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Investigation of Morphometric Parameters and Their Impact on the Hydrological and Geomorphic Processes by Using Arc GIS (Case Study: Tuyserkan Basin)

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ABSTRACT

In general, land and water resources are in decline due to the rapid population growth, urbanization, and industrialization. Indeed, demand for these resources has increased sharply making it essential for sustainable development to make optimal use of water and soil. In this paper, we have tried to study the morphometric characteristics of Tuyserkan Basin. Morphometric parameters for the basin were determined using ASTER images in Geographic Information System. The drainage area of the watershed is 364.82 km^2 and constitutes a 5th-order drainage basin. The result indicates that the drainage area is 364.82 km^2, the perimeter is 324.23 km, the basin length is 37.68 km, the drainage texture is 0.07, the constant of channel maintenance is 9.72, the stream frequency is 0.06, the drainage density is 0.1, and the length overflow is 0.18. A mean bifurcation ratio of 4.29 to the drainage pattern has not been disturbed by structural disturbance. The form factor of 0.25, the circularity ratio of 0.043, and the elongation ratio of 0.57 indicate that the basin is sub-circular to elongate in shape. The results of the analysis of features of the Tuyserkan basin indicate that the watersheds have a moderate roughness. The dendritic drainage network shows the homogeneity of the texture. This type of basin structure helps to explain various parameters of the earth, such as the nature of the earth, penetration capacity, runoff production, and soil erosion. The results of the drainage density and the flow rate of the average permeability are shown.

1. Introduction

Surface water and underground water resources are not threatened by rapid population growth and more water demand for domestic consumption. Increasing water demand during recent years, quantitative and qualitative assessment of water resources, and the optimal use of water has become very important. There is an immediate need to assess water resources because water plays a key role in the sustainability of livelihoods and regional economics. Water management is the primary protection against drought and plays an important role in achieving food security at the local, national and global levels. The growing population and urbanization result in excessive use of water resources, so the pressure on urban facilities is limited, many of which are on the brink of collapse (Jha et al., 2007). The concept of basin management is the recognition of the relationship between the use of land, soil and water, and the relationship between land areas (Tideman and Tideman, 2007). Knowledge of the erosion process of a drainage basin in geomorphic, topographic and hydrological terms is a fundamental requirement for water management (Chorley, 1969). In management and sustainable development of natural resources, it is necessary to minimize environmental hazards in the optimal production and proper use of land and water resources for the inhabitants of a catchment area (Patel et al., 2012). Drainage basins are the basic units for understanding the geometric features of a river landscape, such as the topology of drainage networks, and the description of drainage, pattern, shape, and features of reliefs (Reddy et al., 2004). Identifying the features of the earth, such as geological structures, geomorphic features, and their links with hydrological characteristics, may be indicators of direct or indirect potential of groundwater and surface area. Geomorphic conditions are prerequisites for understanding the characteristics of soil texture and discharge patterns of the basin. The response of rock type and geological structures in the development of flow networks can be improved by studying the nature and type of drainage patterns and using a slightly morphometric analysis. The morphometric parameters of an aquifer basin are significantly affected by the hydrologic response of the basin and can be useful in combining hydrologic behavior and water equilibrium. The geomorphic characterization of human perception of the relationship between different aspects of drainage patterns in the basin is very important and allows the comparison of different drainage basins in

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different geological and climatic regimes. Quantitative morphometric description and analysis of watersheds have been considered the most satisfactory method for planning, proper watershed management, and implementation of soil and water conservation measures (Sreedevi et al., 2013).

Morphometric analysis is an important method for evaluating and understanding the behavior of a hydrological system and provides a quantitative description of drainage systems, which is one of the important aspects of the basin characteristics (Strahler, 1964). According to Clark (1966), geomorphometry is the measurement and mathematical analysis of the configuration of the earth's surface, the shape, and dimensions of the shape of the earth. Height, volume, slope, characteristics, and texture of the earth and other aspects of the drainage basin of the region are the main features that can be analyzed. In order to interpret morphometric parameters, conventional geomorphometric studies have been performed to investigate the relationship between the morphometric properties of drainage networks, climates, relief, lithology, structure, and geology (Kouli et al., 2007). The area of a basin is the most characteristic feature of the basin. Flood discharges and volcanic runoff volumes depend directly on the area of the basin, and the measure of this factor is used to estimate the runoff volume or the maximum instantaneous flood discharge. It is worth noting that the area of a basin is a cumulative form of all branches from branch one to higher branches and the highest order (total area of the basin), including the area of all streams from the lowest to the highest level (Singh and Singh, 1997). Channel ordering is the study and measurement of a flow with the hierarchy of drainage streams of a river (Miller, 1953). Many geomorphologists have presented several designs in this regard: Horton (1945, 1932), Strahler (1954, 1957, and 1964), Shreve (1966, 1967). Stream length is an important morphometric parameter to determine the drainage density and roughness. The stream length is referred to as the length of the main drainage network from the point of departure to the furthest peak of the water dividing line (Brown et al., 1996). Horton (1932) defines the split ratio as the relationship between the number of stream components in a given order and the components ordered (Ramirez, 2000). Drainage density is the number of divisions of the total length of all streams of a basin over the area of the basin, which is usually in kilometer per square kilometer. The drainage density is a criterion that only specifies the distribution of the rivers across a basin (Bobade et al., 2010).

