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Analyzing of Morphometric Parameters and Designing of Thematic Maps Using Raster Geoprocessing Tool

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Abstract

GIS techniques, digital elevation models (DEM), raster geoprocessing tools, and software such as ArcMap are a quick and simultaneous solution for the assessment, measurement, and analysis of morphometric parameters of river basins. This paper aims to show the use of the Digital Elevation Model and the ArcGIS program for the analysis of morphometric parameters and the construction of a set of thematic maps needed for spatial planning, water resources management, and similar purposes. Through these techniques, 18 morphometric parameters were determined and analyzed in the study area, which is located in the central part of the Republic of Kosovo and covers an area of 38 km^2, and 15 thematic maps were constructed. The altitude of the area varies from 544 m to 1019 m, the slope from <5% to > 24%, with a total number of stream segments of 601 and a drainage density of 5.02 km/km^2. The analysis of morphometric parameters presents an important indicator regarding the space and other elements of the river basin.

Keywords: Analysis; Golesh Massif; Morphometric Parameters; ArcGIS; Kosovo.

1. Introduction

The determination of the morphometric parameters of a certain hydrographic area takes special importance in hydrological studies, while the analysis of morphometric parameters plays an important role in understanding the geo-hydrological characteristics of a river watershed. It helps in studying the nature and behavior of drainage basins. Therefore, in order to know the characteristics of the river basin in more detail, different morphometric parameters must be determined. The analysis of morphometric parameters as pointed out by Sandeep (2020) [1] describes the characteristics of the river basin based on the quantitative assessment of different parameters. According to Clarke (1966), Agarwal (1998), Reddy et al. (2002) [2-4], morphometry is the measurement and mathematical analysis of the configuration of the Earth's surface and the shape and dimension of its landforms.

The Water Framework Directive 2000/60 of the Council of Europe [5] emphasizes the need for integrated water management at the level of the river basin. Therefore, the determination and analysis of morphometric parameters, the division of river basins, the construction of thematic maps, such as the map of the risk assessment of floods and erosion, etc., help to fulfill this directive. Their determination decades ago was carried out using topographic maps at different scales (1:25000, 1:50000, etc.), from which measurements were made to determine the watershed of the river basin, where in fact, from this line the other parameters are defined. Today (2022), the digital elevation model (DEM) is used for such purposes, which is easier to use and has a higher degree of accuracy.

According to Patel et al. (2016) [6], the digital elevation model (DEM) is a major dataset for various applications, including hydrology and morphometric studies. In this study area, morphometric was assessed by using the Advanced

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Land Observation Satellite (ALOS)-Digital Elevation Model (with 20×20 m spatial resolution) for the territory of Kosovo and the ArcGIS 10.5 software. The study area covers an area of 38 km^2 and belongs to the Goleshi Ultrabasic Massif. The Golesh massif is a well-known magnesite (Mg) mine. The study area, namely the Golesh Massif, was involved in research and studies of a regional nature during the construction of the geological maps on a scale of 100000, 200000, and hydrogeological maps on a scale of 1: 200000 [7], etc. More detailed research on the area was carried out from 1928 to 1990, which mainly focused on the exploitation of magnesium (Mg) and dunites. Research regarding the hydrological aspects of this area was carried out in 1973 by Labus [8]. In that paper, the author describes the hydrological situation with a focus on the identification of water sources, some of which also have hydrological and physico-chemical parameters. Taking into consideration the data and information so far on this area, it was seen that for this study area there is a lack of data and information related to morphometric parameters, etc. Therefore, in order to increase the fund of data and information during the years 2020 and 2021, research work was undertaken in the field and associated with the digital elevation model to analyze some of the morphometric parameters, the division of some mini-ponds and the construction of a set of thematic maps using the Advanced Land Observation Satellite (ALOS)-Digital Elevation Model (with spatial resolution 20×20 m) for the territory of Kosovo, and the ArcGIS 10.5 program, the Hydrological toolbox.

2. Research Methodology

The study area, Golesh Massif is located in the central part of the Republic of Kosovo with coordinates 42°35' 00" N and 21°00' 00" E (Figure1).

