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Integration between the hydrogeological modeling and morphometric analyses using HEC-HMS and GIS techniques: A case study of Atbara River basin

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ABSTRACT

Atbara River is the last tributary and one of the three main rivers flow their water into the main Nile River. The aim of the present work is to provide new scope for integration between the hydrogeological modeling and morphometric analyses using HEC-HMS and GIS techniques. In Atbara River basin that has in sufficient hydrogeological and morphometrical data for simulating rainfall-runoff events, using hydrogeological modeling of the watershed is appropriate. The hydrogeological HEC-HMS model simulates runoff at the present precipitation rate 15, 30, and 50 mm. As well as it simulates three scenarios in case of high precipitation rate according to any climate change effects (at 75, 100, and 150 mm). The modeling at precipitation rate 15 mm in 24 hours, the hydrographic curve and modeling results indicate that water volume at Atbara River basin is 868.9 X 1000 m^3 with peak discharge with water volume rate is 1.10 m^3/sec. The modeling at precipitation rate equal 30, 50, 75, 100, and 150 mm, the modeling results indicate that water volume are 391.64 X 10^6, 1.663 X 10^9, 4.22 X 10^9, 7.54 X 10^9, and 15.58 X 10^9 m^3 with peak discharge with water volume rate are 475.9, 2023.3, 5228, 9809.4, and 22399.3 m^3/sec respectively.

Key words : *Hydrogeological Model, HEC-HMS, Watershed, GIS, Morphometry, Atbara.*

Introduction

Climate change has effects partially or completely on one or more components of the normal hydrological cycle especially the river basins. This can change the meteorological elements as intensity, frequency, and distribution of precipitation and risk of flooding in some parts than others. It also associated with changes in temperature, evaporation, and all the hydrologic events, which directly affect the water resources.Hydrogeological modeling is generally used as tool to estimate the hydrological parameters for small or large basins. The Hydrologic Modeling System HEC-HMS, is an integrated modeling a tool used for many hydrologic processes for different basins (Mokhtari *et al.*, 2016; Chea and Oeurng 2017; Rauf and Ghumman, 2018). GIS technique and Remote sensing (RS) are essential techniques to determine rainfall rate, land use, soil types, land cover, and modeling of rainfall and runoff which are very important for sustainable development of the water resources and coastal area management (Cetin *et al.*, 2018; Malik *et al.,* 2019).

The aim of the present work is to estimate a new scope for running and complete interpretation of rainfall-runoff modeling. It attempts to get the integration between Arc-GIS and Hydrologic Modeling System (HEC-HMS) techniques to analyze the morphometric and hydrogeologic parameters for Atbara River watershed.

Study Area

Atbara River is the last tributary joins and flow into the Nile River from Khartoum to the Mediterranean Sea. It is one of the three main tributaries that feed their water into the main Nile River with the White Nile and the Blue Nile. The Atbara River basin is spread over three countries: Sudan (northern part), Ethiopia (southern part), and Eritrea (eastern part). It located between latitudes 11° 40′ and 19° 10′ N and between longitudes 33° 52′ and 39° 50′ E (Fig. 1). The Atbara Riverhas three main tributaries. Tekeze (Setit in Sudan) river originates from the highlands northern of Ethiopia plateau along Ethiopia and Eritrea and flows downstream across the lowlands of eastern Sudan. AngerebRiver and upper Atbara River drain from an area that is located in the northern part of Ethiopia plateau 30 km north of Lake Tana. The rainfall along the basin ranges from below 400 mm/y in the east to more than 1200 mm/y in the south (Zenebe, 2009). It contributes approximately an average 13.4 % of the total Nile water, essentially in the rainy season between July and October (Hurst, 1952). The large amount of the total rainfall per year (about 70%) falls in July and August, while it deceases during the dry season from October to February (Nyssen *et al.*, 2005).

