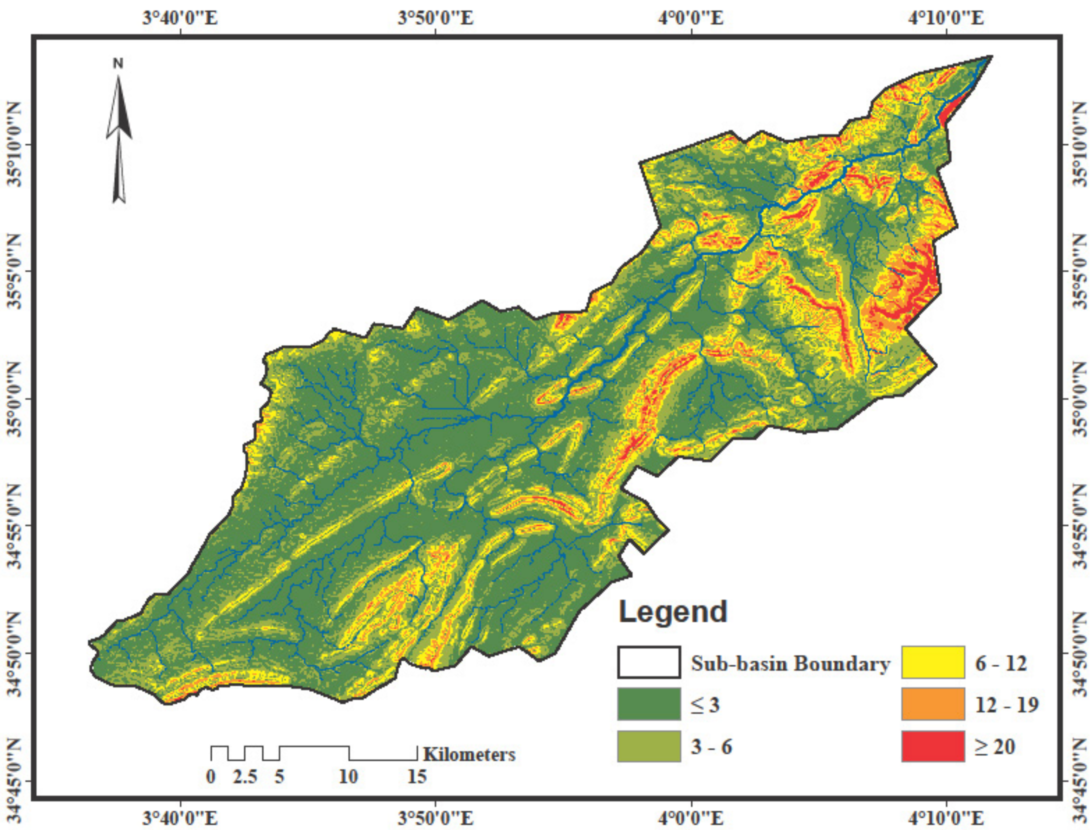

Figure 6- Slope map and slope classes' distribution.

Overall elevation difference

This parameter give us an idea of the difference in altitude between the upstream and downstream of the basin. Equation (4):

$$DG = H5 - H95 \qquad (4)$$

Where:

D_G: Overall elevation difference.

H_{95}: Altitude at 95% of the sub-basin, [m], *H95* = 800 m.

H_5: Altitude at 95% of the sub-basin, [m], H5= 1350 m.

They are determined from the hypsometric curve of the Hodna watershed. We deduce the overall elevation difference of the sub-basin, DG = 550 m.

Overall Slope Index

The relief plays an important role, because it largely controls the runoff capacity of the land. Its apprehension can be made using the global slope index *Ig* given by the equation (5):

$$Ig = \frac{DG}{L} \qquad (5)$$

Where:

Ig: Overall Slope Index, [m/km].

L: Length of the equivalent rectangle, [Km].

D_G: Overall elevation difference, [m].

