Quantitative evaluation of watershed attributes for water resources management in the Rift Valley Lakes Basin, Ethiopia: a case from Tikur Wuha river watershed

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Abstract

Characterization of watershed hydrological process is vital for sustainable water resource management. The principal goal of this study was to investigate the inference of drainage attributes on basic hydrological processes using spatial-based morphometric analysis on Tikur Wuha river watershed. The result obtained indicated that the area was characterized with fifth-order stream. Drainage area with higher stream order has lower infiltration capacity, and the shorter stream lengths were associated with the steepness of the area which affects water flow. Based on N_u value, sub-watersheds were categorized in the active erosion stage (SW7) and matured topography development (SW6). The interpretation from watershed geometry identified circular areas most susceptible to rapid hydrological response (SW11). Hydrological process and underlying materials are mainly correlated with the drainage texture parameter, and the lower the values indicated less rocky terrain and very high infiltration capacity which contributes toward less erosion (SW11). Relief parameters such as R_r value indicate the rate of stream flow and are well used in sediment yield estimation. The findings of this investigation will provide core information for water resource planning and further studies like identification of groundwater potential zones; flood risk assessment; erosion-prone area prioritization; and to select suitable sites for the construction of water harvesting structures.

Keywords Water resource · Hydrology · Morphometric analysis · Tikur Wuha

Introduction

Morphometric analysis of a drainage basin is a quantitative investigation of a basin attributes, and it is an important aspect to know the linear, aerial and relief character of a basin (Strahler 1964; Ayele et al. 2017; Tesfaye and

Wondimu 2014). Mathematical analysis of drainage basin features provides useful inputs in order to characterize and understand various hydrological processes for planning and management (Farrukh et al. 2013; Tesfaye and Wondimu 2014; Yangchan et al. 2015). Since long ago, Horton (1945) and Strahler (1964) tried to indicate the association between morphometric parameters and basin hydrology. As many scholars said, the implementation of watershed management is fundamental to achieve sustainable uses of land and water resources to mitigate the increasing demand (Javed et al. 2009; Rai et al. 2017, 2018; Prakash et al. 2019).

Morphometric characterization assists decision makers in watershed management as it is considered to be the most acceptable method for good watershed management (Geena and Ballukraya 2011; Markose et al. 2014). Morphometric method has been used as a tool to know the area–height correlation and its implication on watershed hydrology for water resource planning (Kanth 2012; Bharadwaj et al. 2014). With the advent of remote sensing (RS) and geospatial information technology (GIS), as several studies confirmed, GIS-based morphometric analysis is most effective,

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time saving and accurate technique for watershed characterization, planning and management (Benukantha et al. 2019).

The Rift Valley Lakes Basin of Ethiopia has undergone a major land use change in the past, and such alterations remain vivid nowadays too, affecting the hydrology and ecology of the basin (WWDSE 2001). The inflow of runoff with heavy silt to Lake Hawassa causes rapid storage loss and an increase in the level of the lake (Mulugeta 2013; World Meteorological Organization 2003; Halcrow Group Limited and Generation Integrated Rural Development (GIRD) Consultants 2008; Yacob 2010). Tikur Wuha river is perennial river that flows to Lake Hawassa, and its drainage area covers approximately half of Lake Hawassa watershed and has been deforested over the past few decades (Yacob 2010; Wolka et al. 2014) causing hydrological imbalance on the lake. The main objective of this study was to implement GIS-assisted morphometric characterization on Tikur Wuha river watershed to reveal its impact on basic hydrological process.

Materials and methods

Study area description

Tikur Wuha river is the major tributary of Lake Hawassa, Ethiopia, draining from the eastern part of the lake watershed (Fig. 1). Tikur Wuha river watershed is found in the

northeast shore of Lake Hawassa geographic location of 6048'00''–7010'00''N latitude and 38°26'30''–38°43'00''E longitude. Its altitude ranges between 1643 m and 2976 m above mean sea level. Agroecologically, the study area was classified into midland and highland. Land use in the watershed is dominated by agriculture/intensive cultivation (Yacob 2010).

