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Morphometric Analysis of East Seti Watershed in Gandaki Province, Nepal using GIS

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Abstract

Being drained by numerous rivers, Gandaki province has the good potentiality of water resource based development. Analysis of watersheds needs to be performed for proper identification, planning and management of water. In this study, GIS was used as an integrated approach for watershed analysis addressing the smallest of external and internal drivers for changing parameters of a major tributary of Gandaki Basin system, i.e. East Seti Watershed. The watershed delineation was conducted from the available two 90 m DEM datasets after making necessary fill sink and working out the flow direction that created a flow accumulation raster. Point based delineation was conducted for the selected pour point near Ghumaune located ahead the confluence of the Seti River and the Trishuli River. Watershed area and watershed length for East Seti watershed found to be 2951.92 km^2 and 146.79 km respectively. The morphometric parameters were calculated using the ARC HYDRO tools which included linear and areal watershed parameters. Four different stream orders were identified for this watershed giving the total flow length of 454.45 km. On comparison with Marshyangdi watershed, the more or less comparable values of circularity ratio, elongation ratio and form factor indicated the elongated nature of watersheds, steep landforms and strong relief in spite of differing in watershed size, orientations and flow lengths. The sub-watersheds; Seti and Madi delineated has the drainage area of 1,472.45 km^2 and 1,123.79 km^2 respectively. Additionally, temporal comparison of morphometric parameters of Seti watershed at two different time frames was conducted to address the changes in course of time. The results can be reference for proposing watershed based infrastructures and for local level policy making related to Energy, Water Resources, Irrigation, and Infrastructures.

Keywords

Hydrologic analysis, Watershed parameters, Morphometric parameters, Madi watershed

1. Introduction

Morphometry is the science of quantitative land surface analysis. It gathers various mathematical, statistical and image processing techniques that can be used to quantify morphological, hydrological, ecological and other aspects of a land surface. Morphometric analysis using GIS techniques has arisen as an influential tool in current years [1]. It offers integration of spatial and non-spatial data to understand and analyze the watershed processes and helps in drawing a plan for integrated watershed development and management [2]. GIS Tools are integrally used for parameterization of East Seti watershed in this study.

The study area is the East Seti Watershed drained by the Seti Gandaki River, also known as the Seti River or the Seti Khola. It is the left tributary to Trishuli river of the Gandaki Basin system that drains the capital city of the Gandaki province, Pokhara. Figure 1 (a), (b), and (c) shows the study location.

The river has its origin near the base of the Mount Machhapuchhre (6,997 m) and the Mount Annapurna IV (7,525 m) at 28°27’40” N and 84°0’0” E approx. and is fed by the glaciers [3]. Then, it flows south and south-east past Pokhara and Damauli to join the Trishuli River at 27°49’15” N and 84°27’15” E approx. near Devghat. The Mardi and the Vijaypur are the major tributaries. Besides that, Bhurjung Khola, Fusre Khola, Bagadi Khola, Bange Khola, Oltang Khola, and Madi River are other tributaries of the Seti River. The quantification of the various components of watershed parameters remains a challenging topic as the hydrological system is altered by internal and external drivers. Every year, heavy monsoon rainfall causes overflows through the banks of Seti river sweeping away the neighboring settlements and infrastructures. Knowing the morphometric parameters will help the province in probable hazard management and also infrastructures projects like bridge and hydropower [4].

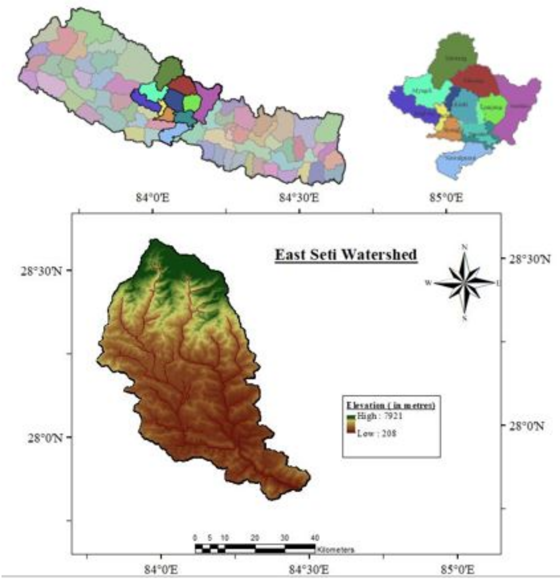


Figure 1: (a) Map of Nepal with all the districts (top left) (b) Gandaki Province and its constituent districts (top right) (c) Study Area map of East Seti watershed (bottom)