The overall slope index of the sub-basin is, Ig = 6.43 m/km

Specific elevation difference

It is defined as the product of the overall slope index (Ig) by the square root of the watershed area **(Claude & Jacques, 2000, p. 92)**. The relief of the sub-basin are classified according to this parameter according to the classification of the O.R.S.T.O.M (Office of Overseas

Scientific and Technical Research) indicated in table 3.The equation (6) shows this:

$$Ds = Ig\sqrt{A} \qquad (6)$$

Ds: Specific elevation difference, Ds = 206.90 m.

I_g: Over all Slope Index, Ig = 6.43 (m/km)

$\sqrt{A}$: Square root of the sub-basin area, [km].

Table 3.Relief classification according to ORSTOM.

R1	Very low relief	DS<10 m
R2	Low relief	10m<Ds>25m
R3	Fairly low relief	25m<Ds>50m
R4	Moderate relief	50m<Ds>100m
R5	Fairly strong relief	**100m<Ds>250m**
R6	Strong relief	250m<Ds>500
R7	Very strong relief	Ds>500

ORSTOM: Office of Overseas Scientific and Technical Research

The specific elevation of the Boussaada Wadi sub-basin is, ***Ds = 206.90 m.***

According to ***Ds*** obtained, and according to the ORSTOM classification of the relief, the Boussaada Wadi sub-basin is fairly ***strong relief*** as shown in (Figure 7).