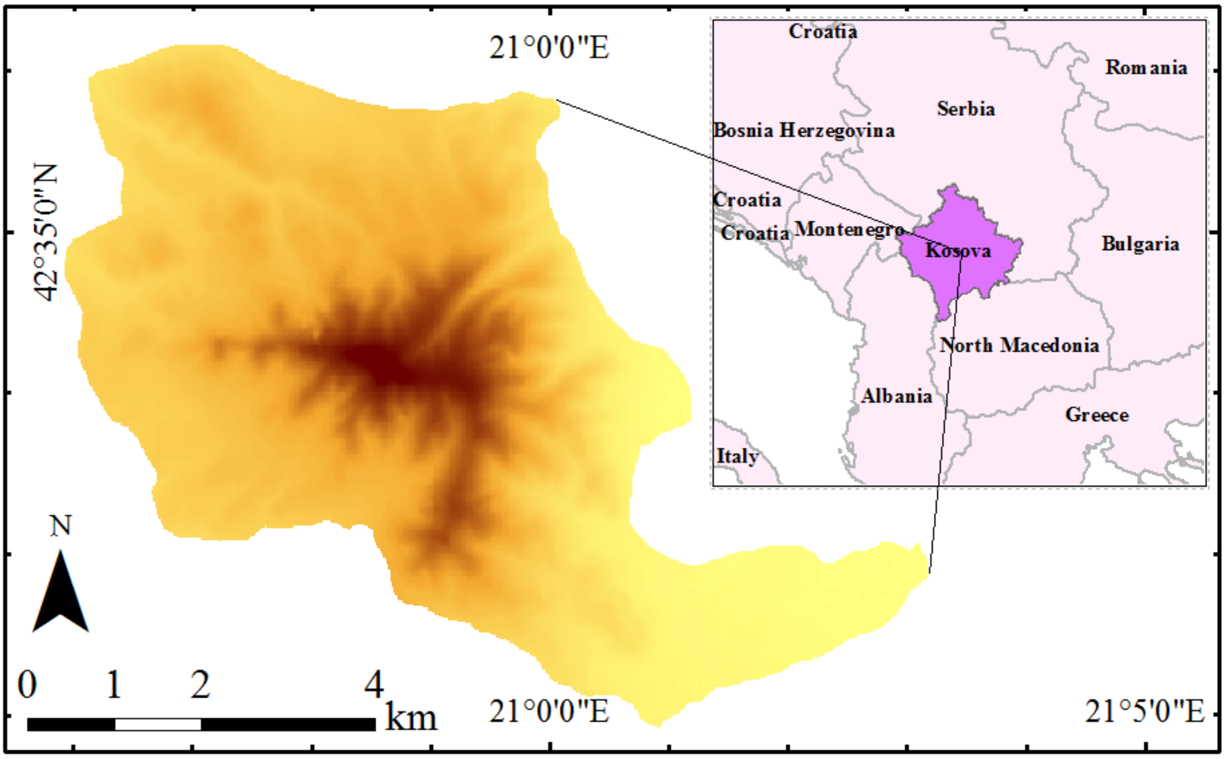

Figure 1. The position of the study area

It has an area of 38 km^2 and an altitude ranging from 544 m to 1019 m (Neck of Golesh). For the realization of this study, a working methodology divided into three main phases was followed. The first phase was characterized by the collection of data and earlier information conducted in this area. At this stage all relevant data for the purpose of the study were selected, they were systematized, processed and some of them are presented in this paper. The second phase is characterized by fieldwork, measurable coordinates, and altitude. The third phase was characterized by the elaboration of the data, including the tabular, graphic, analytical, interpretive, and concluding parts (Figure 2). The materials used to achieve the purpose of this paper were GPS-handheld, meter, camera, and topographic maps (1:25000). For the construction of maps, the Digital Elevation Model (DEM), Advanced Land Observation Satellite (ALOS), with 20 × 20 m spatial resolution, was used. The determination of the watershed, stream network, network and maps based on digital elevation models was accomplished using the hydrology tools in the ArcGIS 10.5 software geo-processing toolbox. The Spatial Analyst Tools-hydrology are used to derive several datasets that collectively describe the drainage patterns of the basin. Geo-processing analysis is performed to recondition the digital elevation model and generate data on fill, flow direction, flow accumulation, basin, stream order, stream to feature and watersheds.

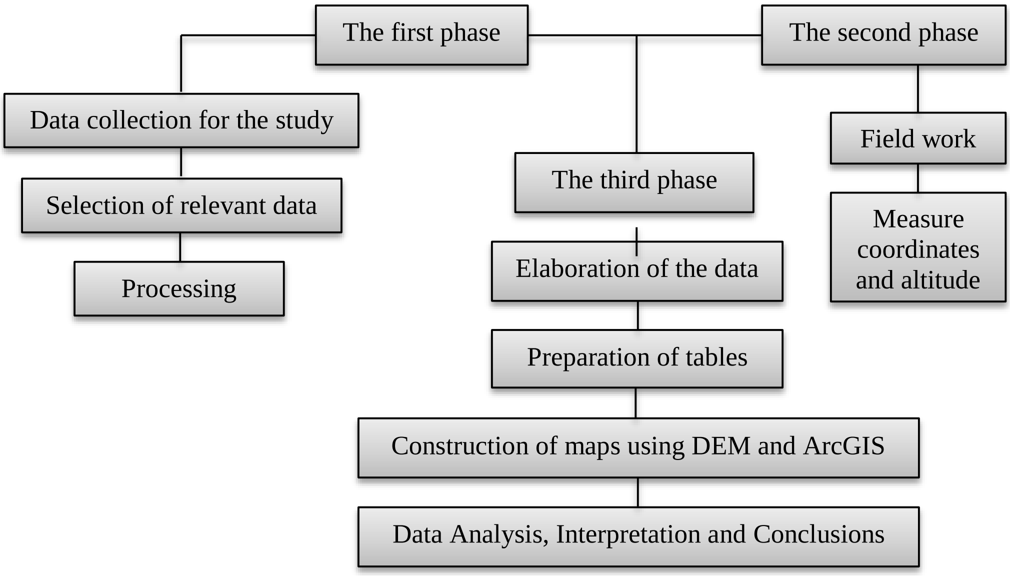

Figure 2. Flowchart of work methodology

3. Results and Discussions

An area of 38 km^2 and a perimeter of 32.64 km were included in this study. From this surface through the menu Spatial Analyst Tools-Hydrology were created the function Fill, Flow direction, Flow accumulation and Basin (Figure 3). We used these functions to derive the other results presented below.

