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Physiographic Study of the Sidi Chahed Dam Watershed (Morocco)

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Abstract**—** *The use of GIS software allowed to characterize the area of the Sidi Chahed dam and its retaining, from the SRTM images by realizing the hypsometric map, The map of the slopes and their exposures, the sub-watershed map, the hydrographic network thematic map and its classification, and the superposition of the hydrographic networks. From the thematic maps realized for the catchment area studied, several geometric calculations were affected out to characterize the sub-watersheds from a length point of view, width, equivalent rectangle, surface, perimeter, and compactness index. These parameters have shown that the sub-watersheds studied are of elongated shape favoring low flows and are characterized by a greater water delivery time and a considerable total quantity of precipitation harvested. The high altitudes are located at the upstream levels of the upstream Mikkes sub-basins and Sidi Khlef. The slopes also showed the predominance of the north and North-west orientations with respectively 24.12 % and 20.34 % of the total slopes of the Mikkes watershed.*

Keywords**—** *Watershed, physical characteristics, GIS, Dam of Sidi Chahed, SRTM images.*

I. INTRODUCTION

The waters of the drained Mikkes watershed are stored in the retaining of the Sidi Chahed dam. In terms of socio-economics, this retaining plays an important for the cities of Meknes and Fez which are supplied from this water body with drinking water and irrigation of 1200 ha [1]. This watershed has made the objective of several previous works, such as the study of heavy metals in the sediments of the retaining of the Sidi Chahed dam, the climatic study and the hydro-geological study [2-5]. In order to determine the main geomorphometric properties of the Mikkes watershed such as the hypsometric shape, the slope, the hierarchy of the hydrographic network, etc., we realized thematic maps using Geographic Information Systems (GIS). The main objective of this work is to compare the geological map with the hydrographic network map in order to see the likely relationships between the sediment characteristics of the retaining of the Sidi Chahed dam and the geological nature of the soils of the watershed studied.

II. GEOGRAPHICAL CONTEXT

The Sidi Chahed retaining is located in Oued Mikkes, downstream from Oued Malleh, about 30 km North-east of the city of Meknes and about 30 km North-west of the city of Fez (Figure 1). The construction of this dam retaining has been mainly intended for the supply of drinking water to the city of Meknes; its capacity is 170 Mm^3.

From a geological point of view, the previous studies [6-9] have shown that the origin of Mikkes basin is related to the dislocation of the Liasic substratum, which occurs under the Neogene cover. It thus forms a broad graben which extends since the Middle Atlasic at the south to the Pre-Rif domain to the north, depending North-south direction [5].

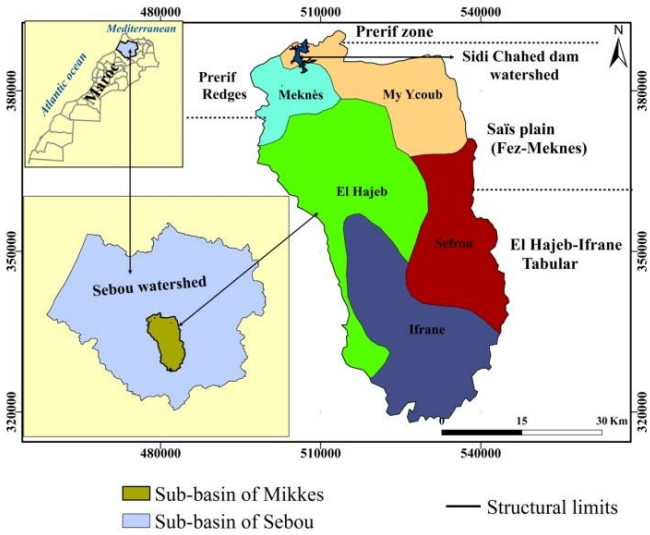

Fig. 1. Geographical location of the Mikkes watershed.

III. EXTRACTION OF THEMATIC MAPS

The use of geographic information systems (GIS) and SRTM images (Shuttle Radar Topography Mission) was chosen for the determination of another source of information to fully understand the aspects of the spot studied. The DEM (Digital Elevation Model) has been used to extract information with the addition of thematic maps relating to altitudes, at slopes and their exposure, delimitation of sub-basins, hydrographic networks and hypsometric curves.

A. Extraction of Contour Lines

The contour lines were extracted from the SRTM images. At the level of the downstream part of the watershed, the contour lines very spaced indicate the retaining of the dam Sidi Chahed. Around the retaining, the tight curves reflect the reliefs of the close watershed formed by the ridges of the Southern Rif (Figure 2).