Few methods and models are available to find the shape of a basin as one of the most important geometric features of the basins. These quantitative models are, in fact, the most important means of expressing, describing and comparing drainage basin patterns. The shape of a basin, also, affects the function and functioning of the basin units and their emergence and development. Particularly where the roundabout indicators of the basins are low, moderate or high, they can indicate the stages of youth, puberty and aging, the evolution of the drainage basin. The key to interpreting the shape factors are:

- ✓ Rf: The form factor in different basins is different from zero (very long shape) to one (circular). This means that as the length of a basin (the elongation of a basin's shape) increases, Rf decreases. This is confirmed in the Tuyserkan basin so that the shape of the basin is more intense than the circle.
- ✓ Bs: The Bs has an inverse relationship with the shape factor of the basin (Horton, 1945).
- ✓ Re: These values can be divided into three categories: circular (> 0.9), elliptic (0.8-0.9), slightly elongated (<0.7) (Strahler, 1964). The value of Re in the Tuyserkan basin is 0.57, which represents a topographic shape of elongation.
- ✓ Cc: If the shape of a basin is circular, the Cc will be equal to one; otherwise, the value of this factor will be greater than one, indicating the deviation of the shape of the basin from a circle. In the studied area, the value of this index clearly shows the distancing of the shape of the basin from circle.
- ✓ Cc: The values close to Miller roundness will also result in a more rounded form of the basin. In the Tuyserkan basin, this index shows that the shape of the basin is elongated.

The hypsometric curve shows an area's characteristic at different altitude levels from above up to a level surface. This curve contains information about the area-height ratio. While a spatial property is non-dimensional (i.e. cumulative percent), it is considered absolutely in height. In this case, the value of the area is in proportion to the total sum of the area (a/A), and in contrast, the height of the corresponding curves is written as a proportion of the total height (h/H) represented by the percentage. Therefore, the percentage of the hypsometric curve is used to better represent the erosion and the erosion level at a certain level of the prediction of the dynamics of the nature of the basins and territories at the stage of their development (Taherkhani, 2009: 121). Basin relief (Bh), or "total relief" of a basin, is defined as the difference in elevation between the highest and lowest points on the basin (Schumm, 1956). Generally, basin relief measures are indicative of the potential energy of a drainage system present by the virtue of elevation above a given datum (Strahler, 1964).

An analysis of morphometric characteristics is used to assess groundwater potential and hydrologic behavior of watersheds (Angillieri, 2008). The quantitative analysis of hydrological units and drainage networks was initiated by the Horton rules and subsequently modified and developed by a number of geomorphologists including Strahler (1952), Leopold and Miller (1956), Omon (1956), Melton (1957), Morisawa (1957), Strahler (1957 and 1958), Scheidegger (1965), Shreve (1967), and Gregory and Walling (1976). Many studies have also been conducted in

different parts of the world using the same rules (Jenson and Domingue, 1988; Helsel and Hirsch, 1992; Beven and Moore, 1993; Gurnell and Montgomery, 2000; Dinesh, 2008; Pareta and Pareta, 2011; Ali and Khan; 2013; Karuppannan et al., 2015; Farhan et al., 2015; Chandniha and Kansal, 2017).

In this study, various morphometric parameters were evaluated using ArcGIS10.2 software for Tuyserkan basin. Linear, shape and topographic dimensions were used to interpret different geomorphometric parameters for the basin.

2. Study area location

The Tuyserkan Basin (longitudes of 48°18'-48°37' E., latitudes of 34°27'-34°42' N.) is located on the southwest slopes of Alvand Batholith in the province of Hamedan (Fig. 1). The area of the basin is about 364 km^2. The highest peak elevation is 3530 meters and the lowest elevation is 1650 meters. The average height of the study area is 2590 meters. Over 70% of the area is at an altitude of between 2000-3000 meters. A large part of the basin has the altitude of 2050-2150 m (Fig. 2).