Datasets used

Drainage aspects of Tikur Wuha river watershed were mathematically measured using hydrological tools in ArcGIS 10.7.1 setup. To carry out the analysis, digital elevation model (DEM) from <https://earthexplorer.usgs.gov/> with 20 m by 20 m resolution was acquired as a data source. Prior to morphometric analysis, delineation of watershed boundary and digitization of all existing stream including its tributaries were done digitally in ArcGIS package (Kotei et al. 2015). Sink fill and flow direction was computed to understand which way the water is flowing by comparing each cell with its neighboring using the eight-direction pour-point method (ESRI 2011). The accumulated number of cells that are draining to any particular cell was also identified using the flow direction grid to define the stream network and determine where streams turn into river. Then, watershed subdivision was carried out after stream segmentation (Gajul et al. 2016; Panhalkar et al. 2012). In this study, the mathematical expression (Table 1) of morphometric parameters assembled into linear aspect, watershed geometry,

Fig. 1 Location map of Tikur Wuha river watershed (satellite map)

Table 1 Adopted mathematical equations to compute the morphometric parameters

Parameters	Name	Given equation	References
Linear aspect	Stream order (u)	Hierarchical rank	Strahler (1952)
	Stream number (N_u)	$N_u = N_1 + N_2 + \dots + N_n$ where, $N_u = N_Q$ of segments of order 'u'	Horton (1945)
	Stream length (L_u)	$L_u = L_1 + L_2 + \dots + L_n$ where, L_u = total stream length of order 'u' (km)	Horton (1945)
	Mean stream length (L_{um})	$L_{um} = L_u / N_u$ where L_{um} = mean stream length of order 'u'	Horton (1945)
	Stream length ratio (L_{ur})	$L_{ur} = L_{um} / L_{um-1}$ where L_{um-1} = mean stream length of its next lower order	Horton (1945)
	Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$ where N_{u+1} = N_Q of segments of next higher order	Strahler (1964)
	Mean bifurcation ratio (R_{bm})	R_{bm} = Average of bifurcation ratio of all orders	Strahler (1964)
	Rho coefficient (ρ)	$\rho = L_{ur} / R_b$	Horton (1945)
Geometric features	Basin length (L_b)	Length of the basin (km) obtained from ArcGIS	Horton (1945)
	Area of the basin (A)	Plan area obtained from ArcMap (km ²)	Horton (1945)
	Basin Perimeter (P)	Perimeter (km) obtained from ArcMap	Horton (1945)
	Shape factor ratio (B_s)	$B_s = L_b^2 / A$	Horton (1945)
	Form factor ratio (F_f)	$R_f = A / L_b^2$	Horton (1932)
	Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)/L_b}$	Schumm (1956)
	Circularity ration (R_c)	$R_c = 4\pi A / P^2$	Strahler (1964)
	Fitness ratio (F_f)	$F_f = C_f / P$	Melton, 1957
	Compactness coefficient (C_c)	$C_c = 0.2824 * P / \sqrt{A}$	Gravelius (1914)
Drainage texture	Drainage density (D_d)	$D_d = L_u / A$	Horton (1932)
	Length of overland flow (L_g)	$L_g = 1 / 2D_d$	Horton (1945)
	Stream frequency (F_s)	$F_s = H / HL_b - L_b$	Horton (1932)
	Drainage intensity (I_d)	$I_d = F_s / D_d$	Faniran (1968)
	Texture ratio (D_t)	$D_t = N_u / P$	Horton (1945)
	Infiltration number (I_f)	$I_f = D_d \times F_s$	Praveen et al. (2018)
	Constant of channel maintenance (C)	$C = 1 / D_d$	Schumm (1956)
Relief aspect	Basin (relative) relief (H)	$H = Z - z$, where Z = maximum basin highest and z = minimum height (m)	Strahler (1952)
	Relief ratio (R_r)	$R_r = H / L_b$	Schumm (1956)
	Relative relief ratio (R_{hp})	$R_{hp} = H * 100 / P$	Melton (1958)
	Ruggedness number (R_n)	$R_n = D_d * H / 1000$	Patton and Baker (1976)
	Dissection index (D_{is})	$D_{is} = H / H_{max}$	Singh and Dubey (1994)
	Hypsometric curve	Plot of relative area with relative altitude	Strahler (1952)

drainage texture and relief parameters was adopted from different sources. Further, the geological map of the study area was also used to correlate the underlying conditions with the morphometric parameters.

Analysis of morphometric attributes

Interrelation between parameters

To understand how the different morphometric parameters interact and influence each other, the relationship between variables was tested using graphical regression equation and tabular correlation matrix (Ali and Hassan, 2018).