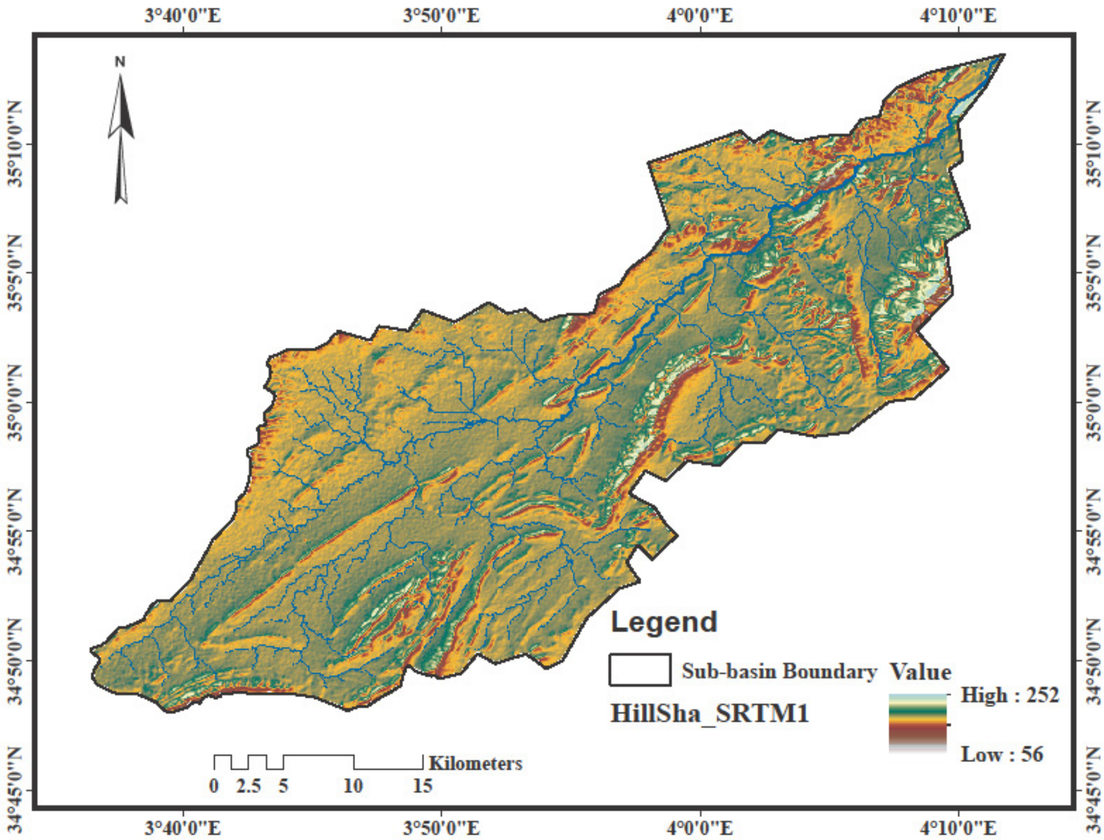

Figure 7- DEM Boussaada Wadi sub-basin

Characteristics of the hydrographic network

In examining the characteristics of the study area, we observe a well-developed hydrographic network as shown in Figure 8. This density is largely attributed to steep slopes and surface formations with low permeability, which intensify land erosion due to runoff. The morphometric features strongly promote surface runoff, while the lithological conditions support water infiltration. Additionally, the vegetation cover further contributes to runoff, thereby accelerating erosion and sediment transport.

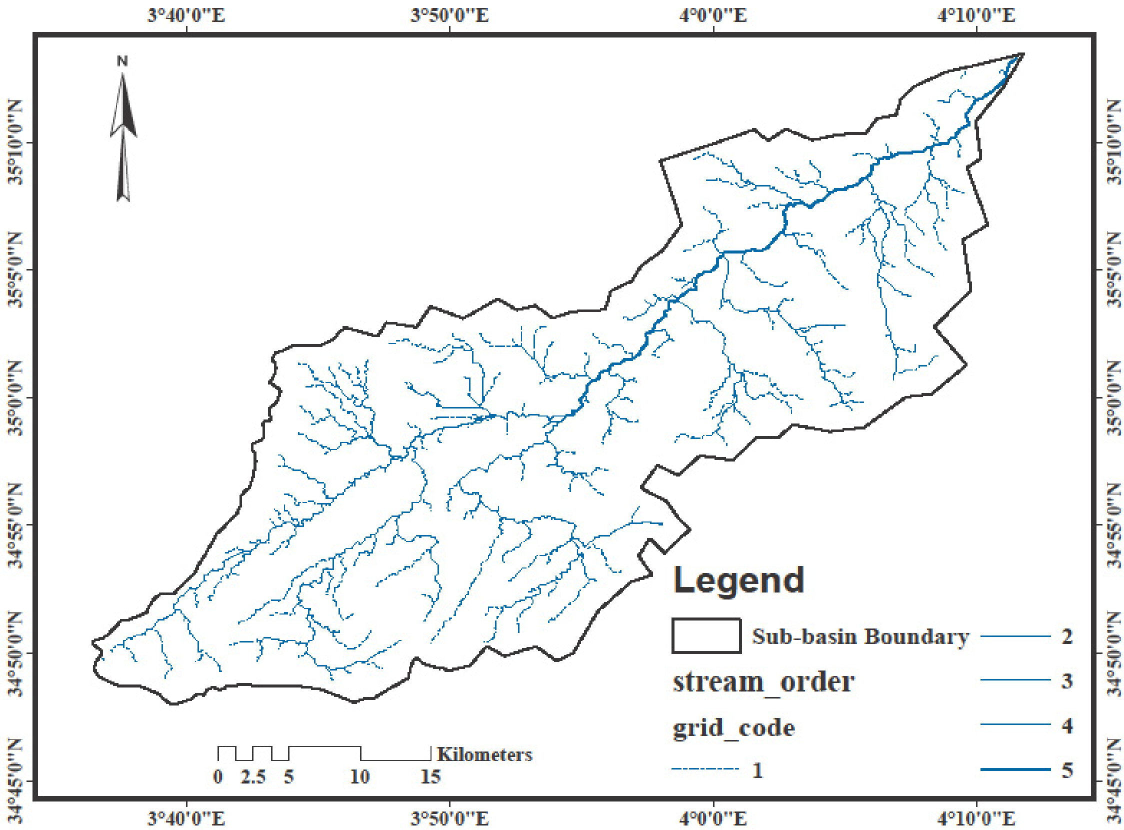

Figure 8- Hydrographic Network Map of Sub-basin

Topology: Network structure and stream order

The topology is useful in the description of the hydrographic network, in particular by proposing a classification of these (Musy, 2005, p. 118). This classification is facilitated by a numbering system for the sections of watercourses (main river and tributary). The coding of watercourses is also used for automatic data processing. There are several types of stream section classifications, including Strahler's classification (1957) which is the most widely used (Table 4).