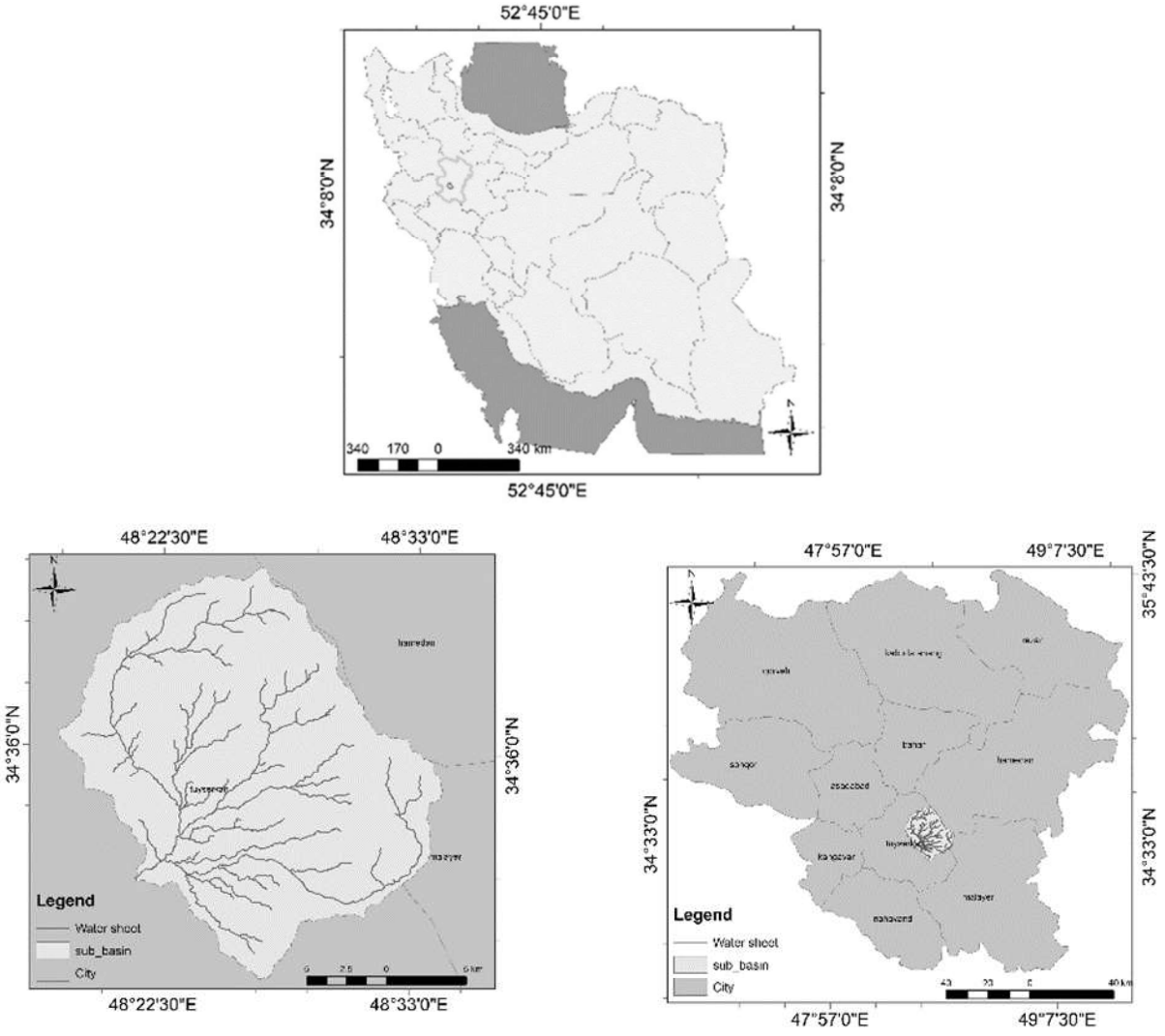


Fig. 1. Location of the case study

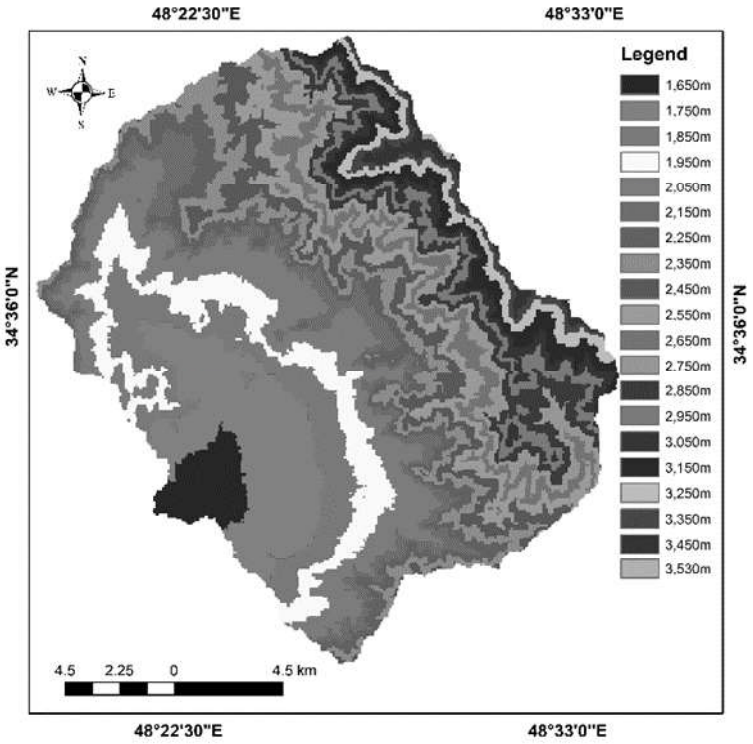


Fig. 2. Digital elevation model of Toyserkan basin

3. Methods

3.1. Geology of the study site

The Alvand Batholith is one of the northwestern mountainous regions of Iran and it is a part of the Zagros Mountains, which is associated with the advent of the Zagros orogeny movement. Geologically, one of the most intense orogenous movements that had not been known in Iran until then has occurred at the end of the Jurassic period (the middle period of the second geological). As a result of intense pressure from the granite classes, rocks between Hamadan and Isfahan were metamorphosed. The Alvand is a batholith. The batholith has transformed the crust of their surrounding rocks, which is called the metamorphic halo, and this transformation of rocks is located around the Alvand Batholith at a radius of 7 kilometers. The layers that lay on the Alvand Batholith have gone out by erosion and the batholith has come out as granite stones. The earliest rocks surrounded by the intrusive mass of the Alvand have been attributed to the Precambrian period, but the age of the granites is determined by radiometric measurements by 64 million years (early Paleocene) (Fig. 3). In terms of lithology, the Alvand mountainous rocks are intrusive granite, shale, slate, and Jurassic schists. Most of them are parallel to the Zagros stroke and the tectonic processes of the central region of Iran influence them, and they have different types of granite including mica granite, granite, and zirconium. Due to the abundance of biota and plagioclase, a relatively small quartz and coarse grain and non-homogeneity, granite rocks