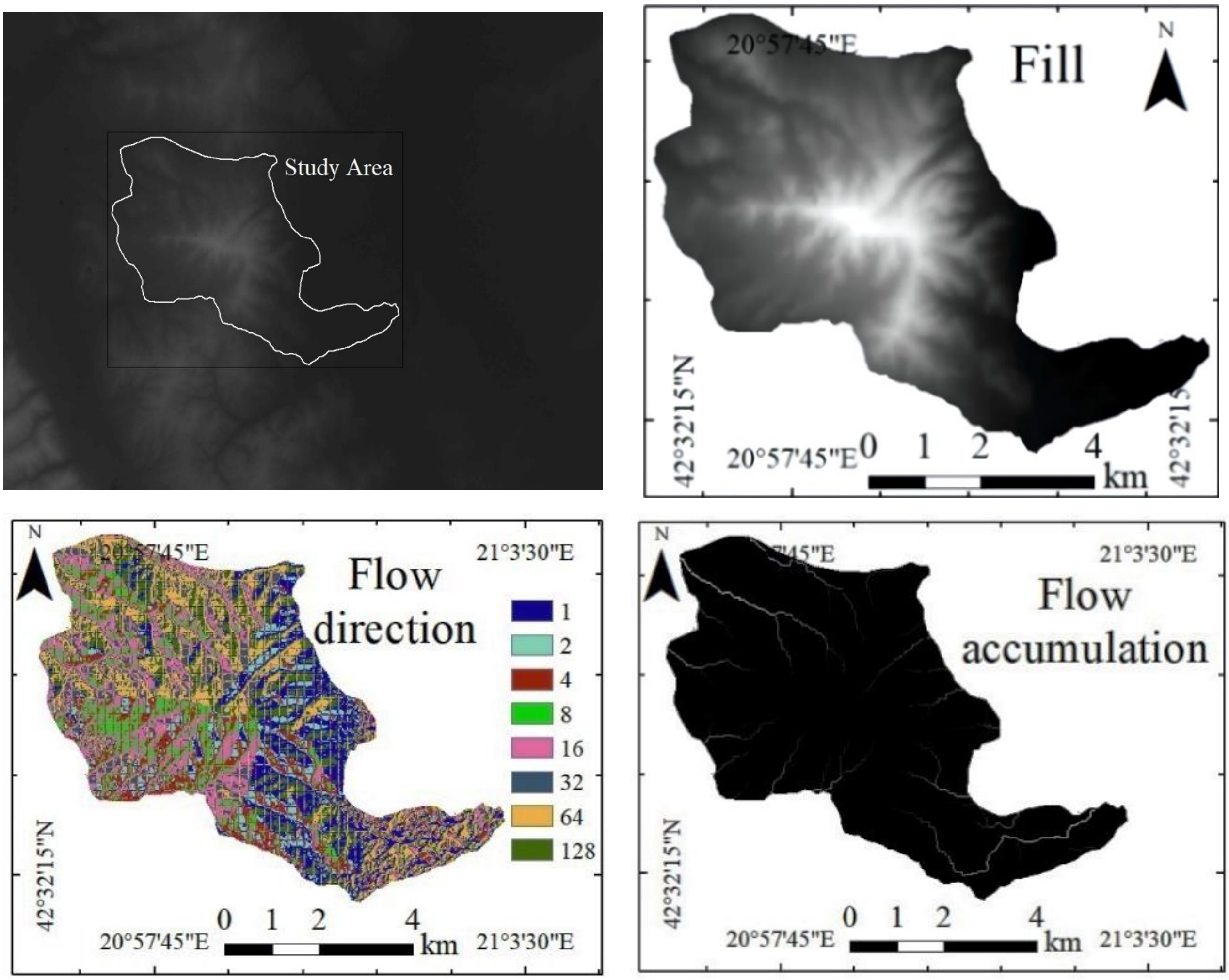

Figure 3. Study area, Fill, Flow direction, Flow accumulation

3.1. Topographic Anomalies

In the study area, elevations (hills) and descents (valleys) are clearly observed. So, topography means the description and presentation of a place, area with the totality of elevations and depressions on the surface of the earth, with its relief and extent. The elevations are the effect of tectonics and the transformations that occurred until its formation, while the depressions (valleys) are the effect of the formation phase but also of external effects, especially the activity of surface water. From the hypsometric point of view, the study area ranges from 544 m to 1019 m (Neck of Golesh). Two topographical profiles are shown in the (Figure 4), one transverse (A-A') and one longitudinal (B-B'), which reflect the natural reality of the study area from the point of view of the rise and fall that this study area has.

