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Research article

Contribution of morphological study to the understanding of watersheds in arid environment: A case study (Morocco)

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Abstract: Watershed planning is often based on the analysis of morphometric parameters, especially in poorly gauged or ungauged basins. These physiographic parameters have, in fact, a main role in water runoff. In many arid countries such as Morocco, there is a significant need for morphometric studies of watersheds to initiate integrated water resources management. For this purpose, we have carried out the watersheds delineation and morphometric analyses, using the Digital Terrain Model (DTM) and the Geographic Information System (GIS). We have applied this approach based on remote sensing and GIS in four sub-basins of the right bank of the Tensift watershed (Bourrous, Al Wiza, El Hallouf and Jamala). The shape indexes of Gravelius and Horton reveal elongated shapes of the four watersheds. In addition, the maximum slope and the drainage density do not exceed 27.15° and 1 Km/Km^2 respectively. The sub-basins do not have a very dense hydrographic network and the Strahler's drainage order is not very high (up to 5). The relief is not very high and do not reach 1000 m. These physiographic conditions do not allow a rapid runoff. The concentration times are precisely quite high (7 to 12 hours for watersheds of 161 to 401 km^2). The use of a sufficiently fine DTM resolution and an appropriate GIS software would allow this kind of study to be very useful for effective watershed management.

Keywords: watershed morphometry; Digital Terrain Model; GIS; arid environment; Morocco

Abbreviations: DTM: Digital Terrain Model; Digital Elevation Model (DEM); GIS: Geographic Information System; SRTM: Shuttle Radar Topography Mission; NASA: National Aeronautics and Space Administration; NGA: National Geospatial-Intelligence Agency; ESRI: Environmental Systems Research Institute

1. Introduction

Considering the global phenomena related to climate change and drought, the management of water resources deserves great attention, especially in arid regions [1–3], this issue is becoming a growing concern in developed countries [4]. Morphometric analysis of watersheds in arid regions is an important topic that can reduce the risks associated with flooding and integrated water resources management [5,6]. The analysis of morphometric parameters provides an accurate scenario of the hydrological behavior of a watershed, especially in ungauged watersheds [7,8]. This study provides an understanding of the hydrological and morphological characteristics of the morphometric parameters. It allows the analysis of the hydrological response of watersheds lacking data and helps to set up management procedures for ungauged watersheds. Ref. [9] recommended this example study to understand watersheds in morphological and hydrological terms.

The physiography of the watershed plays a very important role in the direct flow of the watershed, and consequently on the characteristic flows at the outlet, as well as on the parameters of the hydrological model that represents it [10,11]. In addition, the relationship between watershed physiography and flow characteristics is related. Therefore, the knowledge of watershed morphology before any hydrological study is essential. Also, to understand the flow mechanism in the watershed. For example, in Morocco, several studies have been carried out to determine the morphological parameters of the basin in order to use them in the estimation of water inflow, in the Bouregreg watershed [12]; in Ghdat, Chichaoua, Abadla, Taferiat, Iloudjane and Sidi Rahhal watersheds [13]; in Ourika and Marghène watersheds [14]. On the other hand, in Uttarakhand, the morphometric criteria of the Pindar River watershed were very effective in identifying erosion-prone areas [15]. All these morphometric studies of the watersheds were carried out based on the analysis of the Digital Terrain Model (DTM).

The DTM is a representation of remotely sensed terrain data [16], it is used in hydrological, hydraulic, climate change and water resources studies [17]. The DEM is the primary form of satellite data used to define and analyze watershed morphometry [18]. The fundamental characteristics of any DTM data are the accuracy and resolution of the topographic representation of the land surface [19]. In general, the DTM has a direct impact on the study of any watershed, it is recommended to use a terrain model with a particular resolution and good quality [15,20]. The source of the DTM data is usually provided by the Shuttle Radar Topographic Mission (SRTM), [21]. The SRTM is based on raster and vector topographic files provided by two American agencies, the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA), [22]. This SRTM product was used in a study to conserve soil and water using a 90 m resolution DEM in the Xixian watershed in China [23]; this product has shown good quality for the spatial distribution of flood waters, with a SRTM/DEM of 30 m [24]. This makes SRTM products very useful for research and engineering studies.

The analysis of the digital terrain model requires a Geographic Information System (GIS). The GIS is an information system designed to collect, store, process, analyze, manage and present all types of spatial and geographic data [25]. Among the GIS software, there is ArcGIS, developed by the American company Environmental Systems Research Institute (ESRI), in 1969 [26]. ArcGIS includes important tools for drainage analysis on a terrain model (DTM), these are Arc Hydro Geoprocessing tools [25]. Arc Hydro tools are used to derive several datasets that collectively describe the drainage patterns of the watershed. Their goals are to analyze a matrix to generate data on flow direction, flow accumulation, stream definition, stream segmentation and watershed delineation. These are then used to develop a vector representation of watersheds and drainage lines. The usefulness of the Arc Hydro tools is very important in hydrological modeling.