are associated with abundance and frosty water, which are severely degraded physically and chemically. The result is the formation and accumulation of abundant rocks in the area. Due to Shiest rock properties, the states of the layers and the penetration of water into them and the melting and freezing of water inside them, the Shiest is severely degraded. Existing faults, especially the fault between the Hornfels and Schist organization, have a significant effect on the flow of water, and this process has led to an increase in the destruction of Hornfels in the area. Therefore, with regard to the mentioned characteristics, the extruded stones of the region can be divided into three categories: resistant, semi-resistant, and non-resistant (Ildermi, 2012).

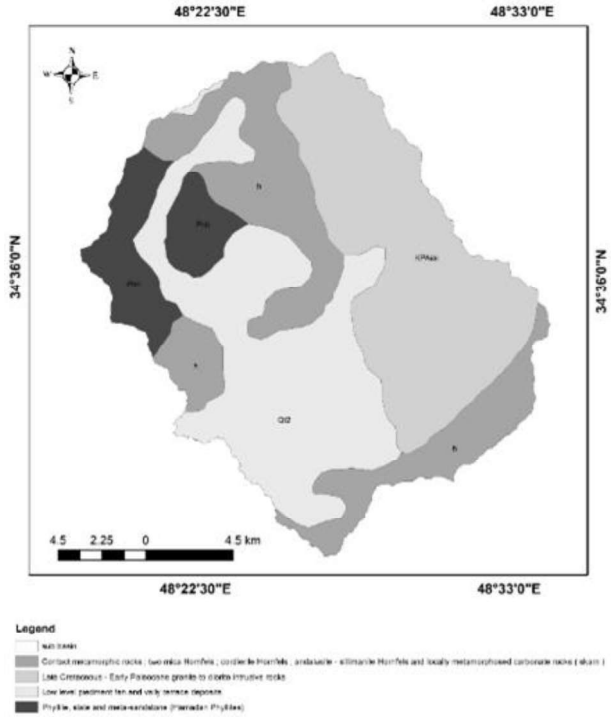


Fig. 3. Geological Map of Study Area

3.2. Methodology and Data Source

We first reviewed scientific literature and findings on the relevant subject matters in other parts of the world through a library and Internet work. In the next step, the study site (Tuyserkan basin) was described with the help of the ASTER digital imagery models with a resolution of 30 meters and ArcGIS software. Arc GIS technique is a powerful tool to analyze spatial information, especially for identifying features and extracting information. The geology of the study site was studied by geological maps of Hamedan province with a scale of 1: 100000. The geomorphometric parameters (base, line, shape, and topography) were estimated for the Tuyserkan basin (22 parameters). To evaluate these indices, we used the mathematical equations defined by Horton (1945), Strahler (1957), Schumm (1956), Miller (1953), and Ratnam et al. (2005) (Fig. 4; Table 1).