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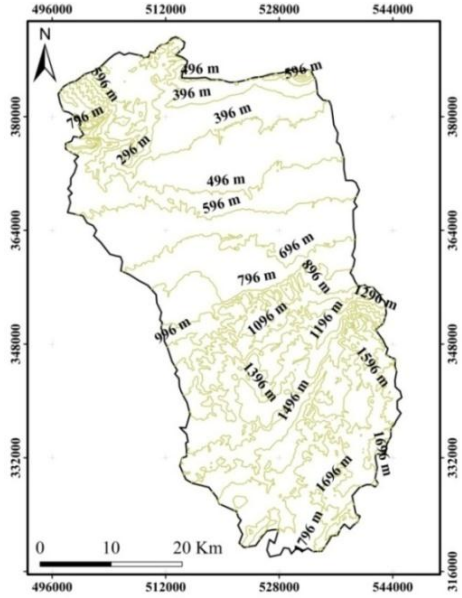

Fig. 2. Contour lines map of the Mikkes watershed.

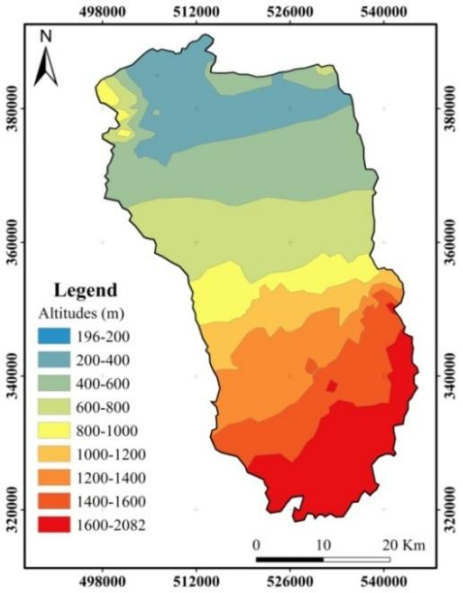

Fig. 4. Hypsometric map from the DEM of the Mikkes watershed.

B. *Dem, Hypsometric and Tin Maps of the Mikkes Watershed*

The DEM (Digital Elevation Model) is a numerical representation of the terrain in terms of altitudes. It allows a representative space analysis, because it reflects information about the morphological structure throughout the watershed [10].

The hypsometric map and the TIN (Triangulated Irregular Network) map, obtained from the digital elevation model (DEM), relating to the Mikkes watershed, showed the existence of essentially low altitudes of about 196 m downstream of the retaining of dam. When we move to upstream, the altitudes become higher and higher up to 2082 m (Figure 3, 4 and 5).

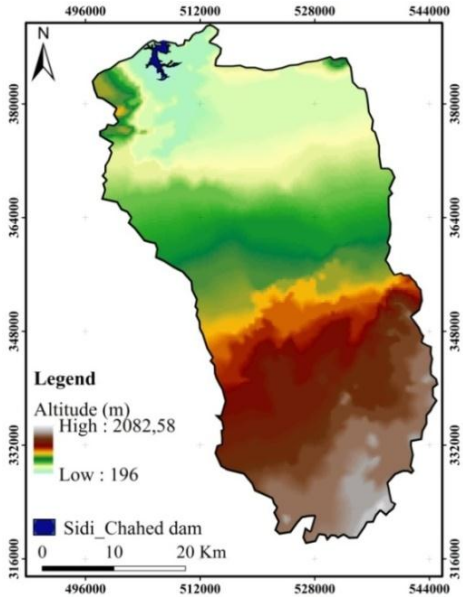

Fig. 3. EDM map of the Mikkes watershed.

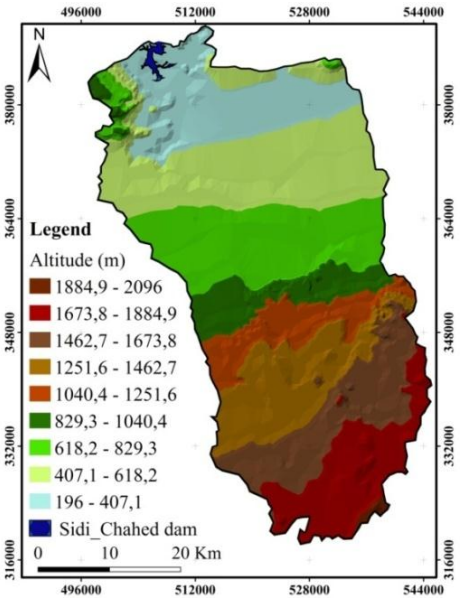

Fig. 5. TIN map of the Mikkes watershed.