The main objective of this study was the morphometric analysis of the East Seti watershed and sub watersheds, using GIS software. In addition to that, the changes in watershed parameters were accessed by comparative analysis of data and parameters were also compared with neighboring Marshyangdi watershed. For the CGIAR-CSI SRTM data, no-data regions due to insufficient textural detail were especially found in mountainous regions (Himalayas). A hole-filling algorithm has been applied to provide continuous elevation surfaces. This is a limitation in accuracy of output computation.

2. Materials and Methods

2.1 Data Acquisition

A 90 m resolution dataset was considered sufficient for morphometric parameterization. Two different 90 m resolution Nepal Digital Elevation model DEM datasets were downloaded from the official website of Humanitarian Data Exchange (HDX) and CIGAR CIS of 2000 A.D. and 2012 A.D. respectively. It was then integrally utilized for generation of database and extraction of various drainage parameters. Those two different raster datasets used for the study are represented in Table 1.

Table 1: Information of Raster Datasets

Data	Source	Official Website	Date of Dataset	Method of Data extraction	Resolution
DEM	USGS	Nepal Digital Elevation Model DEM Humanitarian Data Exchange (HDX)	1 Feb 2000	Direct Observational Data/ Anecdotal Data	90m
DEM	NASA	CIGAR CSI (Consortium for Spatial Information)	8 Nov 2012	Shuttle Radar Topography Mission (SRTM)	90m

One of the major limitations of this study was that the datasets accessible as latest were of 2012 A.D. Therefore, the authors would like to recommend future researchers for using recent data if possible.

2.2 Program Setup and Watershed Delineation

After the data collection of required layers, the spatial datasets were processed and analyzed using ArcMap Desktop 10.5 Software. Delineating the watershed for preprocessing required consistent coordinate system for all the datasets. Hence, all datasets were assigned a projection coordinate system of WGS 1984 UTM zone 44N and further analysis was preceded.

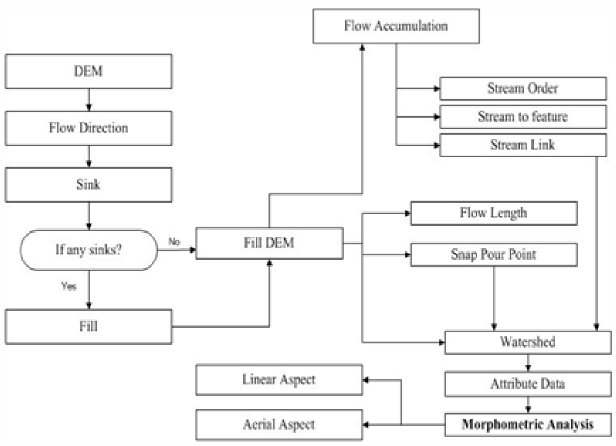


Figure 2: Steps involved in Morphometric Analysis of a Watershed

A watershed is an upslope area that contributes water flow as concentrated drainage. This area can be delineated from a digital elevation model (DEM) using the Hydrology toolset from the Spatial Analyst toolbox. Figure 2 gives a flowchart for Morphometric parameterization of an y watershed.

2.3 Morphometric Parameters Calculation

Morphometric parameters were calculated using the outputs of Arc-GIS on the formulas mentioned in Table 2.