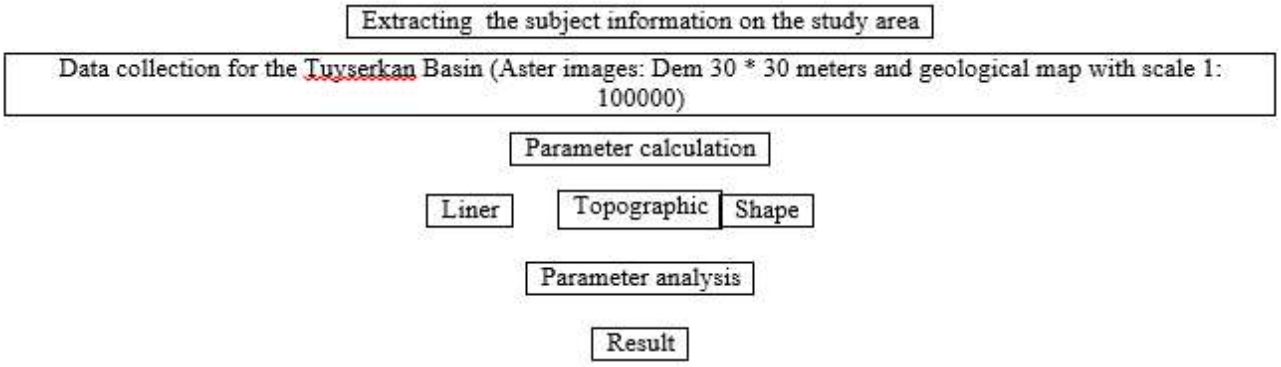


Fig. 4. The methodology of the study

Table1. Formulae adopted for computation of morphometric parameters

Morphometric Parameters		*Formula*	Reference
Basic parameters	*Area (A)*	*Plan area of the watershed (km2) GIS software analysis*	Horton (1945)
	Basin perimeter (P)	*Perimeter of the watershed (km) GIS software analysis*	Horton (1945)
	Stream order	*Hierarchical order*	Strahler (1964)
	Basin length (Lb)	*Length of the stream (km) GIS software analysis*	Ratnam et al. (2005)
	Stream Length (Lu)	*Length of the stream*	Horton (1945)
	Mean stream length (Lsm)	*Lsm = Lu/Nu (km) where, Lsm = mean stream length Lu = total stream length of all orders Nu = total no. of stream segments of order "u" GIS software analysis*	Horton (1945)
Linear	*Bifurcation ratio (Rb)*	*Rb = Nu/Nu + 1, where, Nu + 1 = no. of segments of the next higher order*	Schumm (1956)
	Drainage density (Dd)	*Dd = Lu/A, where, Lu = total stream length of all orders (km) A = area of the watershed (km2)*	Horton (1945)
	Stream frequency(Fu)	$F_u = {}^{N_u}/_{A}$ *Nu = Total no. of stream segments in order 'u'* *A = Area of the basin (Km2)*	Horton (1945)
	Texture Ration(T)	T = *Nu* / P *Nu = Total no. of stream segments of order 'u* *P = Square of the perimeter (Km)*	Horton (1945)
	Length of Overland Flow (Lo)	$L_o = {}^{1}/_{2Dd}$ Dd *= Drainage Density*	Horton (1945)
	Infiltration number (If)	$If = F_u \times D_d$ F_u = Stream frequency Dd *= Drainage Density*	Horton (1945)
	Constant of channel maintenance (C)	$C = \frac{A}{\sum_{i=n}^{i=1} L_u}$ *A = Area of the basin (Km2)* *Lu = Total stream length of all orders*	Horton (1945)
Aerial	Form Factor (Rf)	*Rf=A/Lb2* *Where, Rf = Form Factor* *A = Area of the basin (Km2)* *Lb2 = Square of basin length*	Ratnam et al. (2005)
	Circulatory Ratio (Rc)	*Rc=4*Pi*A/P2 Where, Rc = Circulatory Ratio* *Pi = 'Pi' valu,e i.e., 3.14* *A = Area of the basin (Km2)* *P2 = Square of the perimeter (Km)*	Horton (1945)
	Elongation Ratio (Re)	*Re=2"(A/Pi) / Lb* *Where, Re = Elongation ratio* *A = Area of the basin (Km2)* *Pi = 'Pi' valu,e i.e., 3.14* *Lb = Basin length*	Miller (1953)
	Compactness efficient (Cc)	*Cc = 0.2841 × P /√A* *Cc= Compactness efficient* *A = Area of the basin (Km2)* *P = Square of the perimeter (Km)*	Horton (1945)
Relief	Ruggedness number(Rn)	$R_n = D_d \times \left({}^{B_h}/_{1000}\right)$	Horton (1945)

	Dd = *Drainage Density*	
	B_h = Basin relief	
Basin relief (Bh)	$B_h = h - h_1$	Horton (1945)
	h = *Maximum height*	
	h_1 = *Minimum height*	
Relief ratio (Rh)	$Rh = {B_h}/{L_b}$	Schumm (1956)
	B_h= Basin relief L_b =Basin length	

4. Results and Discussion

The morphometric parameters are divided into bases, lines, shapes, and topographies:

Base Parameters: Spatial properties of drainage network are an important morphometric factor for the analysis of drainage networks by which one can study the basin area, environment, shape, area rules, and hydrographic network (Table 2).

Area: According to Table 2, the area of the Tuyserkan basin is 364.28 km^2.

Table 2. The morphometric parameters of the Toyserkan basin.