To date, the right bank of the Tensift watershed is considered as an area whose morphological characteristics of its sub-basins are undetermined. In particular, the area, perimeter, hydrography, hypsometry, slope and time of concentration [27]. In this work, we study the physiology of four sub-basins of the right bank of the Tensift watershed, as well as define the name of each sub-basin corresponding to the name of their valley, using a geographic information system and a digital terrain model. The objective of the paper is then to establish a comparative study of those ungauged watersheds, with the aim of determining those that would have a good hydrological response to rainfall events and therefore the most appropriate to install hydraulic structures and water storage systems. There would be many papers on morphometric analysis based on remote sensing and GIS approaches that were applied in various geographical environments [15,28,29]. Our study area is arid and not gauged neither for rainfall or hydrometry. However, knowledge of the hydrological behavior in our arid zone is essential to better manage both the scarcity (drought) and the excess (floods) of water resources. In our case, the hydrological runoff, especially for the extreme aspect, could be estimated from the morphometric characteristics of the watersheds. These features could indeed be analyzed using remote sensing tools and GIS approaches. In that respect, the knowledge of the global morphology of the ungauged watersheds in the north of Marrakech city could open up prospects for flash flood prevention in this region.

The study area, the DTM data and methodology used in this work are presented in section 2. Results and discussion are described in section 3. Finally, conclusions are provided in section 4.

2. Material and methods

2.1. Study area

Bourrous, Al Wiza, El Hallouf and Jamala (Figure 1) are four sub-basins belonging to the right bank of the Tensift watershed. They are located between latitudes 32° 9' and 31° 42' North; longitudes 9° 16' and 7° 39' West. These sub-basins represent areas of 301 Km2, 161 Km2, 204 Km2 and 401 Km2 respectively. They cover a total area of 1,067 Km2. These sub-basins generate interesting water resources feeding on the one hand the groundwater and on the other hand the Tensift wadi. They have no hydrometric and rainfall stations to give an idea of rainfall on the right bank of the Tensift wadi. In these sub-basins, the differences between the daily temperatures are quite important with a maximum of about 45°C in the plain and a minimum of 4°C in the mountains. The average monthly temperatures vary between 12°C and 28°C.

The geological formations of Jbilete (Figure 1) are almost all Paleozoic. The Jbilete is generally constituted by schistose soils, these soils are less rich in organic matter, which makes them of bad quality for agriculture. Mouissate (Figure 1) is entirely constituted by formations of the Upper Jurassic which is transgressive on the Paleozoic or Triassic of the western end of Jbilete. It is constituted by calcareous soils, this type of soil is very rich in organic matter, without stones, which makes them good qualities for agriculture [30].