Table 2: Formulas for Calculation of Parameters of watershed

SN	Parameters	Units	Notation	Formula	Ref.
			Drainage Network		
1	Flow Length	Km	L_u	Length of the stream	Strahler (1964)
2	Stream Length Ratio		L_{ur}	$L_{ur} = \frac{L_u}{L_u - 1}$	Strahler (1964)
3	Bifurcation Ratio		R_b	$R_b = \frac{N_u}{N_u + 1}$	Strahler (1964)
			Basin Geometry		
1	Drainage Area	Sq.km	A	GIS Software Analysis	Schumm (1956)
2	Perimeter	Km	P	GIS Software Analysis	Schumm (1956)
3	Watershed Length	Km	L	GIS Software Analysis	Schumm (1956)
4	Circularity Ratio		Rc	$Rc = \frac{4\pi A}{P^2}$	Strahler (1964)
5	Elongation Ratio		Re	$Re = \frac{2\sqrt{A/\pi}}{L}$	Schumm (1956)
6	Form Factor		Ff	$Ff = \frac{A}{L^2}$	Horton (1945)
			Drainage Texture		
1	Drainage Density		D_d	$D_d = \frac{L_u}{A}$	Horton (1932)
			Relief Characteristics		
1	Elevation				
	High	m	E_2		
	Low	m	E_1		
2	Watershed Slope		S	$S = \frac{E_2 - E_1}{L}$	Schumm (1956)

3. Results and Discussion

3.1 Gandaki River Basin

Extending from 30°26'33" N and 81°37'00" E to 27°52'38" N and 88°17'53" E approx. Nepal lies on the lap of Himalayas. The Gandaki Province, i.e., 4th provincial state of Nepal lies quite at central Nepal drained by the Gandaki river basin system as shown in the Figure 3 and Figure 4. Of 1,47,181 km^2 of the total area of Nepal, the Gandaki river basin system comprises the area 31,796.4 km^2 within the national boundary of Nepal. The Gandaki province is drained by the tributaries of the river Gandaki (Kali Gandaki, Budhi Gandaki, Seti Gandaki, Marshyangdi, Madi, Daraundi, and Seti). The pour point for the East Seti watershed was selected upstream of the confluence of Seti and Trishuli river at 27°49'16" N and 84°27'20" E and elevation of 229 masl. approximately.

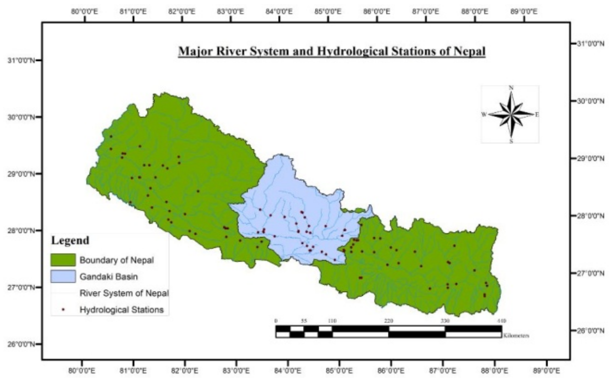


Figure 3: River Systems of Nepal with Gandaki Basin

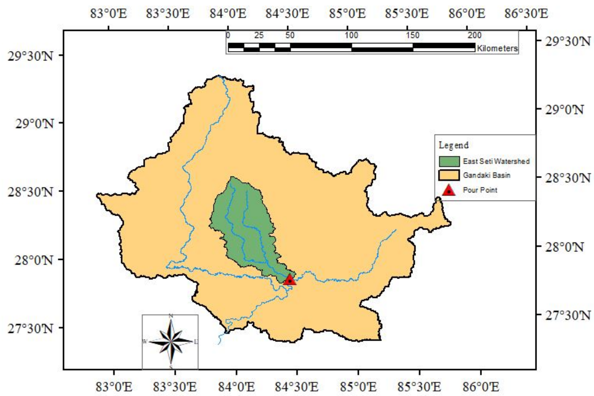
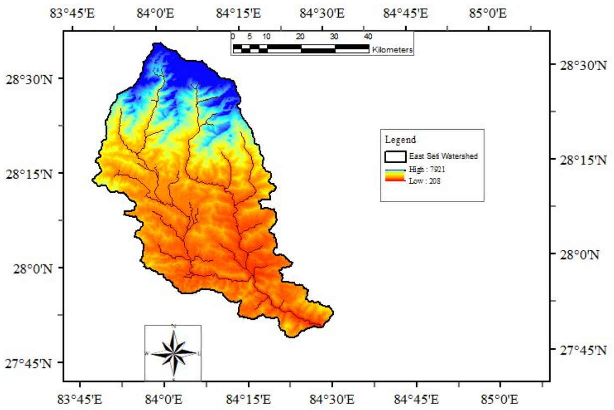