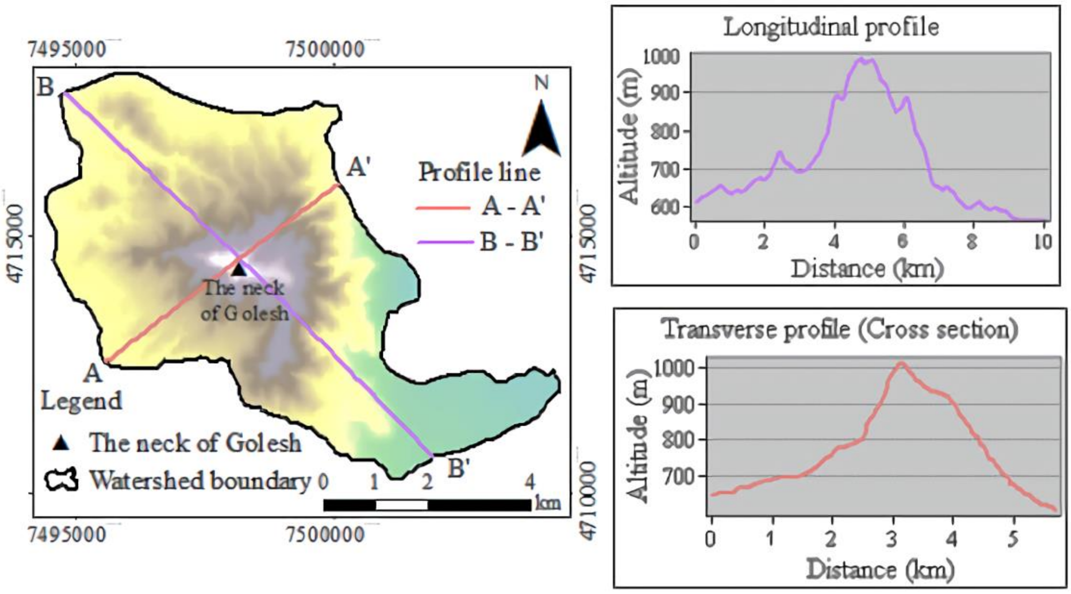

Figure 4. Topographic map and profile

3.2. Slope

Slope is a topographical parameter that is important in hydrological assessment and modeling. The steep terrain favors rapid flow, and in particular when they are built from rock formations with a small infiltration coefficient. Also, the steep terrains are a helpful factor for erosive potential (increased erosion rate) on the one hand, while on the other hand, on steep terrains, the possibility of rapid infiltration of atmospheric waters (rain) decreases, which would benefit underground water supply. In principle, regions or areas with flat terrain are more at risk from hydrological components (floods, erosion), while they are more useful for agricultural activities. The slope in study area varied from low (< 5%), very gentle (5-10%), gentle (10-16%), moderate (16-24%) moderately steep (> 24%) (Figure 5). In general, the variations of slope in study area are controlled by the local lithological settings. In (Figure 6) shows the 3D model of the study area.

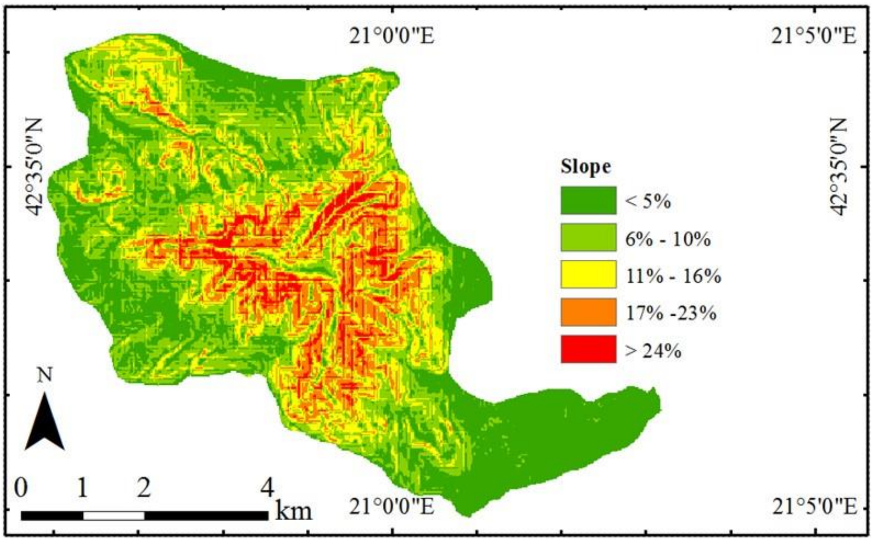

Figure 5. Slope map

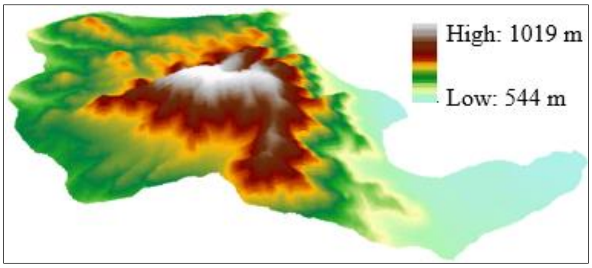

Figure 6. 3D models in study area

3.3. Drainage Network

The study area is characterized by the radial surface water flow system (Figure), where all water flows start from a single center, in this case from the Neck of Goleshi (1019 m) [9]. The shape of the Golesh massif has enabled surface waters to drain in all directions, on its side. In the formation of surface water flow in the study area, an important role has been played; tectonic movements and geological construction as the main factor, while as secondary factors are: climatic conditions, vegetation layer, vegetation, substrate (vegetation nutrient layer) and hydrogeological characteristics. The drainage network is mainly of the stream type where the presence of water in it depends on the amount of precipitation (rain, snow) that falls on this area. So, the waters that bring atmospheric precipitation, in terms of hydrology, are the main source of food for the drainage network in this area.

Stream Order (S_U): there are several river ranking systems in the technical literature. The streams order of the Golesh massif have been ranked according to the method (Hierarchical rank) described by Strahler (1957) [10]. According to Strahler, when two first order streams join, a stream segment of second order is formed, when two order streams join, a segment of third order is formed, which can also take other branches of first and second order and so one (Figure 7).