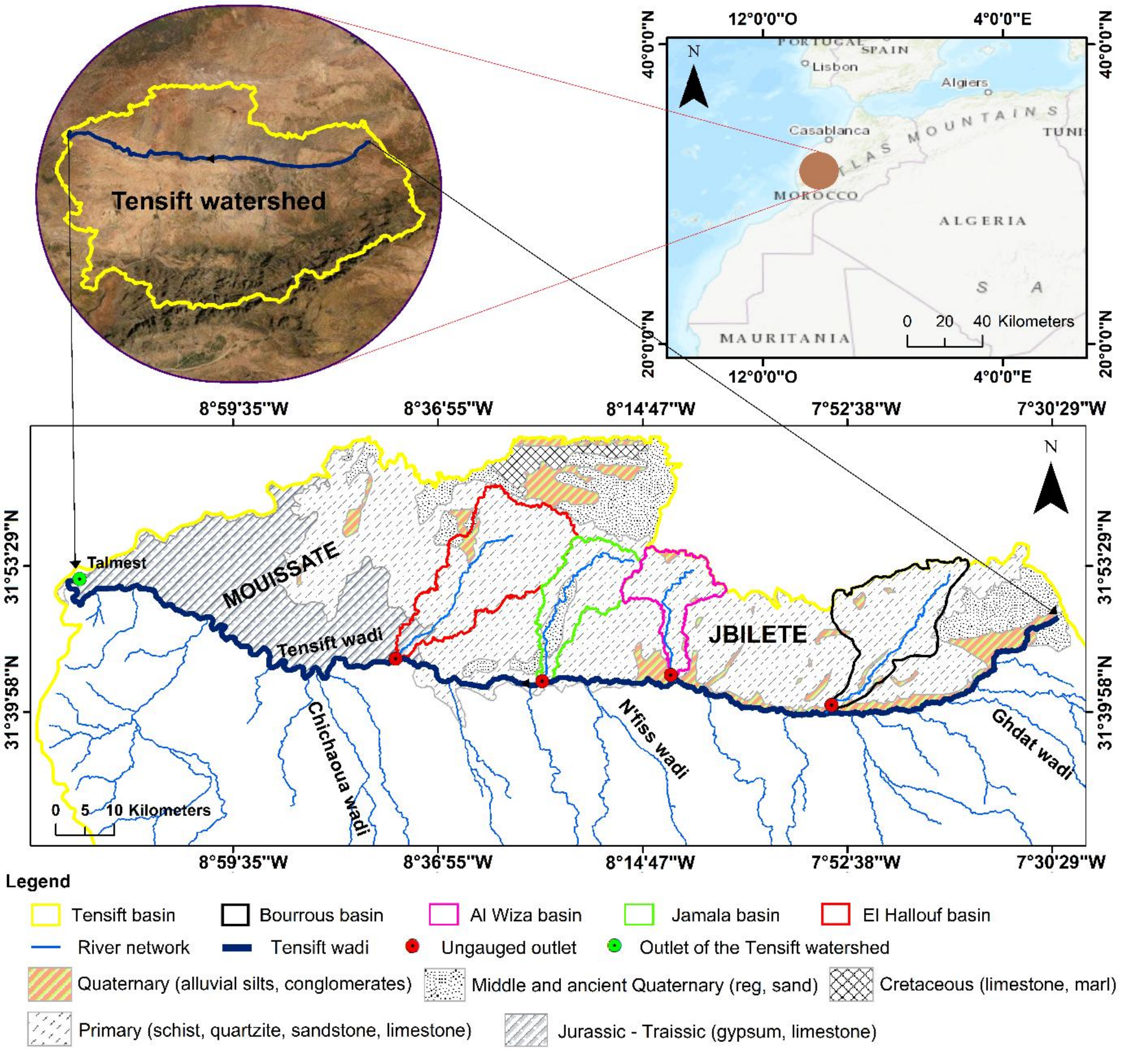

Figure 1. Geographical location of Bourrous, Al Wiza, El Hallouf and Jamala sub-basins.

2.2. Digital Terrain Model

In 11 days, the space shuttle Endeavour started a remote sensing mission SRTM (Shuttle Radar Topography Mission), in February 2000. The SRTM has mapped almost the entire land surface between +/− 60 degrees of latitude. It had two types of antenna panels, C-band and X-band. Near-global topographic maps of the Earth called Digital Elevation Models (DEM) are produced from C-band radar data. While, the X-band radar data are used to create slightly higher resolution DEMs but without the overall coverage of the C-band radar, as the Jet Propulsion Laboratory explained, (https://www2.jpl.nasa.gov/srtm/index.html).

In 2009, the Digital Terrain Model (DTM) was made freely available to the scientific research committee, offering a resolution of 30 meters and covering almost the entire surface of the globe [31]. This DTM does not take into account objects on the surface of the land such as plants and buildings. It is a representation of the topography of a land area in a form suitable for use by GIS software. In this study, DTM was downloaded from the NASA website (https://search.earthdata.nasa.gov/search), with a coordinate system GCS_WGS_1984 (Geographic Latitude and Longitude).

2.3. Methodology

This work consists in studying the morphometry of watersheds located in an arid zone, using a geographic information system (ArcGIS) to determine the different characteristics of ungauged watersheds. These characteristics have been selected according to their representativeness of the watershed morphometry and their impact on the hydrology (runoff velocity, infiltration...etc.). In order to delimit the sub-basins and extract the different maps (slope, hypsometric and hydrographic), we used the DTM maps of the 30, 31 and 32° North zone, with a 30-meter resolution. The processing was done using Arc Hydro representing a set of tools found in ArcGIS software. The new version 10.3 of this software was used in our study.

Arc Hydro utility allowed us to perform several operations such as delineating and characterizing watersheds in raster and vector formats, define and analyze the geometric hydro network, managing time series data and exporting data to digital models [25].

ArcGIS 10.3 software tools that allowed us to delineate the sub-basins presented in this work, as well as to characterize each sub-basins by calculating its structural parameters, are the following: Fill function, this tool fills the wells in the input DTM and generates the output wireframe (by default the command looks for the lowest nearby elevation value and uses it to fill the depression), it is used to locate all the wells to fill; Flow Direction, this tool calculates the flow direction grid for an input DTM. It thus allows to identify their direction; Flow accumulation, this tool generates the flow accumulation grid associated with the input flow direction grid, and adds it to the map; Watershed, this tool allows us to create a delineation map of a watershed. It is possible to proceed in a fully automatic delimitation way. Figure 2 represents the steps applied to define the sub-basins of the right bank of the Tensift wadi.

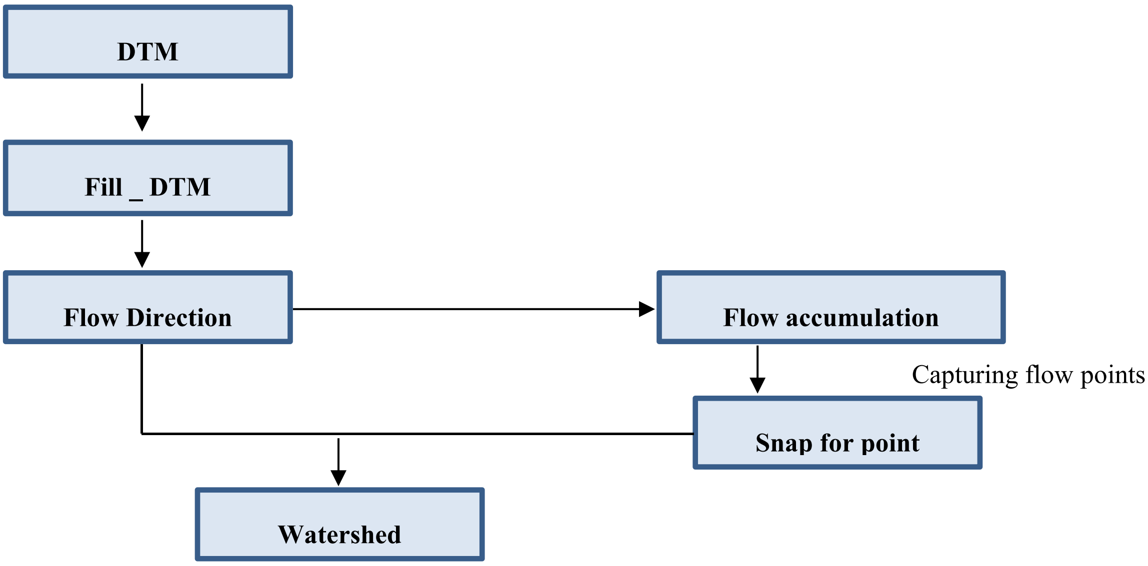

Figure 2. Watershed delineation scheme.