Figure 4: Gandaki Basin with East Seti watershed

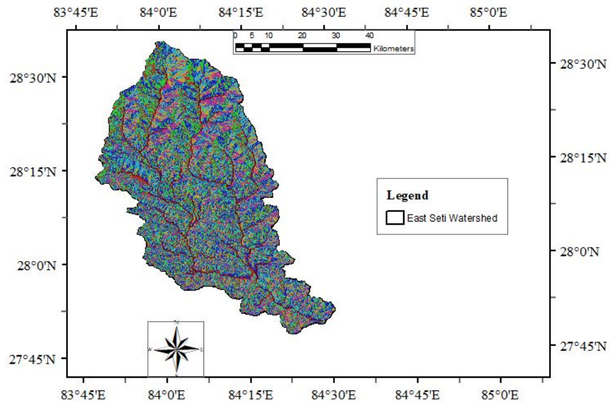
3.2 Watershed Analysis of East Seti Watershed

Figure 5 (a) shows the DEM raster data for East Seti Watershed which was processed for obtaining the Flow direction raster data in Figure 5 (b) and Flow accumulation data in Figure 5 (c).

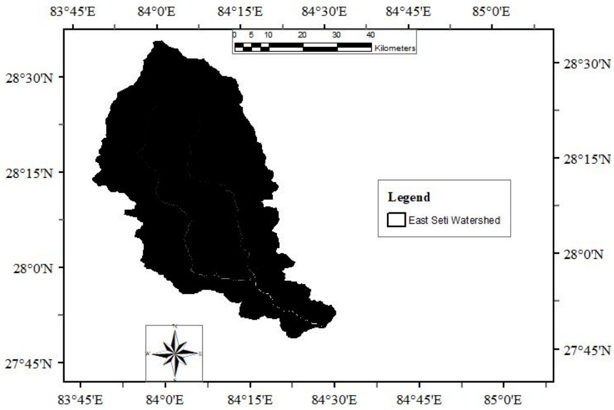
After running the watershed delineation program, the watershed area of the East Seti watershed was determined to be 2951.92 km^2. Further, point based watershed delineation gave two different sub watersheds for this watershed drained respectively by; Seti and Madi Khola. Figure 6 shows the drainage area of each subsequent sub watersheds. The pour points for each sub watersheds were taken approximately ahead of confluence of Seti and Madi river at Damauli as mentioned in Table 3.