Results and discussion

The hydrological response of a catchment was largely controlled by its morphometric parameters (Diakakis 2010). Analyzing morphometric variables of Tikur Wuha river watershed plays an important role to understand various hydrological processes. The result obtained from the morphometric analysis and its implication on the hydrology of the river watershed was discussed henceforward:

Linear aspect

Stream order (u)

SW5 specifically and the study watershed in general accounted for fifth-order stream (Fig. 2) with dendritic type of drainage pattern. It is considered as the trunk stream through which all discharge of water and sediment passes (Strahler 1957). However, SW4, SW5, SW7, SW12 and

SW13 were assigned as fourth order and SW1 was the only one assigned as second order. The remaining eight SWs were categorized as third-order stream hierarchic. Stream order is inversely correlated with infiltration capacity; the higher the u value, the lesser in terms of permeability and infiltration (Gajbhiye et al. 2015). Hence from water resource management aspect, construction of water harvesting structures and the implementation of artificial recharge should be encouraged based on the biophysical condition.

Stream number (N_u)

The N_{uT} per each SW is tabulated in Table 2, 13.5% of the total N_u was situated in SW7, and SW6 accounts the smallest of all, that is, 1.8%. Across the watershed, 273 N_{uT} were counted. In one way or the other, N_u indicates the erosional status and development stage of a given watershed (Gutema et al. 2017). Hence, relatively large N_u as in the case of SW7 indicates the topography is still undergoing erosion and the lesser the value (SW6) implies matured topography. It is

Fig. 2 SW with drainage network (left); flow direction and flow accumulation map (right)

Table 2 Stream number, stream length, mean stream and stream length ratio of individual SWs

SW	Stream number (N_u)						Stream length, L_u (km)						Mean stream length, L_{um} (km)						Stream length ratio (L_{ur})					Mean Lur (L_{um})		
	I		II		III		IV		V		Total		I		II		III		IV		V		Total			
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	III	IV		V	
SW1	5	2	-	-	-	-	7	6.23	2.98	-	-	-	9.21	1.2	1.5	-	-	-	-	-	-	1.25	-	-	1.3	
SW2	14	3	2	-	-	-	19	24.7	6.28	3.18	-	-	34.16	1.76	2.09	1.59	-	-	-	-	-	1.19	0.76	-	1.0	
SW3	15	3	1	-	-	-	19	23.1	7.1	3.6	-	-	33.8	1.54	2.37	3.60	-	-	-	-	-	1.54	1.52	-	1.5	
SW4	4	2	1	1	-	-	8	5.34	0.18	8.45	4.41	-	18.38	1.34	0.18	4.23	4.4	-	-	-	0.13	23.50	1.04	-	8.2	
SW5	8	5	3	3	1	20	6.86	6.39	1.74	9.3	4.15	-	28.44	0.86	1.28	0.58	3.1	4.2	-	-	1.49	0.45	5.34	1.35	2.2	
SW6	3	1	1	-	-	5	6	7.84	6.41	-	-	-	20.25	2.00	7.84	6.41	-	-	-	-	3.92	0.82	-	-	2.4	
SW7	29	6	1	1	-	37	42.2	15.1	2.04	15.3	-	-	74.76	1.46	2.52	2.04	15.3	-	-	-	1.73	0.81	7.50	-	3.3	
SW8	15	3	1	-	-	19	15.4	28.9	3.85	-	-	-	48.18	1.03	9.63	3.85	-	-	-	-	9.35	0.40	-	-	4.9	
SW9	15	4	1	-	-	20	27.7	15.4	9.36	-	-	-	52.51	1.85	3.86	9.36	-	-	-	-	2.09	2.42	-	-	2.3	
SW10	12	1	-	-	-	13	17.4	17.9	-	-	-	-	35.38	1.45	17.99	-	-	-	-	-	12.41	-	-	-	12.4	
SW11	11	2	1	-	-	14	17.4	0.3	17.1	-	-	-	34.79	1.58	0.15	17.10	-	-	-	-	0.09	114	-	-	57.0	
SW12	19	4	1	1	-	25	24.8	8.85	8.1	5.97	-	-	47.72	1.31	2.21	8.10	5.97	-	-	-	1.69	3.67	0.74	-	2.0	
SW13	22	8	2	1	-	33	45.8	45.6	10.2	5.83	-	-	107.3	2.08	5.70	5.10	5.83	-	-	-	2.74	0.89	1.14	-	1.6	
SW14	12	3	1	-	-	16	6.23	2.98	-	-	-	-	9.21	2.11	7.37	2.97	-	-	-	-	3.49	0.40	-	-	1.9	
SW15	14	3	1	-	-	18	24.7	6.28	3.18	-	-	-	34.16	2.09	6.60	2.44	-	-	-	-	3.16	0.37	-	-	1.8	