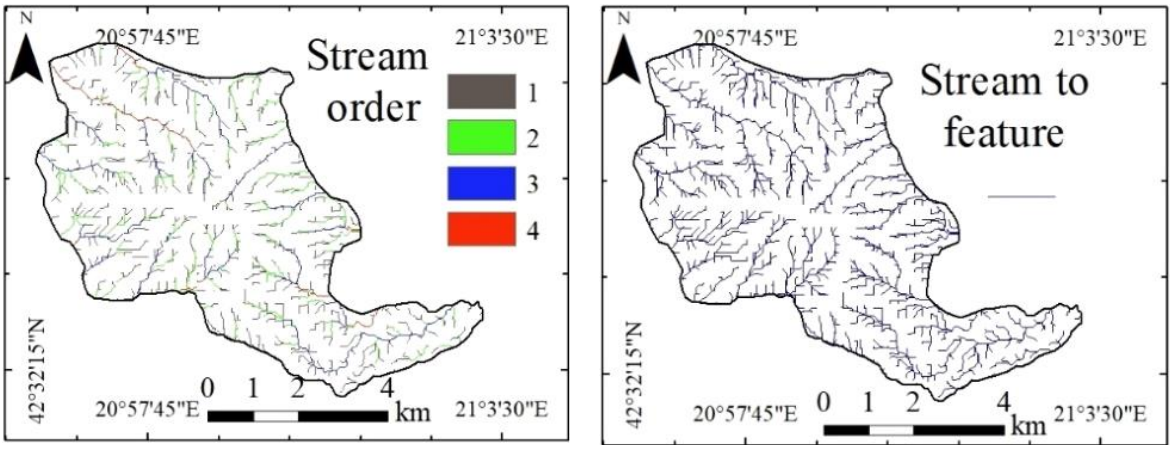

Figure 7. Stream order, stream to feature and stream to feature

Stream Number (Nu): in study area, the total streams segments present are 601 of which 470 or 78 % are first order streams, 2nd order 16.8 %, 3rd order 3.83% and 4th order 1.16%. (Table 1). The largest number of first-order streams 68 was shown in the W8 sub-basin while the smallest 2 in the W9 sub-basin. The largest number of second-order streams 14 was shown in sub-basin W25, while that of third-order streams 3 was shown in sub-basin W8 (Table 2).

$$N_u = N_1 + N_2 + \cdots + N_n \tag{1}$$

Table 1. Stream characteristics

Stream order	Stream Number	Stream Length (km)	Mean Stream Length (km)	Cumulative Stream Length (km)	Stream Length Ratio
1st order	470	112.43	0.24	0.24	-
2nd order	101	41.63	0.41	0.65	0.37
3rd order	23	29.78	1.29	1.95	0.72
4th order	7	8.80	1.26	3.20	0.30
Total	601	192.63	-	-	Av. 0.51
Bifurcation ratio				**Mean bifurcation**	
1st/2nd	**2nd/3rd**	**3rd/4th**		**ratio**	
4.65	4.39	3.29		4.11	

Table 2. Morphometric results in the study area (Golesh Massif)

Watershed	A (km²)	P (km)	Gravelius compactness coefficient (K_G)	Drainage density (Dd) (km/km²)	Constant of channel maintenance (C)	Circulatory ratio (Rc)	Drainage Texture (Rt)	Stream order (S_U)				Stream length (Lu) (km)	Form factor (Rf)	Relief Ratio (Rr)
								1st order	2nd order	3rd order	4th order			
W1	1.03	5.27	1.45	4.99	0.20	0.47	2.85	13	2	0	0	5.15	0.29	0.09
W2	0.95	4.51	1.30	8.07	0.12	0.59	4.88	17	3	2	0	7.67	0.34	0.07
W3	0.52	3.91	1.52	5.51	0.18	0.42	2.55	8	2	0	0	2.85	0.64	0.16
W4	3.18	10.40	1.63	5.45	0.18	0.37	5.68	45	10	3	1	17.33	0.21	0.08
W5	0.26	2.95	1.63	3.94	0.25	0.37	1.69	4	1	0	0	1.01	0.13	0.19
W6	0.55	3.94	1.48	4.86	0.21	0.45	1.78	6	1	0	0	2.68	0.20	0.21
W7	2.30	7.55	1.39	5.24	0.19	0.51	6.23	38	8	1	0	12.05	0.31	0.10
W8	4.72	12.67	1.63	4.89	0.20	0.37	6.47	68	10	3	1	23.12	0.21	0.09
W9	0.25	2.98	1.53	3.27	0.31	0.35	1.01	2	1	0	0	0.82	0.15	0.23
W10	1.08	6.30	1.70	4.16	0.24	0.34	4.60	18	10	1	0	4.50	0.16	0.16
W11	1.04	5.12	1.41	5.2	0.19	0.50	3.90	16	3	1	0	5.43	0.25	0.20
W12	0.32	2.79	1.37	4.5	0.22	0.52	1.79	4	1	0	0	1.47	0.32	0.07
W13	0.78	4.81	1.52	6.4	0.16	0.43	3.33	11	3	1	1	5.03	0.23	0.13
W14	1.78	6.53	1.37	6.0	0.17	0.52	4.44	21	5	2	1	10.70	0.27	0.12
W15	0.32	3.06	1.52	6.5	0.15	0.43	1.64	4	1	0	0	2.06	0.23	0.14
W16	0.90	5.06	1.49	5.1	0.19	0.44	3.56	15	2	1	0	4.63	0.23	0.09
W17	1.21	6.12	1.56	5.5	0.18	0.41	4.41	22	4	1	0	6.67	0.22	0.15
W18	0.40	3.26	1.44	4.0	0.25	0.47	1.23	3	1	0	0	1.59	0.21	0.08
W19	2.37	6.50	1.18	5.5	0.18	0.71	7.08	35	8	2	1	13.16	0.51	0.14
W20	2.13	7.12	1.37	5.5	0.18	0.53	6.04	36	4	2	1	11.75	0.37	0.16
W21	0.17	1.97	1.33	3.8	0.26	0.56	2.03	3	1	0	0	0.65	0.37	0.01
W22	0.39	2.70	1.20	5.2	0.19	0.68	2.59	6	1	0	0	2.05	0.42	0.24
W23	1.27	6.49	1.61	5.5	0.18	0.38	3.08	13	4	2	1	6.97	0.31	0.06
W24	0.42	4.08	1.76	5.6	0.18	0.32	1.47	5	1	0	0	2.39	0.17	0.01
W25	4.23	15.22	2.07	5.2	0.19	0.23	4.73	57	14	1	0	22.20	0.18	0.07
Other surfaces (Wo)	5.43			3.4	0.29	1.89						18.68		