Table 4. Classification of thalwegs

Stream Order	Number of thalwegs	Total length (Km)
1	673	507.83
2	287	216.22
3	173	108.39
4	78	40.86
5	87	57.17
Total	**1298**	**930.46**

This classification allows for a clear and precise description of the development of a basin's drainage network from upstream to downstream as seen in Figure 3.

The characteristic length and slopes of the network

The characteristic length

The length of the main stream (*L*) is the curvilinear distance, from the dividing line of the waters to the outlet, always following the segment of highest order when there is a branch line and by last extension to the topographical limit of the sub-basin area. If the two segments at the branch line are of the same order, we follow the one that drains the largest area. For the main stream of the Wadi Boussaada sub-watershed (Figure 9), the calculated characteristic length is *L = 85.45 km*.

The average slope of a stream

The average slope of a watercourse determines the speed with which the water reaches the outlet of the sub-basin, thus the concentration time. This variable therefore influences the observed maximum flow rate. A steep slope promotes and accelerates surface run-off, while a gentle or no slope gives the water time to infiltrate, in whole or in part, into the soil. The most frequently used method to calculate the longitudinal slope of the stream is to divide the difference in elevation between the extreme points of the profile by the total length of the stream (Bentekhici, 2006, p. 74). Equation (7):

$$Pmoy = \frac{\Delta Hmax}{L} \qquad (7)$$

Where:

P moy: Average slope of a stream / thalweg, [m/km].

ΔH max: Maximum elevation of the river, [m]/ (Altitude difference between furthest point and outfall).

L: Main stream length [km].***P moy* = *1064***/*85.45* = ***12.45 m/km***

The drainage density

This is the most important parameter that characterizes the hydrographic network; it corresponds to the ratio between the total lengths of the streams on the surface of the basin (Equation 8):

$$Dd = \frac{\sum Lx}{A} \qquad (8)$$

Where:

Dd: Drainage density, [m/km²]

Lx: Cumulative length of streams / thalwegs, *Lx = 930.46* Km

A: Sub-basin area, *A = 1035.47 km²*. ***Dd = 0.898 m/km²***

Stream frequency

Represents the number of streams per unit area, as shown in relation (9):

$$Fs = \frac{\sum N}{A} \qquad (9)$$

Where:

***Fs*: Stream frequency;**

N: Number of streams / thalwegs, N= 1298.

***A**: Sub-basin area A = 1035.47 km².*

Fs = 1.25

The Confluence Ratio / Bifurcation Ratio

The confluence ratio, also known as the bifurcation ratio, reflects the rate of bifurcation in the watershed. It is expressed by the ratio of the number of rivers of order (n) to the number of rivers of order (n+1) [Equation 10 & Table 5].

$$Rc = \frac{Nn}{Nn+1}, \text{ Law of numbers.} \qquad (10)$$

Where:

Rc: Stream Confluence Report ("bifurcation ratio").

Nn: Number of streams of order n.

Nn+1: Number of next order streams.

This bifurcation rate is related to the time of sediment concentration in the drainage system the lower the ratio, the less bifurcation there will be bifurcation at the level of the drainage network and the faster the evacuation of sediments downstream will take place **(Benzougagh et** al., **2019)**. According to Strahler (1957 and 1964), the confluence ratio (*Rc*) varies from 3 to 5 for a region where geology has no influence **(Strahler, 1957 & 1964)**.For a homogeneous basin, *Rc is* substantially constant **(Laborde, 2009)**.

Table 5.Confluence ratio of the Boussaada Wadi sub-basin RC.

Order Stream	Number of Stream	Rc
1	673	***
2	287	2.34
3	173	1.65
4	78	2.22
5	87	0.89

In the study area, Rc varies between 0.89 and 2.34, indicating that the geology of the region significantly influences the flow of surface water.