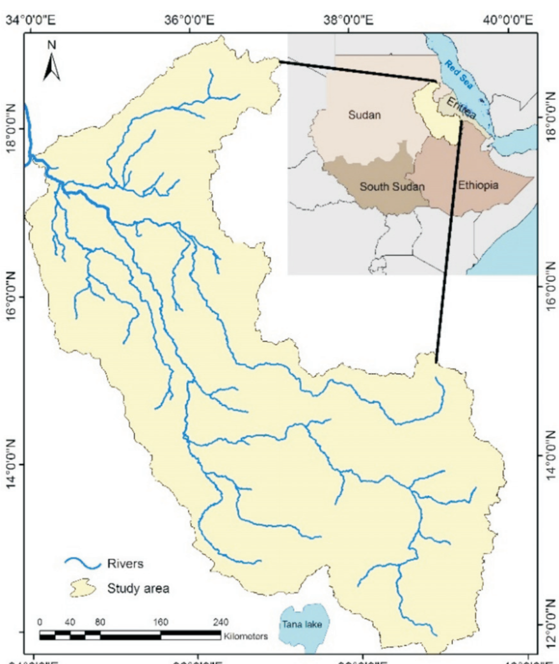

Fig. 1. Location map of Atbara River basin

Materials and Methods

For river basin or watershed, the Hydrologic Modeling System (HEC-HMS) is a comprehensive hydrogiologic modeling tools carried out to simulate the surface runoff. The present study applies the integration between ArcGIS 10.5 (Arc-hydro tool) and Hydrologic Modeling System (HEC-HMS) to analysis the morphometric and hydrogeologic parameters for Atbara River basin. The hydro-morphometric analyses of the drainage system at the study basins require delineation of all existing streams. For collecting data that used for this study, different tools and techniques were carried out such as Shuttle Radar Topography Mission (SRTM) data (90 m spatial resolution), Reflection Global Digital Elevation Model (ASTER GDEM data), and topographic maps (1:50,000 scale) of the Atbara River basins.

The channels and stream ordering use Strahler's method (Strahler, 1964) for classification. Basic hydro-morphometric parameters were estimated. The HEC-HMS model in watershed modeling system (WMS) program need preparing Digital Elevation Model (DEM), flow directions using TOPAZ tools, flow accumulations, and morphometric elements.

Preparing and data sources

To running the HEC-HMS model, many data prepared such as: digital elevation model (DEM)as shown in Figure (2), precipitation rates, SCS methods to compute lag time, and landuse / landcover characteristics with soil types (using to compute Curve Numbers (CN), which very important to define infiltration rates). From the output and results of models are time of peak, peak discharges, and total water volume. As well as to analysis and extract the main Atbara River watershed hydrogeological parameters and its sub-basins (Fig. 3).

Rainfall Distribution

The rainfall considers as the factor controlling the hydrogeological rainfall modeling. The precipitation data of Atbara River catchment were collected from different meteorologicalstations distributed along Sudan, Ethiopia, and Eritrea (as Bahar Dar, Combolcha, Gondar stations from Ethiopia; and Kassala, Sennar, Damazine stations from Sudan).

The variations of precipitation rate in August are 0, 15, 30, and 50 mm. Accordingly, rainfall modeling study the hydrogeological conditions along the ba-