Stream Length (Lu): it is measure with respect to stream orders by using ArcGIS software. According to Aadil Hamid (2013) [11] stream length is demonstrative of sequential improvements of the stream sections including interlude structural tectonic influences. The results for stream length the study area is presented in the (Table 1).

$$L_u = L_1 + L_2 + \cdots + L_n \tag{2}$$

Mean Stream Length (LSM): according to Strahler (1957) [10] the mean stream length of a channel the characteristic size of drainage network components and its contributing basin surface. The results for mean stream length the study area is presented in the (Table 1).

$$\bar{L}_u = \frac{\sum_{i=1}^{n} L_u}{N_u} \tag{3}$$

Stream Length Ratio (RL): the variations in stream length ratio in study area were due to variations in slop and topography. The values for this parameter are presented in the (Table.1).

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \tag{4}$$

Bifurcation Ratio (R_b): the bifurcation ratio between different orders is a constant value for a natural river system and this value is the basin bifurcation ratio. According to Horton (1945) [12], Strahler (1957) [10] and Schumm (1956) [13] bifurcation ratio is the ratio of the number of streams of an order to the number streams of the next higher order. The higher values of bifurcation ratio indicate strong structural control on the drainage patter, while the lower values indicative of watershed that are not affect by structural disturbances. The bifurcation ratio is indicative parameters of shape of the basin also. In the study area bifurcation ratio ranges from 3.29 to 4.65. The mean bifurcation ratio is 4.11 (Table 1).

$$Bifurcation\ ratio\ (R_b) = \frac{Total\ no.of\ stream\ segments\ of\ order\ 'u'\ (N_u)}{No.\ of\ streams\ of\ the\ next\ higher\ order\ (N_{u+1})} \quad (5)$$

Drainage density (Dd): represents the total length of the hydrographic network in relation to the total surface of the basin, while it depends on several factors such as: geological construction-type of rocks, pedology (soil type), hydrological parameters, hydrogeological characteristics and percentage participation of rock masses in the construction of the given surface. Drainage density of the study area is 5.02 km/km^2. The (Table 2) and (Figure 8) show the drainage density values for all sub-basins in this study area. According to IBAL (2009) [14] the classification for drainage density (approximate values): 0.1 to 1.8 km/km^2 (Low), 1.9 to 3.6 km/km^2 (Moderate), 3.7 to 5.6 km/km^2 (High), it turns out that the study area has High density (Table 2). According to Melton (1957) [15] high drainage density represents a highly dissected drainage basin with a moderately fast hydrological reaction to precipitation occasions.

$$Drainage\ density\ (D_d) = \frac{Total\ lenght\ of\ all\ stream\ (L_u)}{Area\ of\ the\ Basin\ (A)} \quad (6)$$

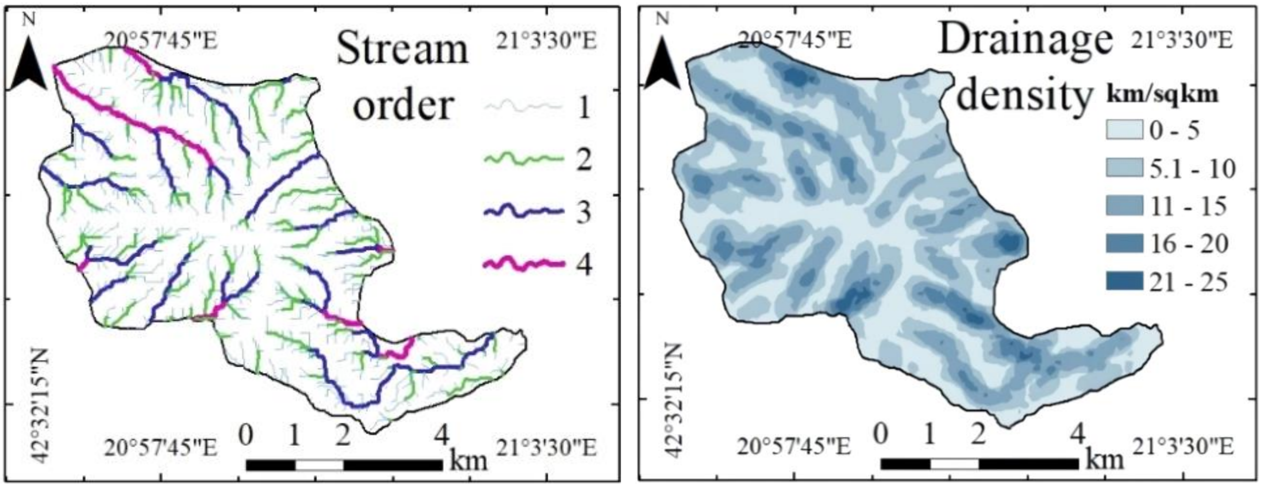

Figure 8. Stream order, stream to feature and drainage density

Gravelius compactness coefficient (K_G): characterizing the shape of a basin, several parameters are used related to the ratio of the surface, perimeter or length of the longest water course. To determine the easiest shape of the basin, the Coefficient of Compactness of Gravelius [16]. The shape of the watershed has a major influence on the shape and peak flow of the entire hydrograph.