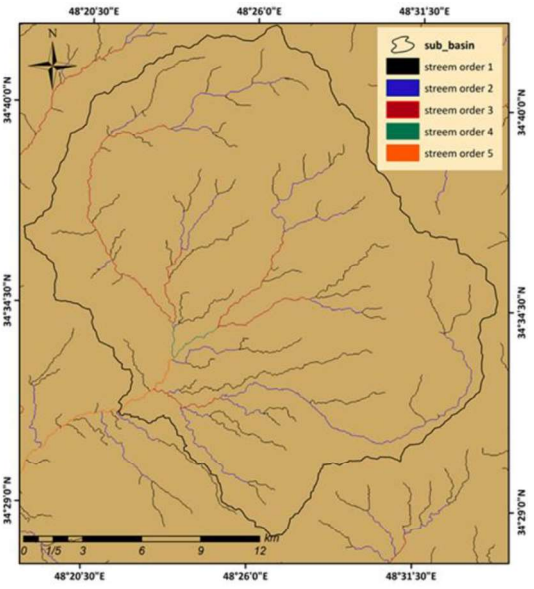
Basic parameters					
A(km^2)	P(km)	Nu	Lb	Lu	Ls
364.82	324.23	125	37.68	37.5	1.57

Perimeter: The length of the water distribution line is said to separate the basin from adjacent basins (Schumm, 1956). The perimeter of the Tuyserkan basin is 324.23 km.

Table 3. The morphometric liner parameters of the Toyserkan basin.

Liner parameters	
D_d	0.1
F_u	0.06
T	0.07
L_o	0.18
If	13.5
C	9.72

Stream order: In the present study, the Strahler orderings were used according to which the Tuyserkan basin is the fifth order of the last order of the drainage network at the basin outlet (Fig. 5). After channel ordering, the frequency of each order was determined (Fig. 6).



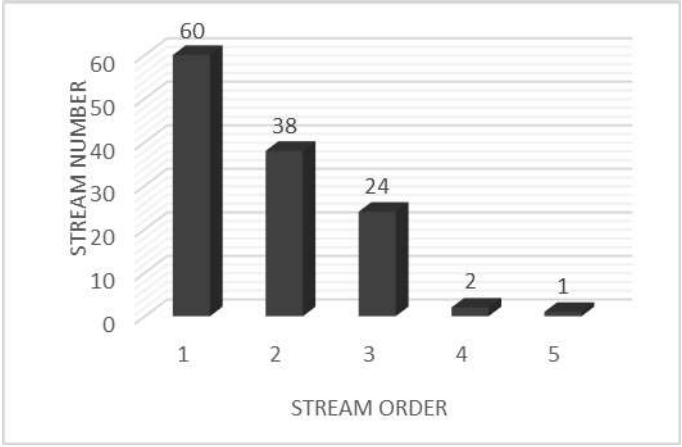


Fig 6: Stream number and stream order

There is a reverse relationship between the stream number and frequency so that from stream number 1 in the last order in the basin outlet, the abundance of the drainage network decreases, and in the output (the fifth order), frequency is ordered one (Fig. 7).

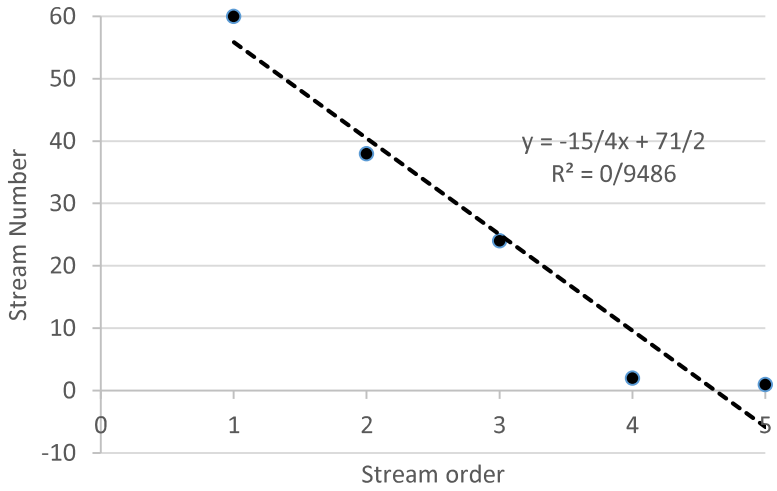


Fig 7. Plots of stream order and stream number

Stream length: The mainstream length of the Tuyserkan basin is 37.5 km. The length of the drainage network of each category was classified as a drainage stream (order 1 to 5) (Fig. 8). The total stream length of the different rating streams with a higher rating tends to decrease. There is a negative relationship between increasing the stream length and order (Fig. 9).