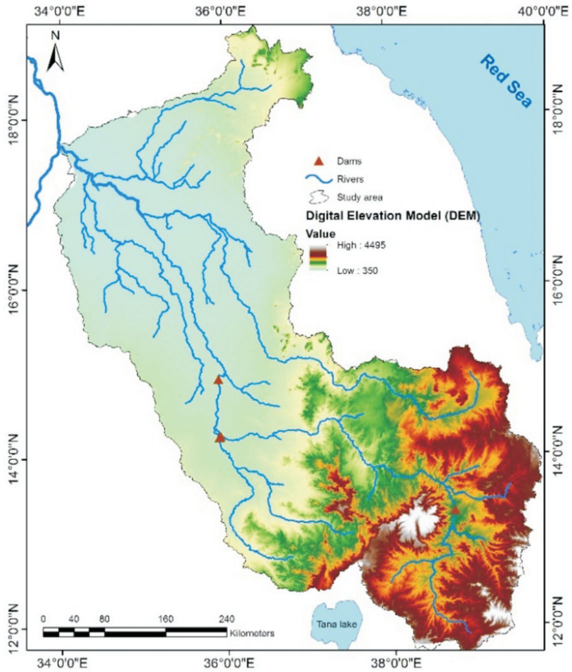

Fig. 2. Digital Elevation Models (DEM).

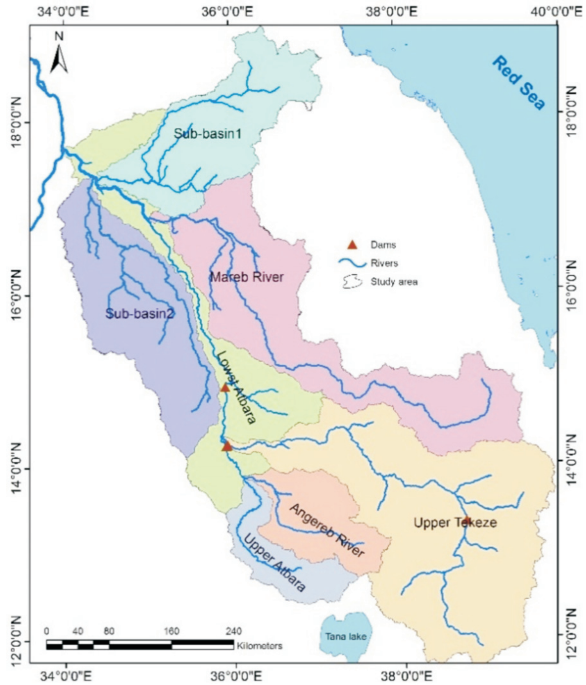

Fig. 3. Sub-basins boundaries map.

sin at the present precipitation rate 15, 30, and 50 mm. As well as the HEC-HMS model study other three scenarios in case of high precipitation rate at 75, 100, and 150 mm. The HEC-HMS model apply II-24 h type. The model design uses the accumulated runoff and accumulated rainfall along the catchment area through 24 hours.

Results and Discussion

Land-use, soil Groups, and Curve Numbers (CN)

The soil properties and the lithology of the surface layer effect on infiltration rate, accumulated rainfall, and runoff. According to the water infiltration rate, the soil classified into four hydrogeological groups, they are group A, B, C, and D (USDA 2009). Using ArcGIS 10.5 produce the hydrogeological soil groups and land-use maps of study area (Fig. 4).

Soil Group A has low runoff potential due to high infiltration rates even when saturated (vary from 8.6 to 11.4 mm/h). It covered 43.4 % of study area (99874.4 km^2). Soil Group B not detected along the area. Soil Group C has a moderately high runoff potential due to slow infiltration rates (vary from 1.3 to 3.8 mm/h). It covered 24 % of study area (55165.4 km^2). Soil Group D has high runoff potential due to very slow infiltration rates (1.3 mm/h). It covered 32.6 % of study area (75177.5 km^2). Composite Curve Numbers (CN) as estimated along Atbara basin vary from 53.3 for upper basins to 78 for lower basins controlled by the soil properties and the lithology of the surface layer which the water runoff