It is expressed by the following Equation 7:

$$K_G = \frac{P}{2\sqrt{\pi * A}} \approx 0.28 * \frac{Perimeter\ of\ the\ basin}{\sqrt{Area\ of\ the\ basin}} \quad (7)$$

The Gravelius coefficient in these study area ranges from 1.18 to 2.07 with an average value of 1.50. According to this coefficient, it turns out that the sub-basins have a mainly elongated shape (Table 2). According to the results obtained for the Gravelius Coefficient, all sub-basins were grouped into five groups (Figure 9). With a coefficient of 1.42 to 1.56 nine sub-basins or 36% were identified, with K_G = 1.21 to 1.41 are seven sub-basins or 28%, K_G = 1.57 to 1.76 are six sub-basins or 24%, K_G = 1.18 to 1.20 are two sub-basins or 8% and with K_G = 1.77 to 2.07 is a sub-basin or 4%.

Drainage Texture (T)-according Horton (1945) [12] the drainage texture is the total number of stream segments of all orders per perimeter to that area. The drainage texture on the underlying lithology, infiltration capacity and relief aspect of the terrain. Smith, 1950 has classified drainage texture into five different textures: < 2 Very Coarse, 2 to 4 Coarse, 4 to 6 Moderate, 6 to 8 Fine and > 8 Very Fine. In the present study area, the drainage texture is ranges from 1.01 to 7.08 km^{-1} with an average value of 3.56 km^{-1} (Table 2 and Table 3). The results for the drainage texture parameter obtained in this study area were compared with the classification given according to Smith (1950) [14] and it turned out that this study area ranks in coarse with a slight tendency from moderate (Table 3).

$$Drainage\ Texture\ (T) = \frac{Total\ number\ of\ streams\ of\ all\ orders\ (Nu)}{Basin\ perimeter\ (P)} \quad (8)$$

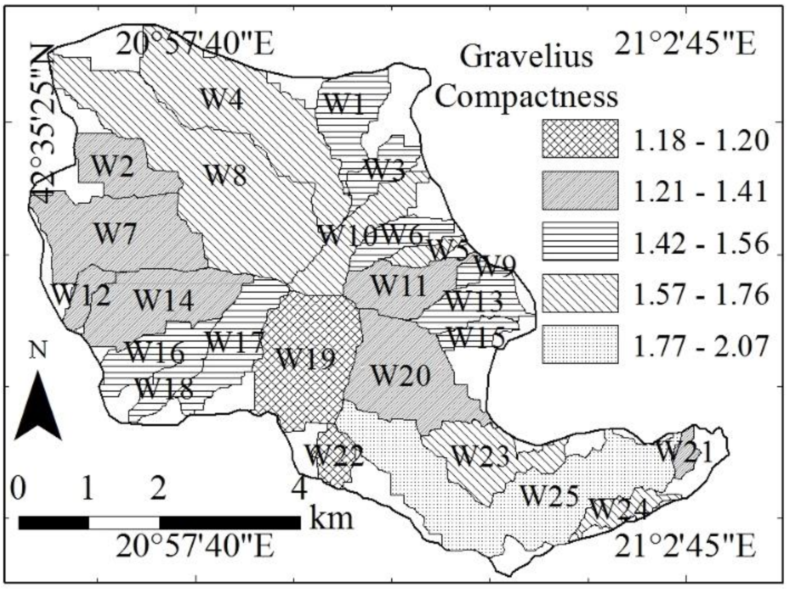

Figure 9. Map of sub-basins according to K_G

Table 3. Value for T, according to Smith and results in study area for T

Drainage Texture, According to Smith, 1950.	Class	Sub-basin in study area	In percentage
> 2	Very Coarse	W5, W6, W9, W12, W15, W18 and W24.	28
2 to 4	Coarse	W1, W3, W11, W13, W16, W21, W22 and W23.	32
4 to 6	Moderate	W2, W4, W10, W14, W17 and W25.	24
6 to 8	Fine	W7, W8, W19 and W20.	16
> 8	Very Fine	-	-

Form factor (Rf): according to Horton (1932) [17] the form factor indicates the flow intensity of a basin of a defined area. The form factor value for the study area ranges from 0.13 to 0.64 with average value 0.28. In general, the results for the form factor parameter are reflected in the (Tables 2 and 4).

$$Form\ factor\ (R_f) = \frac{Area\ of\ the\ basin\ (A)}{Basin\ length\ (L^2)} \tag{9}$$

Table 4. Value according to Perez and number of sub-basins in study area

Form factor (Approximate values, according to Perez, 1979.) [18]	Shape of the basin	Sub-basin in study area	In percentage
< 0.22	Very long	W4, W5, W6, W8, W9, W10, W17, W18, W24 and W25	40
0.22 to 0.30	Elongated	W1, W11, W13, W14, W15 and W23.	24
0.30 to 0.37	Slightly elongated	W2, W7, W12 and W23.	16
0.37 to 0.45	Neither elongated nor widened	W19, W20, W21, W3 and W22	20
0.45 to 0.60	slightly widened		-
0.60 to 0.80	Widened		-
0.80 to 1.20	Very widened		-
> 1.20	Surrounding the drain		-

Circularity ratio (R_c): is defined as the ratio of the area of basin to the area of the circle having the same circumference as the perimeter of the basin [19]. The Rc value for the study area ranges from 0.23 to 0.71 with average value 0.45 (Table 2). According to Miller (1953) [19] the Rc has described the basin of the circularity ratios rang 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geologic materials.

$$Circularity\ ratio\ (R_c) = \frac{4 * \pi * Area\ of\ the\ basin}{Perimeter\ (P^2)} \tag{10}$$

*Constant of channel maintenance (C)***:** it is the inverse of drainage density [15]. The constant of channel maintenance for the study area ranges from 0.12 to 0.31 with average value 0.20 (Table 2). It indicates that magnitude of surface area of watershed needs to sustain unit length of stream segment.

$$Constant\ of\ channel\ maintenance\ (C) = \frac{1}{Rainage\ density\ (D_d)} \tag{11}$$