Law of lengths

Stream length ratio corresponds to the ratio of the average length of streams of order (n+1) to the average length of streams of order (n). We illustrate this in relation (11):

$$RL = \frac{Ln+1}{Ln}, \text{Law of lengths} \qquad (11)$$

Where:

RL: Stream Lengths Ratio;

Ln+1: Total length of streams of order n+1 [Km].

Ln: Total length of streams of order n [Km].

The higher the length ratio, the greater the higher order drains and the easier the sediment evacuations. The length ratios of the Boussaada Wadi sub-basin vary from 0.88 to 1.25 (Table 6).

Table 6. Ratio of length in the Boussaada Wadi sub-basin RL.

Order Stream	Number of Stre-am	Total length (Km)	Average length (Km)	RL
1	673	507.83	0.76	0.87
2	287	216.21	0.75	0.88
3	173	108.38	0.66	0.80
4	78	40.86	0.53	1.25
5	87	57	0.66	***

The Torrentiality coefficient is the ratio of the frequency of first-order watercourses to the drainage density, as described by relation (Equation 12):

$$Ct = F1xDd \qquad (12)$$

Where:

Ct: Torrentiality coefficient, [m/km²].

Dd: Drainage density, [m/km²].

F1: Frequency of Order 1 Thalwegs /Streams, *F1 = 1.25*.

Ct =** 1.25 x 0.898 =* ***1.123 m/km².

In another way, we can calculate Ct:

$$F_i = \frac{Ni}{A} \quad \& \quad Ct = \sum Cti, \text{ Table 7.}$$

This parameter allows the estimation of the size of the erosive energy of the stream.

A: Sub-basin area, A = 1035.47 km².

N*i*: Number of thalweg/stream of order ***i***.

Table 7. Torrentiality coefficient calculation results Ct.

Order stream	Number of streams	Fi	Ct_i
1	673	0.65	0.583
2	287	0.28	0.251
3	173	0.17	0.152
4	78	0.07	0.062
5	87	0.08	0.075

$$\sum Cti = 1.123\ m/km^2$$

The value of the torrentially coefficient is small, which shows that the flow in the thalwegs of order 1 is of small torrentially, this is due to the low slope that characterizes this catchment area, and to the presence of permeable soils. This value reflects that the basin does not represent morphometric characteristics adapted to the flow.

Discussion

The morphometric analysis of watersheds, empowered by Geographic Information Systems (GIS) and remote sensing technologies, has fundamentally transformed the study of landform characteristics and their implications for various hydrological processes. This approach enhances the precision and efficiency of morphometric analyses, offering deep insights into the spatial distribution and interrelationships of landforms within watersheds. The advancements in remote sensing technology and the availability of high-resolution digital elevation models (DEMs) and SRTM have enabled detailed assessments of concave landforms, such as valleys, gullies, and sinkholes (Gudowicz, Paluszkiewicz, MAT, 2021, p. 245). Geomorphometry, the quantitative study of land-surface features, uses these technologies to provide comprehensive analyses based on measurements and mathematical modeling of landform shapes and dimensions, thereby facilitating a better understanding of spatial diversity and the relationships among different landforms. (Nitheshnirmal et al., 2019, p. 158)

Our study, which focused on the Boussaada Wadi sub-basin, leveraged these tools to examine its morphometric properties. The analysis highlighted significant findings, including the sub-basin's area of 1035.47 km^2 and a perimeter of 195.50 km. The Gravelius compactness index (KG) of 1.69 indicates an elongated shape, influencing drainage efficiency and linking to linear and regressive erosion patterns. The hypsometric map and curve revealed the basin's mature state of erosion, with elevations ranging from 554 m to 1618 m. These steep gradients are critical for understanding erosion and sediment transport processes. Additionally, the overall slope index (Ig) and specific elevation difference (Ds) classified the relief as "Fairly strong," emphasizing the significant impact on water flow and erosion.