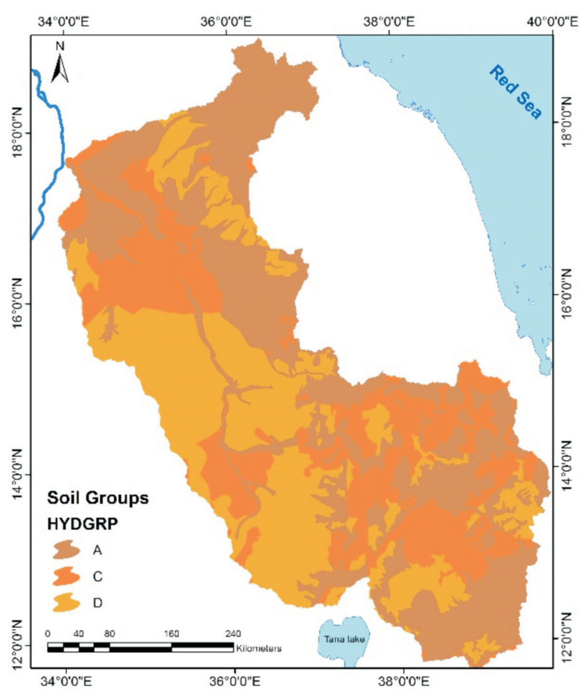

Fig. 4. Soil-distribution map of Atbara.

and/or infiltrated through.

HEC-HMS hydrogeological modeling

The HEC-HMS hydrogeological modeling used to simulate the accumulated rainfall, runoff, and hydrogeological conditions along the Atbara River basin at the present precipitation rate (15, 30, and 50 mm) and in case of future high precipitation rate at 75, 100, and 150 mm (Table 1). Atbara River basin become extremely dangerous during a flash flood precipitation rate exceed 50 mm. This is related to long runoff time along the watershed where the water flow time is more than one month (Fig. 5). The hydrological modeling proposed the rainfall start from first of July in 1:00 am.

In the simulation models, Atbara River basin classified to eight main sub-basins. They are lower Tekeze River, upper Tekeze River, upper Atbara River, Angereb River, lower Atbara River, Mareb River, sub-basin1, sub-basin 2. These sub-basins represent the main water flow at Atbara River watershed. Four from these sub-basins have dams constructed to control the water flow (hydropower generation and irrigation). Tekeze dam located at upper Tekeze River sub-basin (Ethiopia, completed in 2009), Khashm el-Girba Dam builded on the main AtbarahRiver (Sudan, completed in 1964), and upper Atbara and Setit Dam Complex, also known as Rumela-Burdana dam (Sudan, completed in 2017) constructed at the confluence of the lower Tekeze with the upper Atbara and Angereb sub-basins (Fig. 3).

Hydrogeological simulation modeling scenario at precipitation rate 15 mm

The modeling simulates at precipitation rate 15 mm in 24 hours. Hydrographic curve at the outlet of Atbara River indicates that water flow start after 9 hours from rainfall storm, then the flow reaches its maximum after 6 days and 8.30 hours (9150 min). The water runoff along the basin continue one month as shown in Figure 5. In this scenario, the total water volume flow at the Atbara outlet reach 868.9 X 1000 m^3 with peak discharge and highest flow 1.10 m^3/s. Hydrographic curve in this model (Figs. 5 and 6) indicates that upper Tekeze sub-basin has a very low water flow (at precipitation rate 15 mm for 24 hours). As well as observed at lower Tekeze, upper Atbara, and Angereb sub-basins. While at sub-basins that haven't dames as Mareb River, lower Atbara River, sub-basin1, and sub-basin2 get total water volume flow of 300, 201, 160, and 207 X 1000 m^3 respectively with peak discharge are 0.5 m^3/s (in 06-Jul after 8640 min), 0.2 m^3/s (in 10-Jul after 14400 min), 0.4 m^3/s (in 05-Jul after 7200 min), and 0.1 m^3/s (in 04-Jul after 5760 min) respectively.