Relief ratio (R_r): is the ratio of the maximum relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line [15]. For present study area the value of relief ratio ranges from 0.01 to 0.24 with average value 0.12. The results for relief ratio are presented in the (Table 2).

$$Relief\ ratio\ (R_r) = \frac{Basin\ relief\ (R)}{Basin\ length\ (L)} \tag{12}$$

3.4. Watershed

A watershed area is an area of land where all precipitation converges into a common outlet through secondary streams or ravines that flow into a main stream. A watershed can be described in a variety of ways. The shape can be described as ovoid, circular, or rectangular. The shape is largely an expression of the underlying geologic structure, but the geologic structure is intertwined with shape; the shape affects the hydrology, but the hydrology is also partly responsible for the shape. Watershed shape is important because it controls the time it takes for water to enter a stream after it falls as precipitation. The area of the basin is defined as the total area projected onto a horizontal plane [20]. Regarding the size of the basin [21] made the classification into three groups: 1) Small Watersheds < 250 km^2, 2) Medium Watersheds between 250 to 2500 km^2, 3) Large Watersheds >2500 km^2. Based on this classification, it turns out that the size of the Golesh Masiff (A = 38.00 km^2) belongs to the first group, with a small size.

Area (A): area of the basin is calculated as total area projected upon a horizontal plan contributing to accumulate of all order of basin. Area of the basin has a strong relationship with mean annual runoff. The study area covers an area of 38 km$^{2.}$

Perimeter (P): it is measured along the divides betweeb watersheds. The basin parameter dependent on elongation ratio and circulatory ratio [22]. The study area has a perimeter of 32.64 km.

*Sub-basins***:** in the study area are divided 25 sub-basins (mini-basins) which cover an area of 32.49 km² (Figure 10). The subdivision mapping and construction was accomplished through the Spatial Analyst Tool-Hydrology-Watershed toolbox. Their surface area ranges from 0.14 km² or 0.43% (W9) to 4.72 km² or 14.54% (W8).

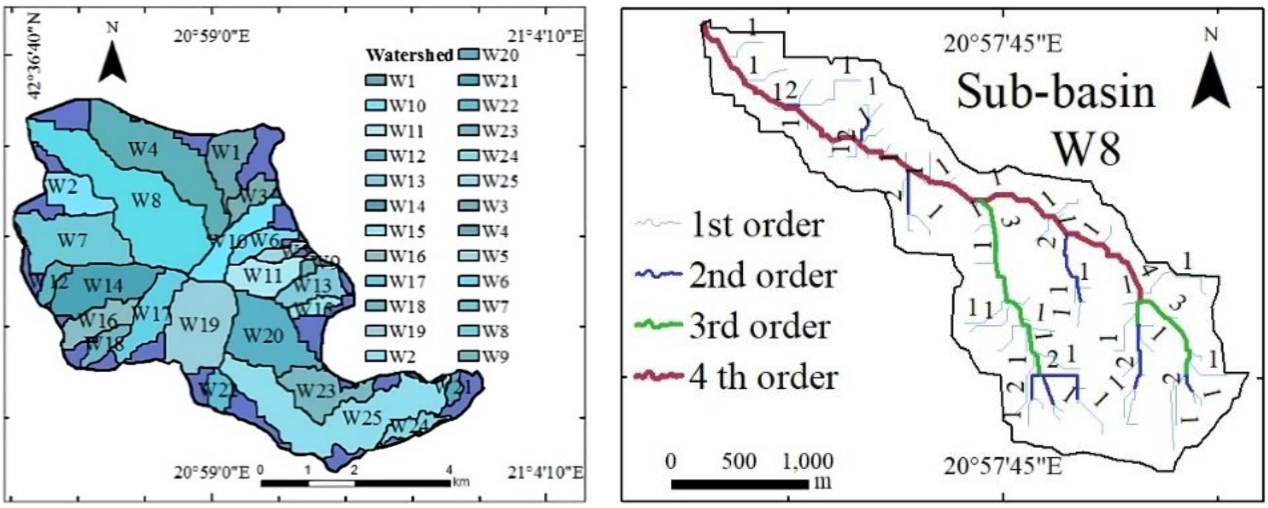

Figure 10. Watershed map and sub-basin W8

4. Conclusion

The present investigation has proved that the techniques of using geographic information, rasters, and geospatial tools in general are more efficient for the computation and analysis of the morphometric parameters. There are 14 morphometric parameters that were calculated with the help of the Arc GIS 10.5 software. Also, with the help of raster-DEM (Digital Elevation Model) and Arc GIS 10.5 software are designing all the thematic maps presented in this paper. These parameters help to understand the terrain characteristics such as topography, slope, lithology, surface runoff, infiltration capacity, and hydrological properties of the study area. According to Strahler classification, the study area has the fourth order and the radial drainage pattern is observed. The bifurcation ratio and stream numbers of the study area show vulnerability to unpredicted floods during heavy rainfall. The value of the mean bifurcation ratio indicates that the watershed is not affected by structural disturbance and geological structures. According to the Gravelius coefficient, the sub-basins in the study area showed mainly elongated shapes. The drainage texture of the sub-basin in the study area is mainly coarse and very coarse. The largest number of sub-basins according to the form factor entered the very long group. In general, the analysis based on DEM and GIS with the morphometric parameter gives a relationship between hydrological aspect, geological, topographical, pedological which is useful for planning and management of watershed construction and watershed structure which enables the solution of many issues such as requires the Water Framework Directive 2000/60.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available in the article.

5.2. Funding

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5.4. Conflicts of Interest

The author declares no conflict of interest.

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