observed (Table 1) that the maximum frequency is in case of first-order streams ($N_u = 198$) and decreases as the stream order increases ($N_u = 1$). This study also confirmed Horton's law of N_u (1945); there is an inverse geometric correlation between u and the logarithm scale of N_u across the area of interest (Fig. 3a and 4). It was believed that the variation observed in the respective parameters was governed by the physiographic difference and structural condition of the watershed (Nikhil Raj and Azeez 2012; Praveen et al. 2018; Biswas 2016). The consistent decrease in N_u against u revealed the presence of erosional landform throughout the watershed (Avijit 2019).

Stream length (L_u)

L_u and slope of any watershed are highly correlated to each other; streams with smaller L_u indicate the area is characterized as steep slope and vice versa (Withanage et al. 2014; Dubey et al. 2015; Christopher et al. 2010). Hence, L_u is considered as a useful hydrological feature to understand surface runoff characteristics as it is dependent on slope. The L_{uT} of Tikur Wuha river watershed was accounted for 646.7 km with fifth order of 4.15 km and first order of 317.42 km (Table 1). In general, the plot of the logarithm of L_u versus u (Fig. 3b) showed some deviation from its general

Fig. 3 The relationship between N_u (a) and L_u (b) with u for Tikur Wuha river watershed

Fig. 4 Regression of N_u against u for each SW

behavior (linear pattern) indicates that the terrain is characterized by variation in lithology and topography (Nageswara et al. 2010). The logarithm scale of L_{uT} is inversely correlated with u for each SW (Fig. 5). More deviation ($r^2 < 0.5$) was observed in six SWs (SW4–8, 11) subjected to varied rock (parent) material, and the remaining nine SWs were characterized with homogeneous rock material (Nageswara et al. 2010).

Mean stream length (L_{um})

L_{um} of the study area was ranged from 0.15 (SW11) to 18 km (SW10). It is directly proportional to the size and topography of a drainage basin (Mangesh 2015). The mean stream length ratio (L_{urm}) was found between 1 (SW2) and

57 (SW11) (Table 1). Variation was also observed in stream length ratio (L_{ur}), among successive stream orders. This variation revealed that the watershed was characterized by varying topography and slope according to Strahler (1964) and Gutema et al. (2017). Hence, it has an important control on discharge and erosional stage of the watershed (Sreedevi et al. 2004).

Bifurcation ratio (R_b)

The mean bifurcation ratio (R_{bm}) of the study watershed was ranged between 2 and 12. The higher the value of R_b implies there is strong structural control on the drainage pattern (Nag and Chakraborty 2003). Referring Table 3, SW10 with high value of R_{bm} was developed over easily erodible steeply dipping that also indicates high overland flow and discharge

Fig. 5 Regression of L_u on u for each SW

Table 3 Bifurcation ratio, mean bifurcation ratio and Rho coefficient

SW	Bifurcation ratio (R_b)				Mean R_b (R_{bm})	Rho coefficient, (ρ)
	I/II	II/III	III/IV	IV/V		
SW1	2.5				2.5	0.5
SW2	4.7	1.5			3.1	0.3
SW3	5	3.0			4	0.4
SW4	4	2.0	2.0		2.7	3.7
SW5	1.6	1.7	1.0	3.0	2	1.1
SW6	3	1.0			2	1.2
SW7	4.8	6.0	1.0		3.9	0.9
SW8	5	3.0			4	1.2
SW9	3.8	4.0			3.9	0.6
SW10	12				12	1.0
SW11	5.5	2.0			3.8	15.0
SW12	4.8	4.0	1.0		3.3	0.6
SW13	2.8	4.0	2.0		2.9	0.5
SW14	4	3.0			3.5	0.6
SW15	4.7	3.0			3.9	0.5