Hydrogeological simulation modeling scenario at precipitation rate 30 mm

The modeling carried out at precipitation rate 30 mm in 24 hours. The modeling results indicate that the total water volume flow at the Atbara River basin in its outlet is 391641 × 1000m^3 with peak discharge and highest flow is 475.9 m^3/s (Fig. 5). As the previous model, the same result was obtained in hydrographic curve of precipitation rate 30 mm for 24 hours. Whereas, the upper Tekeze, lower Tekeze, upper Atbara, and Angereb sub-basins have low water flow. While at sub-basins that haven't dames as lower Atbara River, Mareb River, sub-basin1, and sub-basin2 get total water volume flow of 90548.3, 135607, 72182 and 93303.6 X 1000 m^3 respectively with peak discharge are 99 m^3/s (in 09-Jul after 12960 min), 244.9 m^3/s (in 06-Jul after 8640 min), 185.6 m^3/s (in 05-Jul after 7200 min), and 66.7 m^3/s (in 14-Jul after 20160 min) respectively (Table 1).

Hydrogeological simulation modeling scenario at precipitation rate 50 mm

In this simulation model (precipitation rate 50 mm in 24 hours), the water volume at the Atbara River watershed is 1663313 × 1000 m^3 with peak discharge is 2023.3 (m^3/s) and the flow reaches its maximum after 05-Jul or 7200 min (Table 1). Hydrographic curve for Atbara sub-basins in this model (Fig. 5) indicates that the lowest water volume detected at upper Atbara River sub-basin 1331.5 X 1000 m^3 (peak discharge is 3.6 m^3/s and flow reaches its maximum in 05-Jul after 7200 min) and the highest water volume flow estimated at Mareb River sub-basin 571636.1 X 1000 m^3 (peak discharge is 1032.4 m^3/s and flow reaches its maximum in 06-Jul after 8640 min).

The total water volume flow of the other sub-basins as Angereb River, upper Tekeze, lower Tekeze, lower Atbara, sub-basin1, and sub-basin2 are 1915.2, 4515.4, 4629, 381697.5, 304276 and 393312 × 1000 m^3 respectively. Their highest flow and peak discharge are 6.8 m^3/s (in 04-Jul after 5760 min), 19.6 m^3/s (in 03-Jul after 4320 min), 18.9 m^3/s (in 03-Jul after 4320 min), 18.9 m^3/s (in 03-Jul after 4320 min), 782.6 m^3/s (in 05-Jul after 7200 min), and 281.2

m^3/s (in 13-Jul after 18720 min) respectively.

The rate of water volume flow at the Atbara River basin in its outlet at precipitation rate 15, 30, and 50 mm are 0.26 X 10^9, 11.74 X 10^9, and 49.89 X 10^9 m^3/month in the rainy season between July and October.

Hydrogeological simulation modeling scenarios of high precipitation rate

Along the Atbara River basin in intermittent years, heavy rainfall and flash flooding occurred with precipitation rate more than 50 mm. Furthermore, climate change and rising temperatures will effect on the Earth's water cycle. Which lead to increasing evaporation, then increases in precipitation and risk of flooding. These hydrogeological simulation modeling scenarios run for understanding and prediction of the flooding response to heavy precipitation, accumulation of rainfall and runoff, and determining how the hydrogeological parameters have changed or may continue to modify in a changing climate.

The modeling carried out at precipitation rate of 75, 100, and 150 mm in 24 hours (Table 1). In case of modeling simulation at precipitation rate 75 mm in 24 hours, the hydrographic curve and modeling results indicate that water volume at the Atbara River basin is 4.22159 × 10^9 m^3 with peak discharge and highest flow and the water volume rate is 5228 m^3/s, see Table (1) and Figs. (5 and 6).

Hydrographic curve at the outlet of Atbara River indicates that water flow start after 12 hours (720 min) from rainfall storm, then the flow reaches its maximum after 9 days (12960 min). The water runoff along the basin continue until one month. In case of modeling simulation at precipitation rate 100 mm (in 24 hours), the modeling results reflects that water volume at the Atbara River basin is 7.546428 X 10^9 m^3 at peak discharge with water volume rate is 9809.4 m^3/s (Figs. 5 and 6).