2.3.1. Watershed characteristics

The indices recommended by hydrologists to characterize the shape of watershed are the Gravelius compactness index K_G [32] and the Horton shape index K_H [33]. They allow to characterize the geometrical configuration and the shape of the watershed. This configuration influences the surface runoff representing the response of the watershed to the rainfall it receives. K_G and K_H indices are calculated by Eqs 1 and 2 respectively.

$$K_G = \frac{P}{2\sqrt{\pi A}} \quad (1)$$

$$K_H = \frac{A}{L^2} \quad (2)$$

Where, K_G: Gravelius compactness index; K_H: Horton shape index; A: area of the basin in Km^2; L: length of longest talweg in Km; P: basin perimeter in Km.

The classification of the sub-watersheds is done according to the Horton shape index and the Gravelius compactness index. It is represented in the Table 1.

Table 1. Watershed classification criteria.

Type	Range
Rounder watershed	$K_H > 1$ and $K_G < 1.15$
Elongated watershed	$K_H < 1$ and $K_G > 1.5$

The Equivalent Rectangle (ER) allows comparison of hydrological behavior between watersheds. It corresponds to a purely geometric transformation of the watershed. ER is a rectangular shape while keeping the same area, the same perimeter, the same compactness index and the same hypsometric distribution. The length and width of the equivalent rectangle are calculated by Eqs 3 and 4 respectively, mentioned in Ref. [34].

$$\mathrm{Leq} = K_G \times \frac{\sqrt{A}}{1{,}12}\left[1 + \sqrt{1 - \left(\frac{1{,}12}{K_G}\right)^2}\right] \quad (3)$$

$$\mathrm{Weq} = K_G \times \frac{\sqrt{A}}{1{,}12}\left[1 - \sqrt{1 - \left(\frac{1{,}12}{K_G}\right)^2}\right] \quad (4)$$

Where, Leq = Length of the equivalent rectangle (Km); Weq = Width of the equivalent rectangle (Km); A = Watershed area (Km^2); KG = Gravelius compactness index.

2.3.2. Classification of the hydrographic network

Ref. [35] and [36] proposed laws that qualify the shape of the hydrographic network, they concern the relationship between the rivers, their numbers and lengths. The hydrographic network is drawn from the Flow Accumulation and Flow Direction layer using the Hydrology tool of ArcGIS, Hydrology - Stream to Feature, [25]. We then proceed to the Schumm- Strahler classification to define the order of the talwegs from 3 rules, such that any stream without tributaries is of order 1; the stream formed by the confluence of two streams of the same order is increased by one; the stream formed by the confluence of two streams of different orders takes the order of the higher of the two.

The hydrographic network obtained with the Hydrology tool of ArcGIS, allowed us to calculate other parameters to characterize the studied sub-basins and its hydrographic networks. Four parameters were adopted, namely, the law of numbers [35], Eq 5; the law of lengths [36], Eq 6; the drainage density [34], Eq 7; the hydrographic density [34], Eq 8.

$$R_B = \frac{n_\omega}{n_{\omega+1}} \quad (5)$$

$$R_L = \frac{\bar{l}_{\omega+1}}{\bar{l}_\omega} \quad (6)$$

$$Dd = \frac{\sum L_i}{A} \quad (7)$$

$$F = \frac{\sum n_i}{A} \quad (8)$$

Where, R_B= Bifurcation ratio; n_ω= Number of streams of order ω; RL= Length ratio; $\bar{l}_\omega$ = Average length of order streams ω; Dd = Drainage density (Km/Km^2); F = Hydrographical density (Km^{-2}); ni = number of streams; Li = Flow length; A = Watershed area.

2.3.3. Hypsometry of watershed

Hypsometry is the measurement of the elevation of land in relation to sea level. It allows to visualize the different altitude zones of a given area on a map [34]. In this study, the data and hypsometric map are defined using the ArcGIS ArcToolbox, 3D Analyst - Reclassify [25]. The average elevation and the fraction of elemental areas for each sub-basin are calculated by Eqs 9 and 10 respectively.

$$H_{avg} = \sum \frac{A_i \times h_i}{A} \quad (9)$$

$$F = \frac{100 \times A_i}{A} \quad (10)$$

Where, H_{avg} = Average altitude (m); F = Fraction of surface (%); hi = Average altitude between two contour lines (m); Ai = Area between two contour lines (km^2); A = Total watershed area (km^2).

2.3.4. Slope of watershed

The average slope of a watershed provides information about its topography. It is considered as an independent variable and radically influences the value of the time of concentration of runoff generated by rainfall. In this work, the slope map and the average slope of the watersheds were determined by the integrated tool of ArcToolbox of ArcGIS, 3D Analyst Tools - raster Surface - Slope, [25], on the other hand the average slope of the flow is calculated by Eq 11, mentioned in Ref. [34].

$$P_{avg.flow} = \frac{H_{max} - H_{min}}{L} \quad (11)$$

Where, P = Average slope (m/m); Hmax = Maximum altitude of a watershed (m); Hmin = Minimum altitude of a watershed (m); L = Length of the longest talweg (m).