C. *Slopes Map*

The slope influence infiltration and retention of water by soils, it also conditions soil erosion when it is poorly protected by the vegetation cover [11].

The map of the slopes of the Mikkes watershed presented by Figure 6 shows the general topography of the region. The biggest part of the map is occupied by slopes strong relatives to ridges Southern Rif. At the level of dam, the slopes become very weak with a flat relief.

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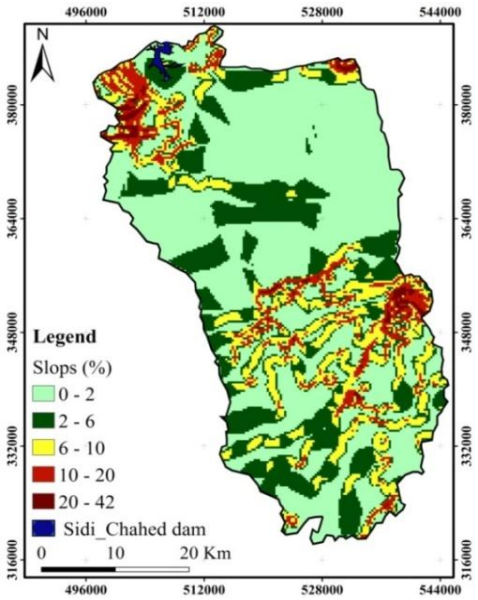

Fig. 6. Slopes map of the Mikkes watershed

D. Slopes Exposure Map

The slopes exposure map is used to determine the orientation of slopes with their percentages and their exposure in the watershed. It shows that the exposure of the slopes relative to our watershed is mainly dominated by the north and North-west orientation (Figure 7 and Table I).

TABLE I. Exposure of slopes (%) for the Mikkes watershed.

Exposure	North	North-east	East	South-east	South	South-west	West	North-west
Percentage	24.12	8.41	4.81	5.54	4.55	5.33	6.73	20.34

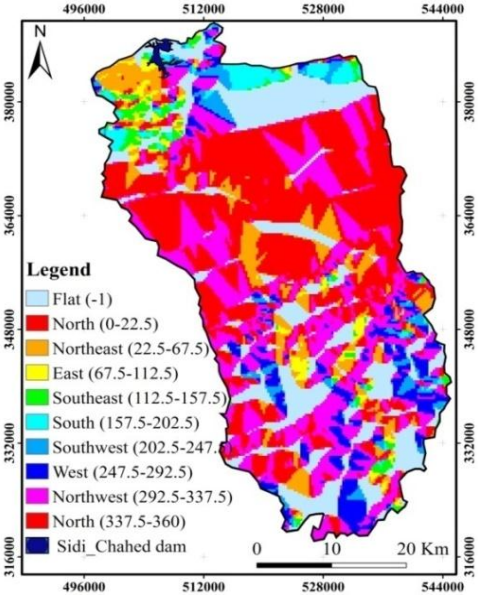

Fig. 7. Slopes exposure map of the Mikkes watershed.

E. River System

The river system is one of the most important characteristics of a watershed. It is defined as all natural or artificial streams, permanent or temporary, which participate in the flow [12]. This river system is one of the main factors responsible for sediment transport to dam retaining [13]. It is therefore necessary to describe the characteristics of this river system.

The map of the river system shows the hydrographic networks of the study area allowing the identification of watercourses. Indeed, this map show that three types of networks appear at the level of the retaining dam Sidi Chahed with the main oueds namely Oued Mikkes in the south, Oued Sidi Khlef in the west, and Oued Malleh in the east. These main courses account for 30.27% of the total river system. However, the secondary oueds account for 69.73% (Figure 8 and Table II).