(Biswas 2016; Gajbhiye et al. 2015; Rawat et al. 2012). High R_b indicates early hydrograph peak with a potential for flash flooding during the storm events which results in degradation of top soil (Ajaykumar et al. 2019). The rest of the Tikur Wuha SWs ($2 < R_{bm} < 5$) were less affected by the underlying geological disturbance and relatively characterized by high permeability and low erodibility (Pankaj and Kumar 2009). However, soil permeability may also be affected by other watershed parameters like shallow soil depth and less structural control on the catchment development (Asiamah et al. 2000; Kotei et al. 2015). The value of R_b is also indicative of the shape of the basin. Elongated basin, which is likely to have higher R_b , yields a low but extended peak flow, while circular basins with low R_b procure sharp peak (Gajbhiye et al. 2015; Harinath and Raghu 2013).

Rho coefficient (ρ)

ρ is an important parameter which assists the evaluation of storage capacity of drainage network and, hence, a determinant of ultimate degree of drainage development in a given watershed (Horton 1945). Climatic, geologic, biologic, geomorphological and anthropogenic factors determine the changes in ρ (Chaitanya and Kanak 2015). ρ values of the study watershed are ranging between 0.3 and 15 for SW2 and SW15, respectively (Table 3). This implies higher hydrological storage during floods and attenuation of effects of erosion during elevated discharge.

Watershed geometry features

Drainage area (A) and perimeter (P)

The size of storm hydrograph and runoff magnitude are directly affected by the generated basin area (Strahler 1957); hence hydrologically, it is an important parameter. The SW's A value is ranged between 11.14 and 89.25 km² with perimeter (it is the length of the SW boundary) measured from 22.8 to 60.35 km, respectively, for SW1 and SW15 (Tables 4 and 5).

Shape factor ratio (B_s)

B_s is the qualitative representation of a watershed that affects the stream discharge pattern. And it was expressed as the inverse of R_f . The computed value of B_s is ranging between 3.7 and 13.5 for SW11 and SW9, respectively. The greater the circular character of the basin is, the greater is the rapid response of the watershed after a storm event (Tucker and Bras 1997). Therefore, in terms of B_s , SW9 has the longest basin lag time and SW11 the shortest.

Form factor ratio (R_f)

Basin with high R_f is characterized by peak flow of shorter duration, whereas elongated watershed with low R_f has lower peak flow with longer duration (Gajbhiye et al. 2015). In this study, maximum R_f was 0.27 for SW11 and minimum value 0.07 for SW9. The result shows that SW9 relatively more elongated the other SWs.

Table 4 Watershed geometry parameters

SW	Basin length (L_b)	Area (A)	Perimeter (P)	Shape factor ratio (B_s)	Form factor (R_f)	Elongation ratio (R_e)	Circularity ratio (R_c)	Compactness constant (C_c)	Fitness ratio (F_f)	Length area relation (L_{ar})
SW1	8	11.14	22.8	5.7	0.17	0.47	0.27	1.93	0.35	5.9
SW2	11	30.15	30.94	4.0	0.25	0.56	0.40	1.59	0.36	10.8
SW3	12	33.61	31.86	4.3	0.23	0.55	0.42	1.55	0.38	11.5
SW4	9	14.28	24.6	5.7	0.18	0.47	0.30	1.84	0.37	6.9
SW5	13	29	45.95	5.8	0.17	0.47	0.17	2.41	0.28	10.6
SW6	11	17.1	28.88	7.1	0.14	0.42	0.26	1.97	0.38	7.7
SW7	22	43.4	43.92	11.2	0.09	0.34	0.28	1.88	0.50	13.4
SW8	19	47.97	45.77	7.5	0.13	0.41	0.29	1.86	0.42	14.3
SW9	22	35.83	46.14	13.5	0.07	0.31	0.21	2.17	0.48	12.0
SW10	21	34.14	53.86	12.9	0.08	0.31	0.15	2.60	0.39	11.6
SW11	14	52.72	53.52	3.7	0.27	0.59	0.23	2.08	0.26	15.1
SW12	21	63.6	55.79	6.9	0.14	0.43	0.26	1.97	0.38	16.9
SW13	19	43.51	44.5	8.3	0.12	0.39	0.28	1.90	0.43	13.5
SW14	18.6	49.38	42.47	7.3	0.14	0.42	0.34	1.70	0.44	14.5
SW15	25	89.25	60.35	7.0	0.14	0.43	0.31	1.80	0.41	20.7