2.3.5. Time of concentration

The Time of Concentration (TC) is a concept used in hydrology to measure the response of a watershed to a rainfall event. It defines the time required for runoff to flow from the hydraulically most distant point in the watershed to the outlet. Thus, the estimation of time of concentration depends on several parameters such as topography, geology and land use in a watershed. In our study, this concentration time was calculated from formulas often used in Morocco [37]. These formulas are summarized in Table 2.

Using ArcGIS software, we determined the parameters necessary to calculate the time of concentration, in particular the surface and perimeter of the watershed, the length of the talweg and the average slope of the watershed. Then, we applied the different formulas (Table 2) to calculate the average time of concentration in each watershed.

Table 2. Formulas for calculating time of concentration.

Name of equation	Equation of calculation	Number of equation
US Corps	$Tc = 0.278 \times \left(\frac{L}{I^{0.25}}\right)^{0.77}$	(12)
Turrazza	$Tc = 0.108 \times \left(\frac{\sqrt[3]{A \times L}}{\sqrt{I}}\right)$	(13)
Californienne	$Tc = 0.1452 \times \left(\frac{L}{\sqrt{I}}\right)^{0.77}$	(14)
Espagnole	$Tc = 0.3 \times \left(\frac{L}{I^{0,25}}\right)^{0.77}$	(15)
Ventura	$Tc = 1.272 \times \left(\sqrt{\frac{A}{100 \times I}}\right)$	(16)
Van Te Chow	$Tc = 0.123 \times \left(\frac{L}{\sqrt{I}}\right)^{0.64}$	(17)

Where, Tc = Time of concentration (hours); L = Length of runoff (Km); I = Slope (m/m); A = Area (km²).

3. Results and discussion

The values of K_G and K_H show that the sub-basins of the right bank of Tensift wadi all have elongated shapes ($K_H < 1$ and $K_G > 1.5$). The ratio of length to equivalent width ranges from 7.77 for the Jamala watershed to 9.38 for the Al Wiza basin. The calculated values of the Horton, the Gravelius indices, as well as the equivalent lengths and widths for the sub-basins of the right bank of Tensift wadi are shown in Table 3.

Table 3. Basin shape characteristics.

Basin	Area (Km^2)	Perimeter (Km)	K_G	K_H	Leq (Km)	Weq (Km)	Leq/Weq
Bourrous	301	112	1.81	0.12	49.98	6.02	8.30
Al Wiza	161	86	1.90	0.11	38.86	4.14	9.38
El Hallouf	204	90	1.77	0.13	39.89	5.11	7.80
Jamala	401	126	1.76	0.12	55.82	7.18	7.77
Min	161	86	1.76	0.11	38.86	4.14	7.77
Max	401	126	1.90	0.13	55.82	7.18	9.38

The classification of the hydrographic network (Table 4) showed that the Strahler order of drainage is between 1 and 5 on all the sub-basins, the Bourrous, the Al Wiza, the El Hallouf and the Jamala, moreover, the maximum drainage density does not exceed 1 Km/Km^2 for these sub-basins. These results allow us to deduce that the flow has only reached a very limited development, the hydrographic network is less branched in these sub-basins. This type of flow is found in regions with very permeable bedrock, with little relief and low precipitation.

The highest R_B ratio is found on the most elongated basins (Jamala and El Hallouf), in general, this R_B ratio is between 2 and 7 on all basins, which shows that the influence of geology on the hydrological response of the basins (Bourrous, Al Wiza, El Hallouf and Jamala) is very low, this is consistent with the description of Strahler [36].

The development of the drainage network, on the sub-basins of the right bank of the Tensift wadi, is an important element to consider to establish correlations between these basins, it shows that the four basins studied receive similar rainfall events. The results of the drainage network classification are presented in Table 4.

Table 4. Classification of the hydrographic network of basins.

Basin	Order	Number law (Nbr)			Length Law (L)			Dd	F
		Nbr	R_B		L (km)	R_L		(km/km^2)	(Km^2)
Bourrous	1	81	R_B (2-1)	3.12	152.04	R_L (2-1)	1.38		
	2	26	R_B (3-2)	3.25	67.13	R_L (3-2)	1.92		
	3	8	R_B (4-3)	4	39.76	R_L (4-3)	3.91	1.00	0.39
	4	2	R_B (5-4)	2	38.90	R_L (5-4)	0.21		
	5	1			4.09				
Al Wiza	1	53	R_B (2-1)	2.94	67.03	R_L (2-1)	2.15		
	2	18	R_B (3-2)	4.5	48.86	R_L (3-2)	1.86	0.96	0.47
	3	4	R_B (4-3)	4	20.23	R_L (4-3)	3.80		
	4	1			19.20				
El Hallouf	1	99	R_B (2-1)	6.19	95.64	R_L (2-1)	3.41		
	2	16	R_B (3-2)	3.2	52.72	R_L (3-2)	1.80		
	3	5	R_B (4-3)	5	29.63	R_L (4-3)	3.70	0.98	0.59
	4	1			21.91				
Jamala	1	174	R_B (2-1)	4.97	197.55	R_L (2-1)	2.62		
	2	35	R_B (3-2)	7	104.04	R_L (3-2)	1.91		
	3	5	R_B (4-3)	2.5	28.39	R_L (4-3)	2.27	0.94	0.54
	4	2	R_B (5-4)	2	25.78	R_L (5-4)	1.50		
	5	1			19.31				

Table 5. Characteristics of the relief for the basins of the right bank of the Tensift wadi.