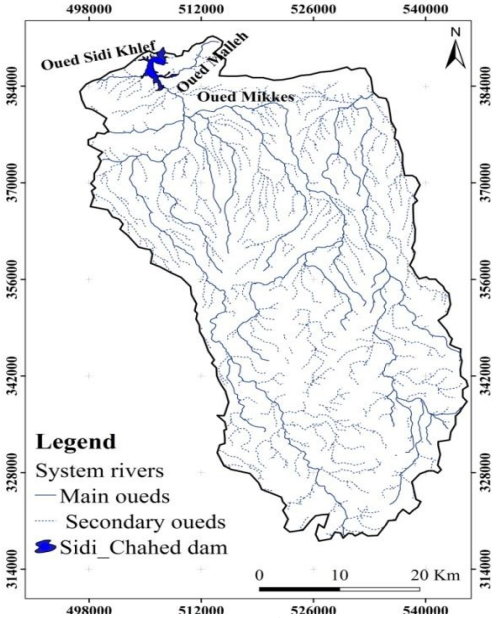

Fig. 8. River system map of the Mikkes watershed.

TABLE II. Characteristics of the river system of the Mikkes watershed.

River system type	Length (km)	Percentage (%)
Main rivers	498	30.27
Secondary rivers	1148	69.73

F. Determination of Sub-Basins

The dam retaining Sidi Chahed belongs to the Oued Mikkes watershed. At the periphery of the dam, four sub-basins were distinguished (Figure 9).

The sub-basin Mikkes is situated towards the south in the upstream part of the dam with 95.91% of the total area of the Mikkes watershed. The sub-basin of Oued Malleh is located in the North-east and participates with surface of 1.52%. The Sidi Khlef sub-basin occupies the western part with an area of 1.97%. While the Mikkes sub-basin downstream situated in the north with an area of 0.60% (Figure 9 and Table III).

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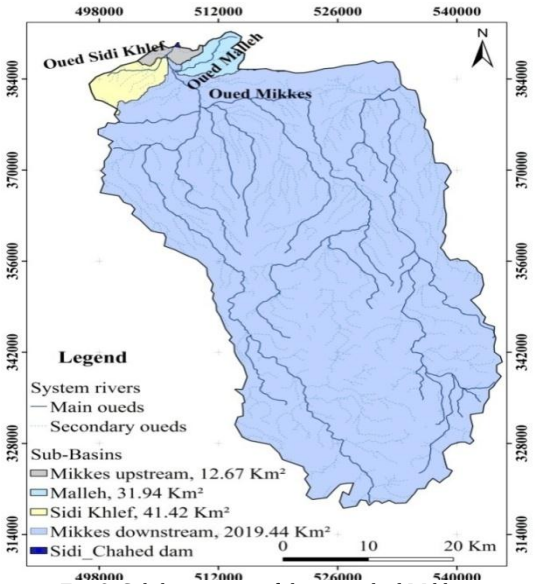

Fig. 9. Sub-basins map of the watershed Mikkes.

TABLE III. Characteristics of the four sub-basins which constitute the Mikkes watershed.

Sub-basin	Surface (Km^2)	Surface (%)	Perimeter (Km)	Perimeter (%)
Mikkes upstream	2019.44	95.91	239.8	71.60
Sidi Khlef	41.42	1.97	35.86	10.71
Malleh	31.94	1.52	35.52	10.61
Mikkes downstream	12.67	0.60	23.74	7.09

G. Hypsometric Maps of the Sub-Basins

The relief is an important factor. It largely determines the ability to run off the land, infiltration and evaporation. It is the important element in the hydrological behavior of a watershed [14].

The hypsometric maps elaborated for the sub-watersheds that constitute the Mikkes watershed are presented in the figure 10. The hypsometric maps show the spatial distribution of the different altitude classes, with their frequency and abundance at the level of each sub-basin. These characteristics are shown in the table IV.