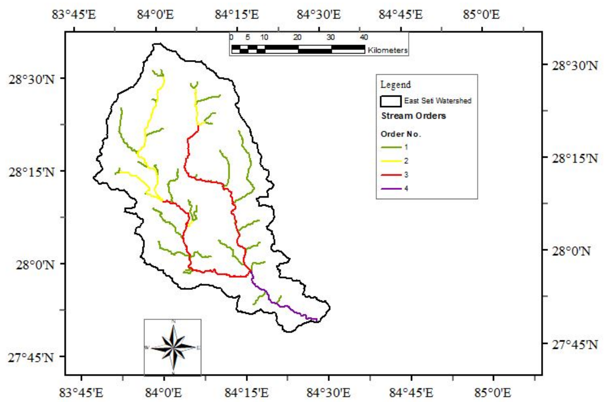
(a) DEM raster data



(b) Flow Direction raster data



(c) Flow accumulation raster data



(d) Stream Orders raster data

Figure 5

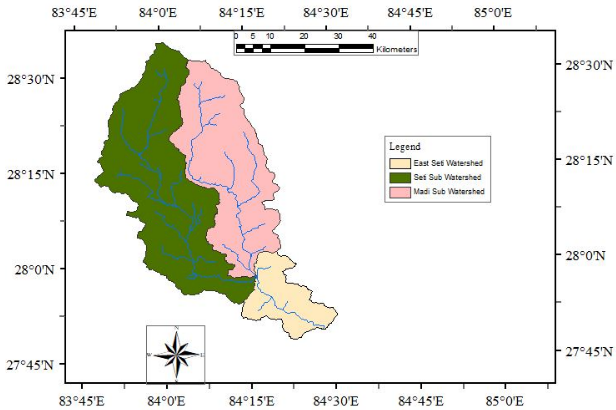


Figure 6: Sub watersheds of East Seti watershed

Table 3: Pour Point Details for Sub watershed Delineation

River	Longitude	Latitude	Elevation	Remarks
Seti	27°57'56" N	84°15'53" E	312 masl	Point
Madi	27°58'19" N	84°15'37" E	310 masl	Point

3.3 Comparison with Previous Studies and Validation

The drainage area is the total area of watershed boundary to a given outlet. It is often necessary to determine watershed area for the calculation of discharge using different approaches (see [5]). Using Arc GIS tools considering pour point upstream of confluence of Seti and Trishuli river, the watershed area was calculated as 2951.92km^2 in this Study. [6] calculated the Seti watershed drainage area to be 2954.02 km^2 using QGIS as shown in Figure 7 (a). Figure 7 (b) shows the East Seti watershed delineated in this project work.

(a) **(b)**

Figure 7:
(a) East Seti Basin (Source: [6])
(b) East Seti Watershed (This Study)

Here, the shape of East Seti watershed is quite similar in both the figures. Since the pour point taken here is upstream of the confluence not at exact confluence, and different soft wares are used for analysis, small variation in watershed area is observed. Both areas are nearly equal, hence the calculation was proceeded using Arc GIS software.

3.4 Calculation of parameters

3.4.1 East Seti Watershed

According to the formulas mentioned in Table 2, Stream order functions gave 4 different order of streams in the East Seti watershed which was extracted as Figure 5 (d) and represented in Table 4. The stream dissolution and stream order function gave the no. of stream segments and respective stream length. Other parameters; Mean stream length, Stream Length ratio and Bifurcation ratio were calculated using the data obtained and formulas given by Strahler, Schumm and Hortan. Stream ordering gives the hierarchal ranking of stream network. As represented in Table 4, Strahler's method of stream ordering was followed with 4499 identified segments out of which 49.79% is first order, 18.25% is Second Order, 25.36% is third order and 6.60% is the fourth order segments. The order number of stream is directly proportional to the watershed dimension. Bifurcation Ratio gives the number of stream of an order to the number of stream of next order expressing the form of drainage basin. The smaller value of the low order segments shows the uniformity and stability in watershed, whereas larger value of higher order segments shows structural complexity and elongated shape.

Table 4: Linear Morphometric Parameters of East Seti Watershed

Stream order	No of stream segments (Nu)	%	Stream Length (km)	Mean Stream length	Stream Length ratio	Bifur-cation ratio
1	2240	49.79	226.73	0.10		2.73
2	821	18.25	82.87	0.10	0.37	0.72
3	1141	25.36	114.66	0.10	1.38	3.83
4	297	6.60	30.19	0.10	0.26	
Sum	**4499**	**100**	**454.45**			

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. Drainage density here attributed to sparse vegetation and relatively permeable sub-surface material. It is used as an important independent variable for formulating other morphometric parameters such as length of overland flow, ruggedness number and constant of channel maintenance. There is much influence of shape and outline of watershed on the stream-discharge characteristics. Long narrow basins with high bifurcation ratio would be expected to have long attenuated flood-discharge period, whereas rotund basins of low bifurcation ratio would be expected to have sharp peak flood discharges [7]. Areal Parameters of East Seti Watershed are presented in Table 8. Being an elongated basin, Seti has small form factor of 0.14 only. Similarly, circularity ratio (Rc) is defined as the ratio of basin area to the area of the circle having same perimeter as the basin. The lower Rc value of 0.38 indicated elongated shape of drainage basin. Elongation ratio (Re) is defined as ratio of the diameter of the circle of the same area as the basin to the maximum basin length. Re values between 0.6 and 1.0 have a wide variety of climate and geology. 0.42 Re value attributed to elongated shape, strong relief and steep ground slope of the Seti watershed.