Basin	Altitude range (m)	Elemental surfaces (km^2)	Surface fraction (%)	Cumulative surface (Km^2)	Cumulative frequencies (%)	Average altitude (m)
Bourrous	960–840	4.17	1.38	4.17	1.38	628.36
	840–800	5.03	1.67	9.19	3.05	
	800–760	9.22	3.06	18.41	6.12	
	760–720	16.98	5.64	35.39	11.76	
	720–680	28.67	9.52	64.06	21.28	
	680–640	60.60	20.13	124.66	41.42	
	640–600	65.68	21.82	190.34	63.24	
	600–560	55.89	18.57	246.24	81.81	
	560–520	28.75	9.55	274.99	91.36	
	520–480	23.40	7.77	298.39	99.13	
	480–460	2.61	0.87	301	100	
Al Wiza	800–750	0.27	0.17	0.27	0.17	487.58
	750–700	0.59	0.37	0.87	0.54	
	700–650	2.14	1.33	3	1.87	
	650–600	7.55	4.69	10.55	6.55	
	600–550	24.64	15.31	35.19	21.86	
	550–500	30.14	18.72	65.33	40.58	
	500–450	47.17	29.30	112.50	69.87	
	450–400	24.93	15.49	137.43	85.36	
	400–350	19.39	12.04	156.82	97.40	
	350–300	4.18	2.60	161	100	
El Hallouf	800–750	0.18	0.09	0.18	0.09	499.81
	750–700	0.45	0.22	0.63	0.31	
	700–650	3.22	1.58	3.85	1.89	
	650–600	15.22	7.46	19.07	9.35	
	600–550	41.52	20.35	60.59	29.70	
	550–500	43.18	21.16	103.77	50.87	
	500–450	43.40	21.27	147.17	72.14	
	450–400	32.30	15.83	179.46	87.97	
	400–350	19.03	9.33	198.49	97.30	
	350–300	5.51	2.70	204	100	
Jamala	600–560	2.11	0.53	2.11	0.53	393.27
	560–520	9.48	2.36	11.59	2.89	
	520–480	32.11	8.01	43.70	10.90	
	480–440	54.95	13.70	98.65	24.60	
	440–400	88.20	22.00	186.85	46.60	
	400–360	90.50	22.57	277.35	69.16	
	360–320	60.73	15.14	338.08	84.31	
	320–280	39.60	9.88	377.68	94.18	
	280–240	23.32	5.82	401	100	