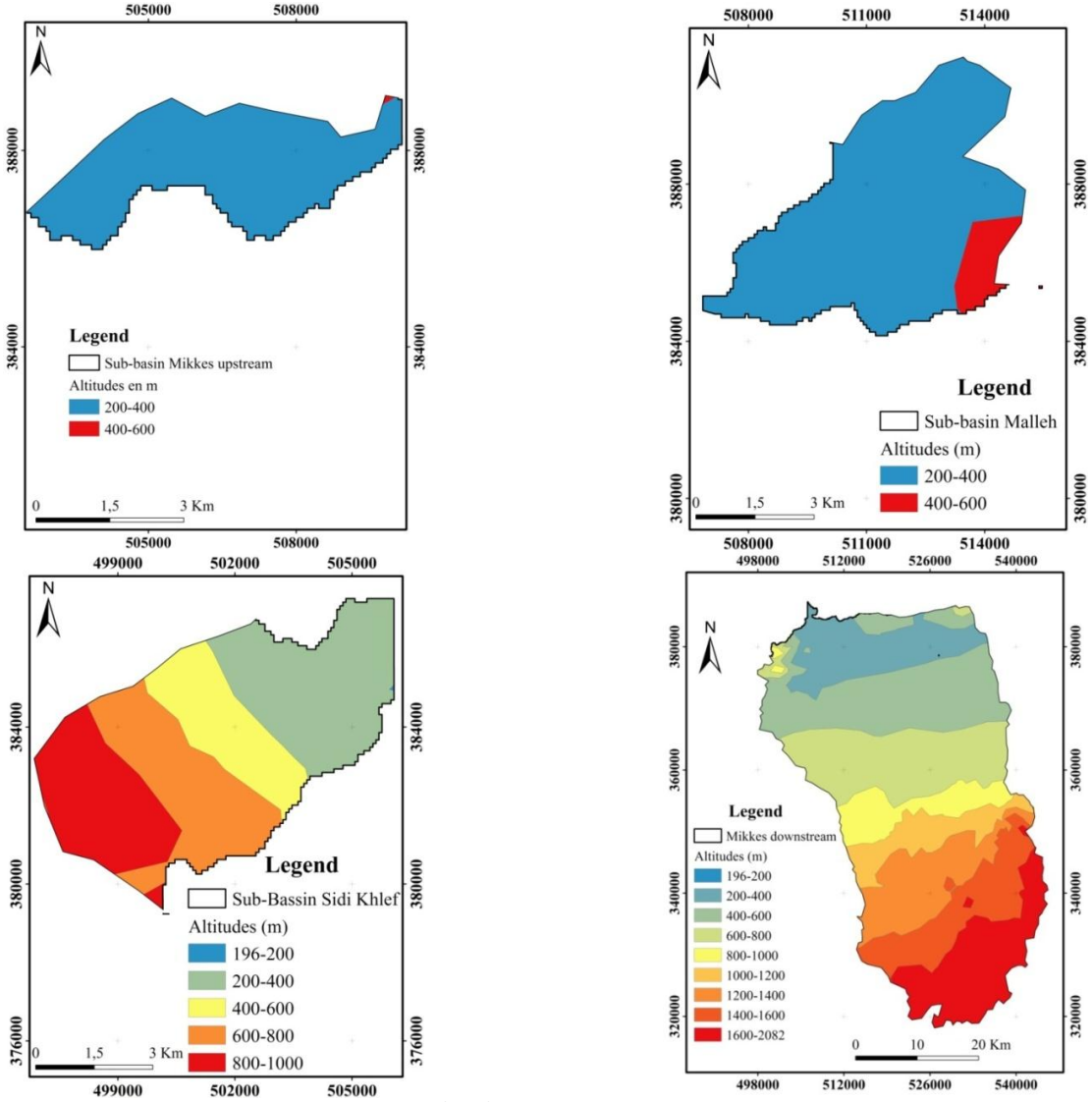

Fig. 10. Hypsometric maps of the four sub-watersheds which constitute the Mikkes watershed.

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TABLE IV. Classes of altitudes of the sub-basins of the Mikkes watershed and their surfaces.

Sub-basin	Altitude classes (m)	Surface (Km²)	%
Mikkes upstream	196 - 200	0.05	0.01
	200 - 400	234.65	11.61
	400 - 600	425.47	21.07
	600 - 800	365.40	18.09
	800 - 1000	139.26	6.90
	1000 - 1200	131.85	6.53
	1200 - 1400	220.57	10.92
	1400 - 1600	223.05	11.04
	1600 - 2082	279.15	13.82
Mikkes downstream	200 - 400	12.64	99.82
	400 - 600	0.02	0.18
Malleh	200 - 400	29.52	92.42
	400 - 600	2.42	7.58
Sidi Khlef	196 - 200	0.01	0.02
	200 - 400	13.33	32.18
	400 - 600	7.49	18.09
	600 - 800	10.72	25.88
	800 - 1000	9.87	23.82

- ✓ In the upstream Mikkes sub-basin, the 400-600 m altitude class is predominant with about 21% and the area nearly of 425 km^2, and the altitude class 600-800 m with almost 18% and the area of approximately 365 km^2. The classes of altitudes 1200-1400; 1400-1600 and 1600-2082 present average area of the order of 239 km^2 (nearly 12 % of the total area); these altitude classes are relatively equivalent. However, the altitude classes 800-1000 m and 1000-1200 m present a small area in relation to the total surface area of the order of 135 km^2, almost 7%. The minimum value of the area is recorded at the level of low-altitude class 196-200, this value is of the order of 0.05 km^2 (0.01 % of the total area).
- ✓ In the downstream Mikkes sub-basin predominates essentially the class of the lowest altitudes 200 - 400 m with an area of about 12 km^2 (almost 99 % of the total area).
- ✓ In the Mellah sub-basin, we have the predominance of the altitude class 200 - 400 m. This class presents an area of approximately 29 km^2 (about 92 % of the total area).