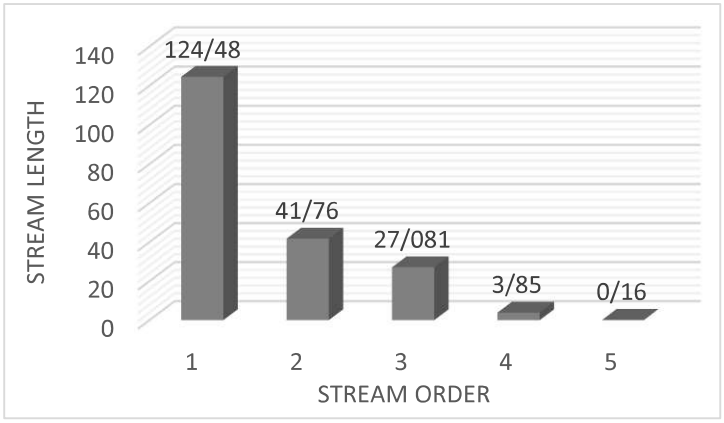


Fig. 8. Stream length and stream order

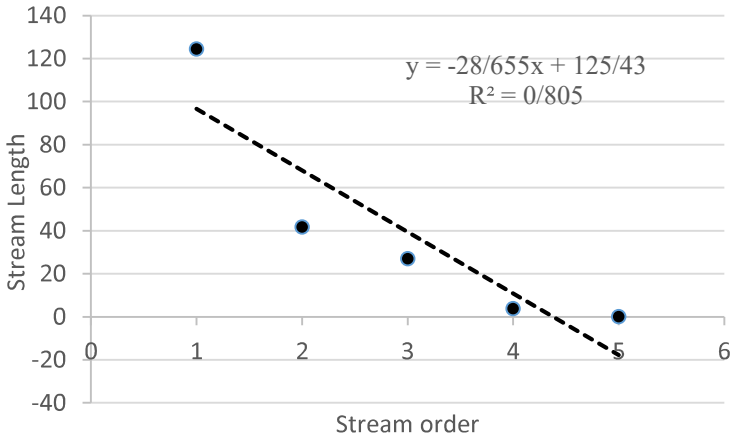


Fig. 9. Plots of stream length ratio and U/U-1

Linear parameters: The study of the linear properties of drainage networks depends mainly on the composition and scale of the drainage channel system.

Bifurcation ratio: The bifurcation ratio is a dimensionless hierarchical property of the drainage basin. In general, the bifurcation ratio is controlled by environmental factors and elevation factors. The bifurcation ratio of the Tuyserkan basin was calculated by Horton's rules; accordingly, this ratio was estimated at, on average, 4.24 (Table 4).

Table 4. Bifurcation ratio of the Nethravathi River basin

Stream order	Nu	LO	Bifurcation ratio	Mean Bifurcation ratio	Length of the stream (km)	Total stream length of all orders
1	60	124.48	1.57			
2	38	41.76	1.58			
3	24	27.081	12	4.29	37.5	197.331
4	2	3.85	2			
5	1	0.16	-			
Total	125	197.331				

Drainage density: Drainage density is a valuable indicator for recognizing the processes in the basin and demonstrating the impact of several environmental factors such as climate, topography, lithology, pedology, vegetation, and humans on the drainage process. Different methods have been presented for calculating this index. We used the method of Horton (1945).

Texture Ration: Drainage tissue is a basic geomorphic concept and an important variable in the drainage network

analysis, which explains the nature of the relative distance of the drainage line. The drainage tissue rate is indicative of the severity of the creepy and the hierarchy of the basin drainage network. Horton (1945), Smith (1939), and Prasad (2007) have described this concept.

The frequency of drainage: The frequency of drainage, or the frequency of flow, refers to the total number of drainage lines in a drainage basin or a morphological unit in a region. This has been discussed by Horton (1945) and Strahler (1957). Reddy (2004) state that low values of this index indicate permeable subsoil material and low relief. Fs total pool is 0.06.

Length of Overland Flow (**Lo**): Lo indicates the length of the water flow in the ground and is approximately equal to half of the drainage density symmetry (Horton, 1945). Lo is inversely related to the average channel slope (Patel et al., 2012) and is one of the most important independent parameters that affect hydrological and hydrographic development in the basin (Horton, 1945). Lo for the Tuyserkan basin is 0.18.

Infiltration number: Infiltration number is the product of the drainage density and the stream frequency of the basin. The infiltration number of the Tuyserkan basin is 13.5 (Table 3) indicating low infiltration and high runoff.

Constant of channel maintenance: Schumm (1956) have used reverse drainage density as an equation as the constant of channel maintenance (C). The value of C in the Tuyserkan basin is 72.9.

4.1. Shape parameters

Different methods have been proposed to measure shape indicators, but form factor (Rf), shape factor (Bs), elongation ratio (Re), compactness coefficient (Cc), circularity ratio (Rc), and ruggedness number were used in the present study (Table 5).

Table 5. Morphometric aerial parameters of the Toyserkan basin

Aerial parameters				
R_f	B_s	R_e	Cc	R_c
0.25	3.89	0.57	5.08	0.043

In general, by looking at the shape indicators and interpreting them with the given guidance, it is clear that the Tuyserkan basin is in the final stage of the young age (the breadth of the basin) and the beginning of the puberty period. Of course, it should be noted that all of the above parameters depend on variables such as rippling, gradient, geological structure, petrographic characteristics, and so on.