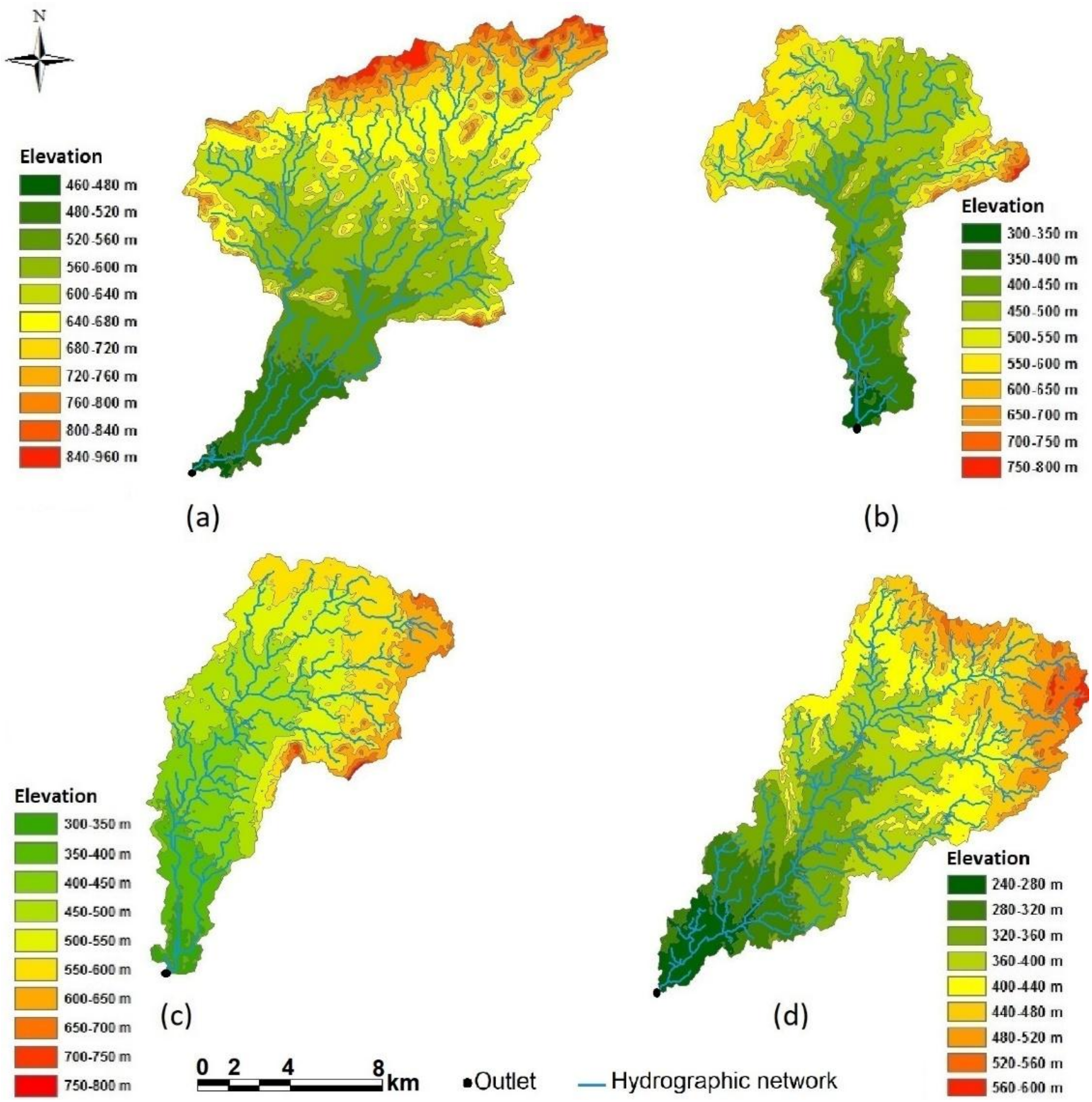

Figure 3. Hypsometric map of Bourrous (a), Al Wiza (b), El Hallouf (c) and Jamala (d) basins.

The average altitude of these basins is between 393.27 m and 628.36 m, this is for the basins of Jamala and Bourrous, respectively. Moreover, the distribution of the surface area of the sub-basin areas (Bourrous, Al Wiza, El Hallouf and Jamala) in relation to the change in altitude is low (Table 5). Similarly, the minimum and maximum altitudes, ranging from 240 m to 960 m respectively, for the Jamala and the Bourrous (Table 5). In general, the results of hypsometry between all the basins of Bourrous, Al Wiza, El Hallouf and Jamala are almost homogeneous, we deduce that we are in a plain area where the altitude is low, refer to the hypsometric map in Figure 3.

By evaluating the altitudes of the basins of the right bank of Tensift, with the basins of the left bank of Tensift wadi, where the altitude is located between 500 m and 4,100 m, we see that the altitudes of the right bank of Tensift wadi are very low. This may explain the climatological variation between these two banks of the Tensift wadi, as well as the aridity of the right bank of the Tensift watershed.

The values found of the average slope, on the sub-catchments (Bourrous, Al Wiza, El Hallouf and Jamala), they vary respectively from 5.12 to 9% for the basin of Jamala and Al Wiza. Thus, the average slope of the main flow varies respectively from 0.57 to 1.16% for these two basins. These results allow us to notice that the sub-basins of the right bank of the Tensift wadi represent low slopes. The calculated values of slope for all sub-basins are represented in Table 6.

In addition, the slope map (Figure 4) developed using ArcGIS software shows that the maximum slope on these basins does not exceed 27.15 (51%).

Comparing these results with the slopes of the left bank watersheds of the Tensift wadi, we notice that there is a big difference compared to the mountainous basins. For example, in the basin of Ourika, the average slope is 35% [14]; as well as in the basins of Armed (slope 50.38%) and Sidi Hsain (slope 16.60%) [38]. This difference is explained by the variation in altitude between the two banks of the Tensift basin.

Table 6. Slopes calculated for Bourrous, Al Wiza, El Hallouf and Jamala basins.

Basin	$P_{avg.}$ basin (%)	$P_{avg.}$ flow (%)
Bourrous	7.22	0.80
Al Wiza	9.00	1.16
El Hallouf	6,05	1,13
Jamala	5.12	0.57
Min	5.12	0.57
Max	9.00	1.16

The time of concentration (Table 7) calculated for the sub-basins, Bourrous, Al Wiza, El Hallouf and Jamala, by different formulas, we can see that the formula of Van Te Chow gives very low values. While the other formulas give an estimate of the time of concentration close to each other. In order to take into account, the rather contrasting values obtained by these formulas, we have eliminated the result of the Van Te Chow equation which is often very low compared to the other results. In Table 7, the results of the time of concentration calculation for each watershed are presented.

The concentration times calculated by the average of the selected formulas, US Corps, Turrazza, Californian, Spanish and Ventura, they vary between 6.71 h and 11.48 h, for all those sub-basins. Thus, the Jamala basin, having the largest surface area (401 Km^2) has the largest time of concentration (11.48 h). These values of concentration time depend mainly on the size of the basin.

Table 7. Concentration times calculated for the basins of the right bank of the Tensift wadi.