In the Sidi Khlef sub-basin, we have four important classes of altitudes with a slight importance of the 200-400 m altitude class which present an area of around 13 km^2 (about 32% of the total area).

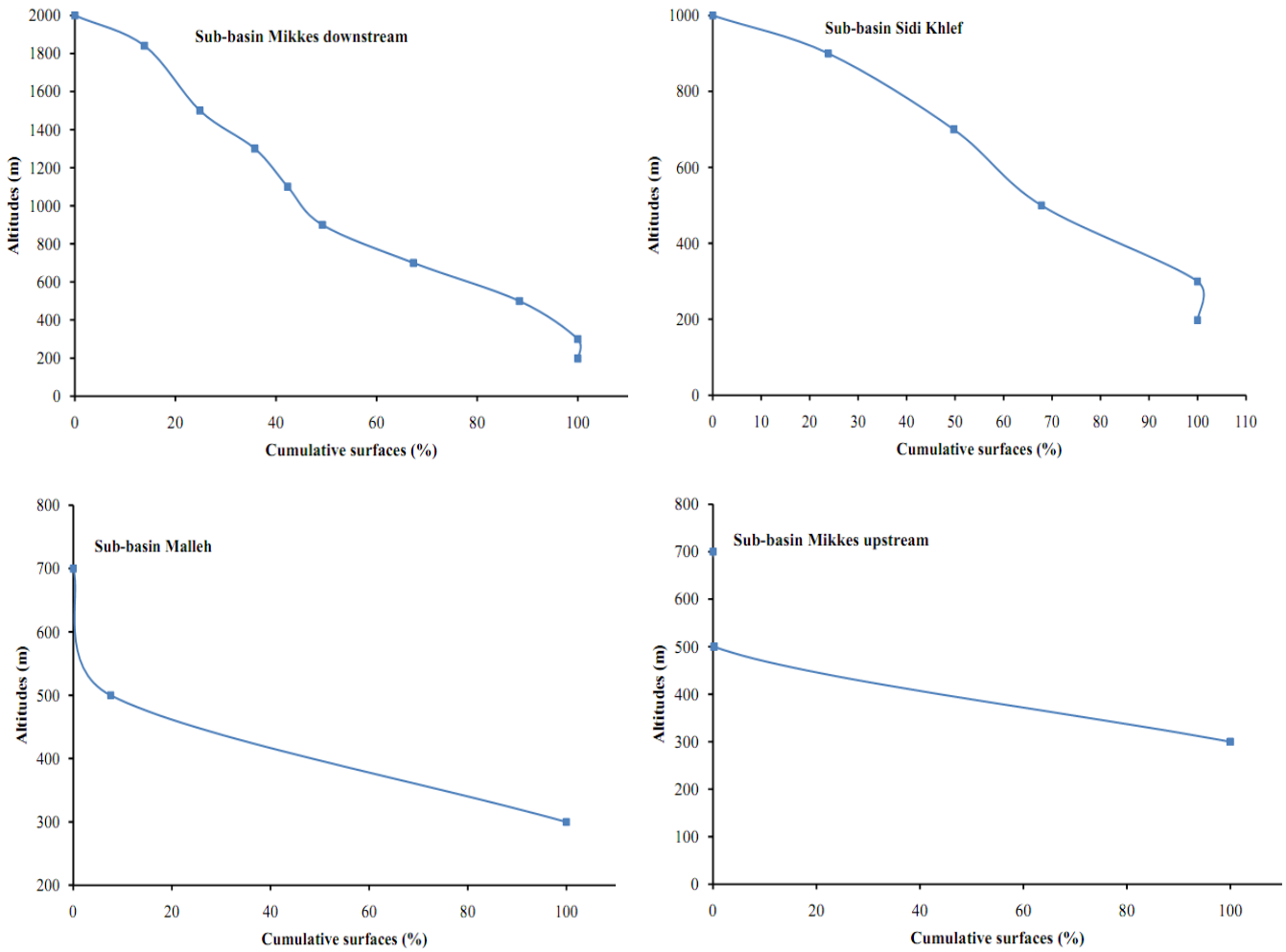

Fig. 11. Hypsometric curves of the four sub-basins which constitute the Mikkes watershed.