Table 5 Drainage parameters of the study area

SW	Drainage density (D_d)	Length of over-land flow (L_g)	Stream frequency (F_s)	Drainage intensity (I_d)	Infiltration number (I_f)	Drainage texture (D_t)	Constant channel maintenance (C)
SW1	0.83	0.60	0.63	0.76	0.52	0.31	1.21
SW2	1.13	0.44	0.63	0.56	0.71	0.61	0.88
SW3	1.01	0.50	0.57	0.56	0.58	0.60	0.99
SW4	1.29	0.39	0.56	0.43	0.72	0.33	0.78
SW5	0.98	0.51	0.69	0.70	0.68	0.44	1.02
SW6	1.18	0.42	0.29	0.25	0.34	0.17	0.84
SW7	1.72	0.29	0.85	0.49	1.46	0.84	0.58
SW8	1.00	0.50	0.40	0.40	0.40	0.42	1.00
SW9	1.47	0.34	0.56	0.38	0.82	0.43	0.68
SW10	1.04	0.48	0.38	0.37	0.40	0.24	0.96
SW11	0.66	0.76	0.27	0.41	0.18	0.26	1.52
SW12	0.75	0.67	0.39	0.52	0.29	0.45	1.33
SW13	2.47	0.20	0.76	0.31	1.88	0.74	0.41
SW14	1.02	0.49	0.32	0.31	0.33	0.38	0.98
SW15	0.58	0.87	0.20	0.34	0.12	0.30	1.74

Elongation ratio (R_e)

The R_e values of near 1 indicate that there are less geomorphological controls on river basin (Strahler 1964). A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh 1997). The R_e values of Tikur Wuha SW were varied from 0.31 to 0.59. The result indicated that SW9 and SW10 are more elongate than others implying low peak discharge, whereas SW2, SW3 and SW11 were relatively circular in nature (Avijit 2019).

Circularity ratio (R_c)

The R_c is an important tool to understand the geomorphological development stage of tributary basins. It varies depending on the lithological characteristics and other morphometric parameters of specific basin. R_c value of 0.42 (maximum) was calculated for SW3 indicative of circular shape, moderate to high relief and permeable surface relatively with old development stage. A minimum R_c value of 0.15 was assigned for SW10 that indicates elongated, low relief and

impermeable surface with a young stage of geomorphological adjustment (Ajaykumar et al. 2019).

Compactness coefficient (C_c)

The C_c value of a basin is inversely related with R_e (Waikar and Aditya 2014; Zakaria et al. 2016). In this study, the C_c varies from 1.55 to 2.6 (Table 3). The lower value of C_c in the case of SW3 was the indication of more elongation and less erosion, while the reverse was observed in SW10, that is, the higher the C_c value, the lower the elongation and the higher the erosion occurrence probability. The C_c directly corresponds to its infiltration capacity (Ajaykumar et al. 2019).

Fitness ratio (F_f)

The F_f value of the study is varied between 0.26 and 0.5 for SW11 and SW7, respectively. It is a measure of topographic fitness (Praveen et al. 2018; Melton 1957).

Length area relation (L_{ar})

In this study, the L_{ar} is ranged from a maximum of 20.7 for SW15 to a minimum value of 5.9 for SW1. L_{ar} is an important geometric parameter to understand the association between stream length and basin area (Hack 1957).

Drainage texture attributes

Drainage density (D_d)

Because of its wide ratio of variation, drainage density is a number of primary importance in landform scale analysis (Strahler 1957). According to Melton in 1957, high value of D_d indicates highly dissected catchment with a relatively rapid hydrological response to rainfall, while a low drainage density expresses a poorly drained basin with a slow hydrological response.

Figure 6 indicates the D_d distribution map generated based on Smith (1950) and Chandrashekar et al. (2015) classification range. D_d is one of the factors controlling the surface runoff and consequently influences the output of sediment and water from the basin (Chorley 1969). In general, as the D_d number increases, the size of individual drainage units, such as the first-order drainage basin, decreases proportionately (Strahler 1957). The lower drainage density of any watershed indicates streams are widely spaced and low erosion occurrence is expected (Ajaykumar et al. 2019).