3.4.2 Sub Watersheds

The drainage area of Seti and Madi Sub watersheds were calculated to be 1472.45 km^2 and 1123.79 km^2 respectively shown in Figure 6 and other parameters are represented in Table 5, Table 6 and Table 7. Stream order functions gave 3 different order of stream in both the Sub watersheds. The smaller value of bifurcation ratio of the low order segments showed the uniformity and stability in watershed, whereas larger value of higher order segments showed structural complexity and elongated shape.

Table 5: Linear Morphometric Parameters of Seti Sub Watershed

Stream order	No. of stream segments (Nu)	%	Stream Length (km)	Mean Stream length	Stream Length ratio	Bifur-cation ratio
1	1165	49.68	117.01	0.10		1.73
2	674	28.74	68.48	0.10	0.59	1.33
3	506	21.58	50.80	0.10	0.74	
Sum	**2345**	**100**	**236.29**			

Table 6: Linear Morphometric Parameters of Madi Sub Watershed

Stream order	No. of stream segments (Nu)	%	Stream Length (km)	Mean Stream length	Stream Length ratio	Bifur-cation ratio
1	917	53.81	93.12	0.10		6.20
2	147	8.63	14.38	0.10	0.15	0.23
3	640	37.56	63.93	0.10	4.44	
Sum	**1704**	**100**	**171.44**			

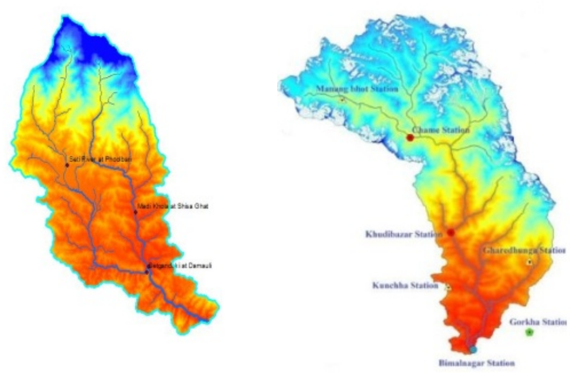
Table 7: Areal Morphometric Parameters of Seti and Madi Subwatershed

Parameters	Units	Notation	Sub Watershed	
			Seti	Madi
Drainage Area	Sq.km	A	1,472.45	1,123.79
Perimeter	Km	P	250.24	196.41
WS Length	Km	L	115.43	89.86
Flow Length	Km	L_u	236.29	171.44
Drainage Density		D_d	0.16	0.15
Elevation: High	m	E_2	7,512	7,921
Elevation: Low	m	E_1	306	304
Watershed Slope			0.06	0.08
Circularity Ratio		Rc	0.30	0.37
Elongation Ratio		Re	0.38	0.42

On comparative view point, Seti sub watershed contributes more drainage area to East Seti watershed than Madi sub watershed. Also, contributing perimeter, watershed length and flow length of Seti sub watershed are greater. But the contributing altitudes are greater for Madi sub watersheds giving steeper watershed slope too. Also, circularity ratio, elongation ratio and form factor are more for Madi than for Seti. It indicates Madi to be more circular than Seti as the values are nearer to 1.

3.5 Comparision with Marshyangdi Watershed

Figure 8 shows the respective contribution of East Seti and Marshyangdi sub basins in overall Gandaki basin system.



(a) (b)

Figure 8:
(a) East Seti Watershed
(b) Marshyangdi Watershed (Source: [6])

In Table 8, the parameters of Marshyangdi watershed is given [6].