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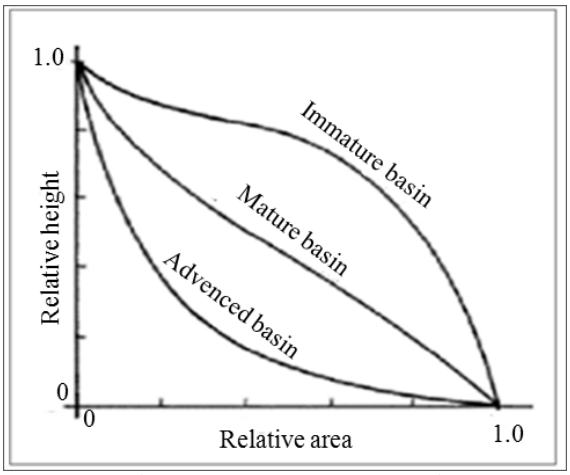

Fig. 12. Shape of the hypsometric curve and state of the maturity of watersheds relief [16]

The lowest altitudes extend over the Mikkes downstream sub-basin, the sub-basin Mellah and the upstream of the sub-basin downstream Mikkes, and the Sidi Khlef sub-basin. The highest altitudes are situated at the level of the downstream of the sub-basin downstream Mikkes and the downstream of Sidi Khlef (1000 and 2082 m) altitudes respectively, which reflect a relativity mountainous character of these two sub-basins.

Hypsometric curves of the sub-basins

The hypsometric curve provides a synthetic view of the basin slope. This curve represents the repartition of the surface of the watershed according to its altitude. This curve which carries on the abscissa the percentage of area (cumulative area) of the basin which lies above the altitude represented on the ordinate also reflects its potential dynamic equilibrium state [15].

In the present study, the hypsometric curves were drawn from the distribution of altitudes tranche of the four sub-basins defined previously (Figure 11). However, according to Strahler [16], the type of the hypsometric curve characterizes the state of maturity of the relief (Immature. mature and advanced basin) and its erosive capacity (Figure 12). Indeed, a convex curve is a characteristic of a immature relief where the erosion is still intense. While a concave shape will reflect a stabilization of erosion processes [17], [18].

The different hypsometric curves presented in figure 11 were plotted from the elevations and relative surfaces calculated for each sub-basin. They show a convexity and concavity towards the highest altitudes respectively for the Sidi Khlef sub-basin and the Malleh sub-basin. For the upstream Mikkes sub-basin, we have a convexity towards the highest altitudes and a concavity towards the mean altitudes. By contrast, the hypsometric curve of the sub-basin Mikkes downstream shows that the relief is in a state of equilibrium.

The sub-basins which reveal a morphology that tends towards disequilibrium in the relief could be linked to the nature of the geological formations, inducing to a strong incision by the water erosion forces. This factor, which favors water erosion is to be taken into account especially for the sub-basins located upstream of the retaining of the Sidi Chahed dam in order to attenuate its siltation.

IV. Index of Compactness or Coefficient of Gravelius

The Gravelius coefficient K_G characterizes the compactness and makes it possible to identify the shape of the sub-basin [2]:

$$K_G = \frac{P}{2\times\sqrt{\pi\times S}} \approx 0.28\times\frac{P}{\sqrt{S}}$$

S: Surface of the watershed (km^2).
P: Perimeter of the watershed (km).

The closer this coefficient to the value of 1, the more the watershed shape becomes circular. While the values superior than 1 indicate an elongated basin. In this work the compactness index allowed us to show that the four sub-basins that constitute the Mikkes watershed are elongated, their K_G coefficients are between 1.49 and 1.87 (Table V).

TABLE V. Gravelius coefficients of the sub-basins which constitute the Mikkes watershed.