Fig. 6 Drainage density distribution map

Stream frequency (F_s)

F_s is directly correlated with D_d ; the lesser the F_s indicates less D_d resulted in low runoff value, and hence, flooding is less likely to occur (Thomas et al. 2010). F_s depends on the rainfall, relief, as well as drainage density of the basin. In the study, SW's F_s value (Tables 4 and 5) is ranged from 0.2 to 0.85 numbers per km^2 . Low F_s indicates that the watershed has less rocky terrain and very high infiltration capacity which contributes toward less erosion (Ajaykumar et al. 2019; Avijit 2019). The higher F_s value of 0.85 numbers per km^2 in SW7 indicated that the area was dominated by high slope and low permeability. Low value of F_s was observed in SW6 and SW11 that reveals the sub-watersheds were characterized by less relief and low slope ranges.

Drainage texture (D_t)

D_t is an important fluvial parameter which denotes the relative spacing of drainage network of any basin (Avijit 2019). D_t is affected by the amount of rainfall, density of vegetation, soil types, infiltration capacity, stages of geomorphic development and relief (Horton 1945; Smith 1950). Based on Smith (1950) classification range, the D_t less than 2

indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. The D_t of the entire area was below 2 indicating very coarse texture range (Tables 4 and 5), which implies higher permeability and enhanced groundwater (Albaroot et al. 2018). Regions of low infiltration capacity will give rise to higher D_t and thus will lead to more erosion (Ajaykumar et al. 2019). In this study, minimum value was accounted for SW6 that revealed the SW is plain with lower degree of slopes, while maximum D_t value indicates the SW was associated with high degree of slope (SW7 for instance) as noted by Gajbhiye et al. (2015).

Length of overland flow (L_g)

L_g is one of the most important independent variables affecting both the hydrological and physiographic development of drainage basins. Referring Tables 4 and 5, a higher value of L_g (SW15) represents low relief, whereas a low value of L_g (SW7 and SW13) is an indicative of high relief (Biswas 2016). L_g is directly related to average slope of drainage channel; hence, the greater the value, more is the erosion severity in the case of SW15 (Ajaykumar et al. 2019).

Constant of channel maintenance (C)

The lower value of C indicates higher flood potentiality and young geomorphological adjustment. Steep slope area generally has low C values due to lower infiltration of bare soil. The calculated C value is varied between minimum of 0.41 for SW13 and maximum of 1.74 for SW15 (Tables 4 and 5). Low C value for SW13 revealed that the SW is associated with very low-resistance and low infiltration capacity of bare soils; sparse vegetation and mountainous (steep slope) terrain resulted in high overland flow and high flood potentiality (Farrukh et al. 2013; Avijit 2019).

Relief aspect

Basin relief (H)

H indicates the erosional stage of a river basin, and it varies relaying upon the underlain geology, geomorphology and drainage characteristics of particular region. Mountain–plain front river basin has higher basin relief than plateau–plain front river basin (Thomas et al. 2010). The elevation of Tikur Wuha river basin ranged from 1643 m (SW5, the outlet to Lake Hawassa) in the northwestern part to 2976 m (SW15) in the southern part of the study area (Fig. 1). In the present study, the maximum H value is 988 m for SW13 indication

of susceptibility for erosional activity and the minimum was 95 m for SW6.

Relief ratio (R_r)

The R_r indicates the overall slope of the watershed surface (Strahler 1964) and also tells us the average drop in elevation per unit length of the stream. According to Ajaykumar et al. (2019), high R_r values indicate high rate of stream flow and erosion vulnerability due to high sediment loss. As confirmed by Schumm in 1954, R_r is useful in estimating sediment yield. The value obtained here varied from 0.01 (for SW5 and SW6) to 0.07 for SW3.

Ruggedness number (R_n)

The R_n value implies the susceptibility of watershed to soil erosion (Gutema et al. 2017). Ruggedness values range between zero and one, values nearer to 0 refer to relatively smoother situation, and those nearer to 1 show more rugged terrain characteristics. The higher the values of D_d and H are, the higher the value of R_n will become. As a result, the slope is not only steep but long. Referring to Table 6, SW13 with higher value of D_d and H scores the maximum R_n value 2.44 and SW6 with the minimum amount, that is, 0.11.