The high density of the hydrographic network indicates steep slopes and less permeable surfaces, leading to increased runoff and erosion. Stream order analysis, using the Strahler classification and metrics like drainage density and stream frequency, further elucidated the basin's hydrological behavior (Mangan, Haq & Baral, 2019, p. 112).

These findings are consistent with other regional studies, underscoring the relevance and applicability of GIS-based morphometric analysis in diverse geographical contexts.

For instance, research on the Shanur River Basin in Maharashtra, India (Pande, Moharir, 2017, p. 84), and the Kanhar River Basin has demonstrated the utility of GIS in extracting river basins and analyzing drainage networks (Rai, Praveen et al., 2014, p. 96).

These studies underscore the importance of GIS in characterizing watershed hydrological responses, highlighting the widespread applicability of this approach.

Comparative studies in other regions reveal that the morphometric characteristics of the Boussaada Wadi sub-basin align with typical patterns observed in arid and semi-arid regions. Similar characteristics, such as elongated shapes and high drainage densities, have been noted in the Wadi Wala watershed and the Wadi Al-Shumar catchment in Jordan (Makhamreh et al., 2020, p. 98). These regions exhibit hydrological behaviors influenced by their morphometric properties. The use of GIS and DEMs in our study provided a more nuanced understanding of how geometric and relief parameters influence water flow and erosion, offering greater precision than traditional methods.

This advanced approach is crucial for effective water resource management and risk mitigation.

The integration of advanced tools and techniques, such as Geographic Information Systems (GIS) and remote sensing technologies, in morphometric analysis has significant implications for risk management and planning (Ragi Rahitya & Mallikarjuna, 2023, p. 112). This integration has been widely recognized as a valuable approach for identifying potential problems and analyzing the likelihood of their occurrence, thereby enabling proactive measures to prevent and minimize risks.

The importance of this study on planning against risk lies in its ability to provide insights into the spatial distribution and relationships of landforms within watersheds, which are crucial for understanding and mitigating potential risks (Yousuf Abrar et al., 2020, p. 86). By utilizing GIS-based morphometric analysis, project managers and risk management professionals can gain awareness of the many risks that might occur in a project and develop various means of addressing them. This approach allows for the identification and management of risks, providing a reliable process for risk assessment and response strategies (Mangan, Haq & Baral, 2019, p. 119).

Furthermore, the insights gained from GIS-based morphometric analysis can aid in optimizing land use planning and addressing environmental challenges within watersheds. Understanding the morphometric characteristics of a specific area, such as the Boussaada Wadi sub-basin, can guide the design of better flood control measures, erosion prevention strategies, and sustainable water management practices. By leveraging the detailed analysis provided by GIS and remote sensing technologies, organizations can ensure efficient water use and develop effective risk response plans to address potential challenges.

Conclusion

In this study, we evaluated the morphometric characteristics of the Boussaada Wadi sub-basin, which spans an area of 1035.471 km^2. Given the critical role of water resources in the development of sectors such as agriculture and energy production, the automatic extraction of geomorphological and hydrometric parameters has become an essential technique. These advanced methods save time and effort for hydrologists, offering precise calculations of parameters that influence surface water flow. The results demonstrate the capabilities of GIS and digital terrain models in accurately assessing the hydrological behavior of the sub-basin.

Our findings reveal that the Boussaada Wadi sub-basin has an elongated form, is a mature basin, and features a relatively strong relief. The hydrographic network displays an average hierarchy, with overall permeable formations and a low runoff concentration time, allowing ample time for surface water infiltration. These morphometric characteristics are invaluable in decision-making processes, optimizing the monitoring and management of water resources and related challenges.

In Sum, the detailed analysis of morphometric characteristics using GIS and remote sensing offers valuable insights into watershed behavior, allowing for the identification of areas at risk and informing future development planning to mitigate potential issues. By focusing on the Boussaada Wadi sub-basin, our study highlights the importance of morphometric analysis in understanding the dynamics of surface runoff, erosion, and sediment transport. This approach provides a comprehensive perspective that enhances water resource management and environmental planning, underscoring the critical role of morphometric factors in assessing watershed health and resilience.

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