Sub-basin	K_G
Mikkes upstream	1.49
Sidi Khlef	1.56
Malleh	1.76
Mikkes downstream	1.87

V. Equivalent Rectangle

The equivalent rectangle is a geometric representation of the watershed having the same perimeter and the same surface, the length and the width of the equivalent rectangle are given by the following formulas [19]:

$$L = \frac{K_G\times\sqrt{s}}{1{,}12}\left(1+\sqrt{1-\left(\frac{1{,}12}{K_G}\right)^2}\right)$$

$$W = \frac{K_G\times\sqrt{s}}{1{,}12}\left(1-\sqrt{1-\left(\frac{1{,}12}{K_G}\right)^2}\right)$$

With:

L: Length of the rectangle.
W: Width of the rectangle.

From the calculations made, all the sub-basins have an elongated shape, with these characteristics, we have low flows, a higher flow time and a considerable amount of precipitation harvested (Table VI).

TABLE VI. Characteristics of the equivalent rectangles of the sub-basins which constitute the Mikkes watershed.

Sub-basin	Length of the equivalent rectangle (km)	Width of the equivalent rectangle (km)	Surface of the equivalent rectangle (km^2)	Perimeter of the equivalent rectangle (km)
Mikkes upstream	81.92	36.73	3008.97	237.30
Sidi Khlef	12.70	5.09	64.62	35.58
Malleh	13.44	4.18	56.21	35.25
Mikkes downstream	9.23	2.57	23.69	23.59

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VI. Superposition of the River System with the Geological Map

The superposition of the river system with the geological map of the Mikkes watershed made it possible to extract the nature of the sediment transported from the sub-basins to the retaining of the Sidi Chahed dam.

The geological map (figure 13) shows that:

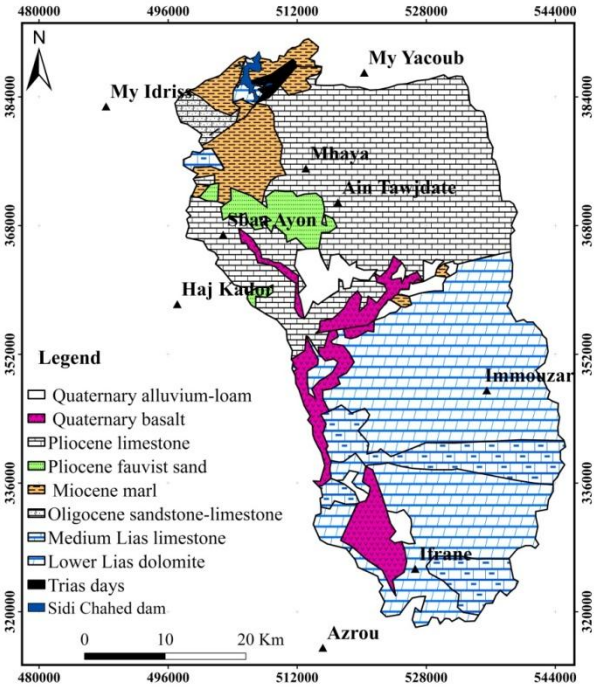

Fig. 13. Geological map of the Mikkes watershed.

- ✓ The area that covers the Sidi Chahed retaining is dominated by marly soils of the Miocene belonging to the Southern Rif ridges.
- ✓ The waters of the Malleh sub-basin flow on red clays of Triassic.
- ✓ The Oued Mikkes crosses the carbonate soils of the Middle Atlas, the Lacustrine Limestone and the tawny sands of Saïs.

In the eastern part, the red clays of the Triassic, which threaten the retaining of dam by the impact salts inputs, are transported by the Oued Malleh. Towards the south, the carbonate sediments of the Middle Atlas and the Saïs are transported by the Oued Mikkes. The Marls and Miocene Limestone is transported by the rest of the river of system.

VII. Conclusion

The topographic, morphological and hydrographic characterization of the watershed of the retaining of the Sidi Chahed dam was carried out using Geographic Information Systems (GIS). The basic data are summarized in SRTM images and the topographic, geological data. Their treatment allowed the realization of several thematic maps as well as their interpretation.

The high altitudes are located at the upstream level of the sub-basins Mikkes and Sidi Khlef. The low altitudes are located at the level of the sub-basin Mikkes downstream. The slopes show the predominance of the north and North-west orientations with respectively 24.12% and 20.34% of the total slopes of the Mikkes watershed.

Through this study, we have shown that the four sub-basins have an elongated shape which favors low flows and a important flow time. Almost, the entire area surrounding the retaining of the Sidi Chahed dam is surrounded by Miocene Marls rich in calcium carbonates and the red clays of the Triassic.

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