Bassin	Formulas of concentration times Tc (h)						Average Tc (h)
	US Corps	Turrazza	Californienne	Espagnole	Ventura	Van Te Chow	
Bourrous	9.37	9.89	8.12	10.11	8.21	3.49	9.14
Al Wiza	7.40	6.61	6.14	7.99	5.38	2.77	6.71
El Hallouf	8.16	8.78	7.31	8.80	7.35	3.20	8.08
Jamal	10.90	13.41	10.09	11.77	11.26	4.18	11.48
Min	7.40	6.61	6.14	7.99	5.38	2.77	6.71
Max	10.90	13.41	10.09	11.77	11.26	4.18	11.48

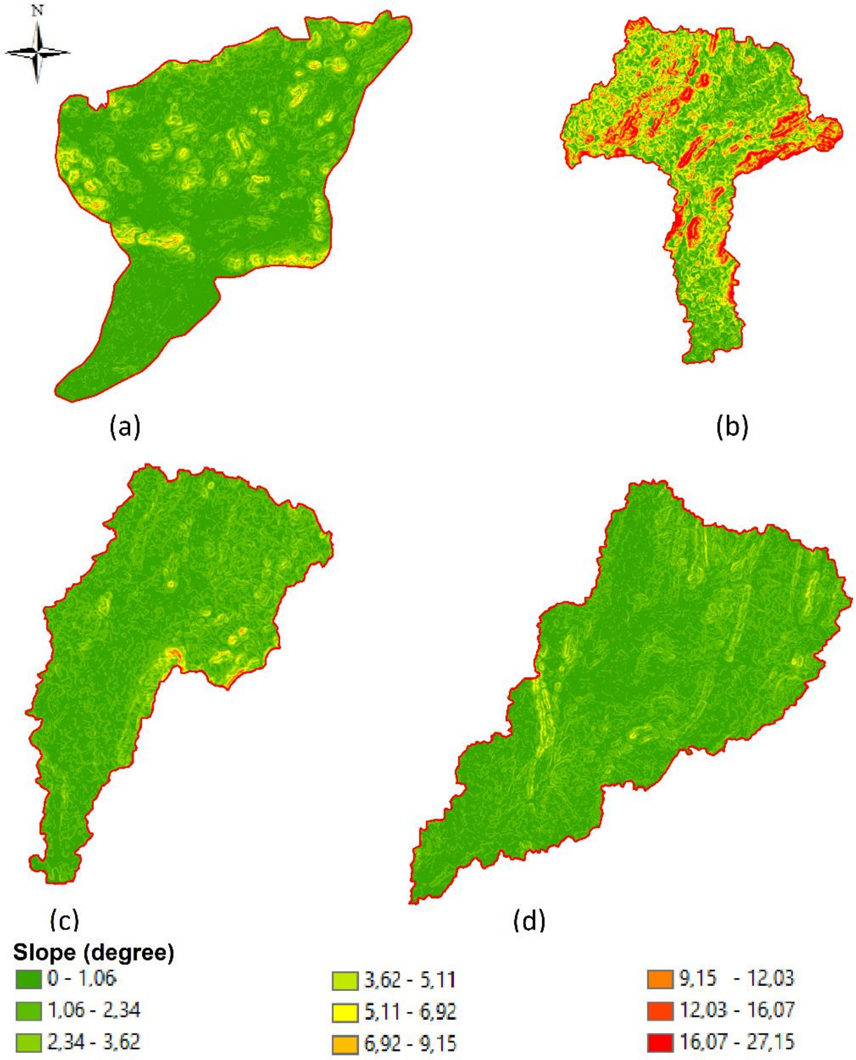

Figure 4. Slope map of Bourrous (a), Al Wiza (b), El Hallouf (c) and Jamala (d) basins.

This approach to analyzing morphometric parameters of watersheds allowed us to understand their hydrological response, in an arid environment, where observed data are not available. It can be confirmed that the use of satellite data (DTM) provides effective resources to calculate morphometric parameters of watersheds. In Ref [15] the authors showed that using a Digital Elevation Model (DEM), with a spatial resolution of 30 m, the results of the calculated morphometric criteria of the watersheds were very effective. Thus, these parameters have been very effective in identifying areas prone to erosion against landslides. However, our approach is often applied to study the behavior of the watershed, it is only a step toward a hydrological study or other scientific investigation.

The main limitation of the study is the use of very high spatial resolution terrain model data to identify watershed parameters. This limitation can be overcome by adopting high-resolution data (DTM).

4. Conclusions

Africa is characterized by a large number of watersheds located in arid environments where the morphometric characteristics of the basins are unknown. In North Africa, particularly in Morocco, there is a great need for morphometric studies of watersheds to initiate integrated water resources management. For this reason, our study was conducted to understand the hydrologic response of those sub-basins to the rainfall events they receive.

In this study, we used the DTM and the ArcGIS geographic information system to produce maps of the geographical location of the sub-basins, the hydrographic network, the hypsometry and the slope. Its objective is to conduct an analysis of the morphometric parameters of the sub-basins of the right bank of the Tensift watershed by processing the DTM of the Shuttle Radar Topography Mission (SRTM).

The result of the shape indices showed that the four sub-basins of the right bank of Tensift wadi all have elongated shapes with ratios between the equivalent length and width varying from 7.77 for the Jamala basin to 9.38 for the Al Wiza basin. These results of the sub-basins of the right bank of Tensift wadi show a great difference when compared with the sub-basins of the left bank of Tensift wadi where the area of the basins reaches 10,309 km^2, Abadla basin and 2,127 km^2, Chichaoua basin, also, the altitudes in this left bank exceed 4000 meters [13].

This study then showed the importance of DTM data and geographic information systems to perform a morphometric study of watersheds in arid environments, in order to understand their functioning. The analysis of the physiographic parameters of watersheds can indeed help hydrologists and researchers to establish a preliminary study dedicated to understanding the study area in the context of drought and lack of data.

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Conflicts of Interest

The authors declare no conflict of interest.

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