4.2. Topographic Parameters

In general, the basis of geomorphologic analysis of various complications depends on altitude differences, slopes, dimensions, magnitudes, and other features that exist within geomorphologic units in the catchment area. At the same time, these analyses and interpretations are closely related to the three-dimensional aspects of rippling components. In the present study, the hypersonic curves index, rippling ratio, and rippling ratio were used for the analysis of the characteristics of ripples (Table 6).

Table 6. Morphometric relief parameters of the Toyserkan basin

Minimum elevation (m)	Maximum elevation (m)	B_h	Rh	R_n
1650	3530	1880	49.89	1.015

Hypsometric (hypsographic) curve

Strahler (1952) and King (1966) have used a methodology for assessing the morphological stage of basin development (Prasad, 2007) (Table 7). It can be inferred from the hypsometric curve that the Tuyserkan basin has an S-like shape; in other words, the shape of the basin is concave at the source, and it has a convex shape at the outlet of the basin. The studied basin is at the end of the young and early stages of puberty (Fig. 10).

Table 7. Morphological stages of basin development by the Australian and King methods

3	2	1	
30> Curve percentage	30< Curve percentage <60	Curve percentage >60	Curve percentage
Aging stage	Maturity stage	Young stage	Erosion stage

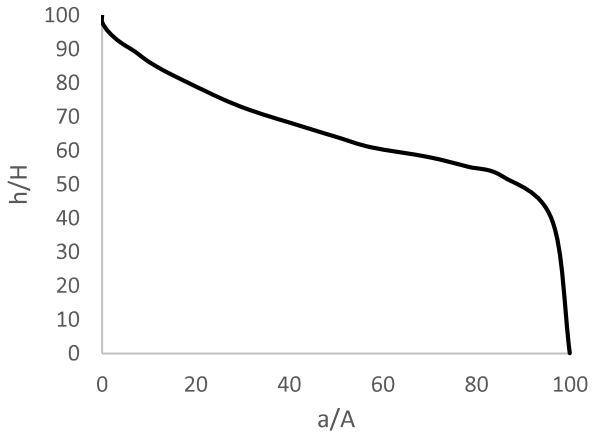


Figure 10. Hypsometric curve illustrates the youth and maturity stage of development of the Toyserkan basin

Rippling number: Basin relief is an essential factor in understanding the denotational characteristics of a watershed, landforms and drainage network development, overland flow, and through-flow and erosion properties of a terrain. The difference between the highest and lowest altitude of the basin is estimated at 1880 m. According to the classification shown in Table 8, the Tuyserkan basin is located in the upper rippling group.

Table 8. Rigidity classification

300< Altitude differences	100-300	100> Altitude differences	Altitude differences
High	Moderate	Low	The amount of difference

Roughness ratio: Rr is a variable obtained from the ratio between the height and length of the basin. This ratio expresses the gradient attribute of the longitudinal profile of the drainage basins, which mainly controls the severity and extent of the cuts and incisions caused by the degradation processes. This ratio is dependent on the gradient of the longitudinal path of the channels. It also affects the amount of discharge, the intensity of the flow of water, and the capacity of the river channel transmission. In accordance with the formula given by Schumm (1956), this ratio was 49.89 in the Tuyserkan basin. In general, the shorter the length of the valley, the higher the ratio and the higher the maximum roughness of the basin in the cutoff valleys, which gradually decreases based on the length of the valley and the reduction of the roughness of the basin. This ratio has a complete relationship with drainage density, the shape of the domain, and the circular index.

5. Conclusions

Remote sensing and GIS techniques are convenient tools for morphometric analysis. Geological field verification also supports the present morphological-based prioritization. Landscape morphology is a function of drainage, climate, and structure of a particular basin region. The present paper present the morphometric analysis based on several drainage parameters by which the basin was classified among the fifth order basins. By reviewing the topographic parameters of the basin, the late adolescence and admission into the maturity period are confirmed in the study of the basin. The formulas used to evaluate the morphometric parameter are tabulated in Table 1. The results of this analysis are tabulated in Tables 2-5. The results of the analysis of features of the Tuyserkan basin indicate that the watersheds have a moderate roughness. The dendritic drainage network shows the homogeneity of the texture. This type of basin structure helps to explain various parameters of the earth, such as the nature of the earth, penetration capacity, runoff production, and soil erosion. The results of the drainage density and the flow rate of the average permeability are shown. The evaluation of the parameters shows that measures should be taken for the control of surface water and soil conservation in order to manage water resources. The information obtained from the present study helps to understand the status of landform and its processes, drainage management, and groundwater potential for basin planning and management. This study will be useful for planners and decision makers in groundwater development programs to manage micro-level water resources. The results of this study, along with other hydrological information, land cover, terrain, geology, surface and soil in the GIS domain, will help develop a sound groundwater management plan and make decisions about suitable locations for soil and water conservation structures (runway, check dam and penetration pond, charging shaft, etc.

6. References

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