Table 8: Areal Morphometric Parameters of East Seti and Marshyangdi Watershed

Parameters	Units	Notation	Watershed	
			East Seti	Marshyangdi
Drainage Area	Sq.km	A	2,951.16	4798.66
Perimeter	Km	P	310.60	443.60
WS Length	Km	L	146.79	166.78
Flow Length	Km	L_u	454.45	233.91
Drainage Density		D_d	0.15	0.05
Elevation: High	m	E_2	7,921.00	4333
Elevation: Low	m	E_1	208.00	261
Watershed Slope			0.05	0.02
Circularity Ratio		Rc	0.38	0.31
Elongation Ratio		Re	0.42	0.47
Form Factor		Ff	0.14	0.17

Here, these two differ quite in size and orientations but watershed slope, circularity ratio, and form factor are quantitatively similar. Besides being larger in watershed area, Marshyangdi River has shorter flow length and smaller Elevation difference. This makes Seti steeper watershed. The more or less comparable values of circularity ratio, elongation ratio and form factor of both the watershed indicates the elongated nature of watershed, steep landforms and strong relief.

3.6 Temporal Comparision

The main source of the datasets used in the project were NASA and USGS datasets downloaded directly from the official websites mentioned in Table 1. On analysis of calculated parameters of watershed and sub watersheds on two different time frames which is represented in Table 9. Not any significant changes on the parameters were identified. But, for the altitude contributing to drainage area, highest altitude for overall watershed and constituent sub watersheds, have increased considerably on the range of 6-17 m above sea level. To support the fact, flow length has also increased for both sub watersheds and overall watershed. This can be an indication of lengthening of flow length of waterways in future and increase in drainage contribution area for any watershed. About other basin structure defining parameters like circulatory ratio, elongation ratio and form factor, they were consistent throughout those years.

Table 9: Temporal Comparison of Areal Morphometric Parameters of East Seti Watershed and Sub watersheds

Parameters	Units	Notation	Watershed		Sub watersheds			
			East Seti		Seti		Madi	
			2000	2012	2000	2012	2000	2012
Drainage Area	Sq.km	A	2,951.57	2,951.92	1,472.58	1,472.45	1,123.44	1,123.79
Perimeter	Km	P	309.90	310.60	250.48	250.24	196.13	196.41
WS Length	Km	L	145.80	146.79	114.41	115.43	89.93	89.86
Flow Length	Km	L_u	447.78	454.45	233.11	236.29	168.14	171.44
Drainage Density		D_d	0.15	0.15	0.16	0.16	0.15	0.15
Elevation: High	m	E_2	7,915	7,921	7,495	7,512	7,915	7,921
Elevation: Low	m	E_1	208.00	208.00	308.00	306.00	304.00	304.00
Watershed Slope			0.05	0.05	0.06	0.06	0.08	0.08
Circularity Ratio		Rc	0.39	0.38	0.29	0.30	0.37	0.37
Elongation Ratio		Re	0.42	0.42	0.38	0.38	0.42	0.42
Form Factor		Ff	0.14	0.14	0.11	0.11	0.14	0.14

4. Conclusion

The analysis of East Seti Watershed was performed taking upstream of confluence of the Seti river and Trishuli river as the pour point site. The drainage area and watershed length of East Seti watershed found to be 2951.92 km^2 and 146.79 km respectively. Further the respective morphometric parameters of the watershed including two sub watersheds were calculated and compared in this study. Sub watershed analysis gave two sub watersheds; Seti and Madi with respective drainage areas of 1472.45 km^2 and 1123.79 km^2 respectively. The morphometric parameters were calculated using the ARC HYDRO tools which included linear and areal watershed parameters. Drainage density of 0.15 attributed to sparse vegetation and relatively permeable sub-surface material. And, 0.42 elongation ratio value attributed to elongated shape, strong relief and steep ground slope of the Seti watershed. Four different stream orders were identified for this watershed giving the watershed length of 146.79 km. The morphometric parameters thus obtained for East Seti watershed was compared with that for the Marshyangdi watershed. Marshyangdi River found out to be of shorter flow length and smaller elevation difference that suggests the Seti watershed to be more steeper. Finally, temporal comparison conducted for time frame of 2000 A.D. and 2012 A.D. indicated minor changes on drainage areas but significant changes on flow lengths and contributing highest altitudes. Watershed parameters can be used as a reference for infrastructure planning in the study location and it can also be used as future study reference. Overall, it can be a distinct tool for decision making and water resource management. The significance of the study includes prediction of water hazards like flood, induced landslides and control measures for them, determination future water course and parameters prediction.

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