Slope and aspect of the watershed

The slope gradient directly influences the formation of drainage networks, and it enables the assessment of runoff generation, direction and amount (Zavoianca 1985). The runoff speed from a particular basin is dependent on the associated slope range, thereby affecting the required time for rainwater to enter in the stream beds (Mesa 2006). The slope of the study watershed varies from 0° to 73° and reclassified (Fig. 7). There is a high slope gradient in the eastern parts (northeast and southeast) because of the presence of high relief causing rapid runoff, increasing erosion rates, and low recharge potential. As slope determines the infiltration vs runoff relation, it is important to understand the nature of slope in any region. Infiltration capacity is inversely related to the slope (Avijit 2019).

The result obtained from the correlation index (Table 7) indicated that relatively there is a strong correlation between drainage texture parameters. The two watershed geometry attributes: C_c and R_c , are inversely correlated to each other. Strong positive correlation was also observed between R_c and R_f ; L_g and D_d were correlated inversely to each other. It is well correlated with L_g in opposite manner, and D_t was highly correlated with F_s . Direct relationship was identified between R_n and I_f . D_{is} is more strongly correlated with the R_{hp} of the watershed.

Table 6 Relief aspects of Tikur Wuha river basin

SW	Lowest height (z)	Highest height (Z)	Basin relief (H)	Relief ratio (R_r)	Ruggedness number (R_n)	Relative relief (R_{rp})	Dissection index (D_{is})
SW1	1678	1869	191	0.02	0.16	0.8	0.10
SW2	1678	2087	409	0.04	0.46	1.3	0.20
SW3	1690	2525	835	0.07	0.84	2.6	0.33
SW4	1678	1933	255	0.03	0.33	0.5	0.13
SW5	1643	1869	226	0.02	0.22	0.4	0.12
SW6	1678	1773	95	0.01	0.11	0.3	0.05
SW7	1681	2639	958	0.04	1.65	2.2	0.36
SW8	1678	2661	983	0.05	0.98	2.1	0.37
SW9	1692	2673	981	0.04	1.44	2.1	0.37
SW10	1678	2495	817	0.04	0.85	1.5	0.33
SW11	1678	2237	559	0.04	0.37	1.0	0.25
SW12	1679	2454	775	0.04	0.58	1.4	0.32
SW13	1685	2688	1003	0.05	2.48	2.3	0.37
SW14	1882	2687	805	0.04	0.82	1.9	0.30
SW15	2182	2976	794	0.03	0.46	1.3	0.27

Fig. 7 Slope distribution (a) and aspect (b) and geological (c) map

Geological feature

Based on the data from Geological Survey of Ethiopia, majority of the underlying area (Fig. 7c) is dominated by Pleistocene–Holocene, undifferentiated followed by lacustrine sediments where commonly created as a result of precipitation of salts dissolved in the lake water (Gilbert 1978) and a river or stream channel has carried sediment into the basin. Alkaline and peralkaline silicics are also found. Ignimbrites are of low density and high porosity, are very weak to weak in compression and have low tensile (Vicki 1993).

Conclusions

In this study, hydrological perspectives of morphometric parameters were assessed on Tikur Wuha river watershed. The result obtained indicated that there are spatial variability and correlation among the morphometric attributes, and hence, the study addressed the hydrological characteristics relying on the different attributes. The study area was characterized with low infiltration capacity as it has higher u value. In general sense, the watershed is in the state of undergoing/active erosion and matured topography development. Some

Table 7 Correlation matrix among different morphometric parameters

	R_{bm}	ρ	A	R_f	R_e	R_c	C_c	F_f	L_{ar}	D_d	L_g	F_s	I_d	I_f	D_t	R_t	R_n	R_{hp}	D_{is}
R_{bm}																			
ρ																			
A																			
R_f																			
R_e																			
R_c																			
C_c																			
F_f																			
L_{ar}																			
D_d																			
L_g																			
F_s																			
I_d																			
I_f																			
D_t																			
R_t																			
R_n																			
R_{hp}																			
D_{is}																			

SWs were characterized circular in nature and are most susceptible to rapid hydrological response due to the shortest time of concentration. Hydrological process and underlying materials are mainly correlated with Dd and Fs, and the lower the values indicated less rocky terrain and very high infiltration capacity which contributes toward less erosion (for example: SW11). With the aim of water resource planning, the findings of this investigation will provide core ideas to identify groundwater potential zones; to study flood risk assessment; and to select suitable sites for the construction of water harvesting structures.

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Compliance with ethical standards

Conflict of interest The authors declared that there is no conflict of interest in this study.

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