The results of the model at precipitation rate 150 mm in 24 hours of Atbara River reflect that, the total water volume flow at its outlet is 15.581924 X 10^9 m^3 at peak discharge with water volume rate is 22399.3 m^3/sec (Table 1).

Morphometric Analysis.

ASTER data were used for preparing DEM of

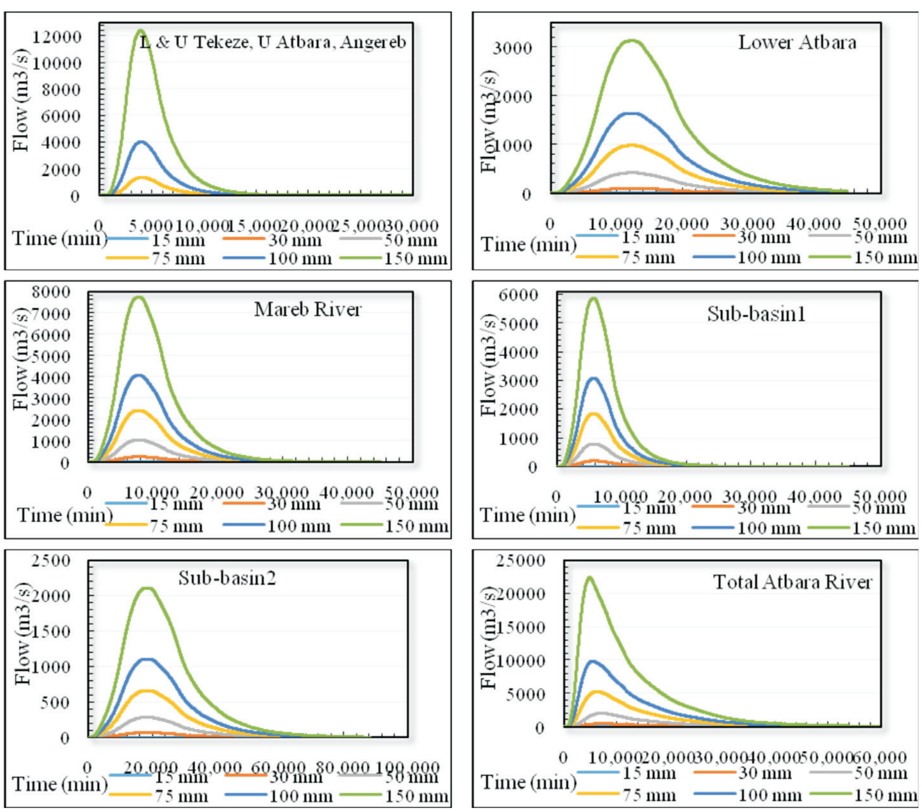

Fig. 5. Outlet Hydrograph created by HEC-HMS modelingfor Atbara River and its sub-basins.

Atbara River basin (Fig. 2) and detect sub-basins boundaries map (Fig. 3). The Atbara River basin classified to six main sub-basins (upper Atbara River, AngerebRiver, Tekeze River, Mareb River, sub-basin1 and sub-basin2).

Drainage network characteristics of Atbara River basin

The stream order of Atbara River basin using Strahler method is tenth-orders. The Atbara River basin stream numbers which specified are 681771 segments (Table 2). The total stream length of Atbara River is 415723.376km and for its sub-basins vary from 16895.8 to 106410.4 km. The mean stream length of Atbara River is 0.558 and for its sub-basins vary from 0.495to 0.679. The average stream length ratio of Atbara River is 0.984 and for its sub-basins vary from 0.956 to 1.009. The variation of stream length ratio values may due to the changes in the topographic and lithological conditions. The Atbara Riverwatershed has Weighted mean bifurcation ratio of 1.62 and for its sub-basins are 1.802 to 3.038. Most of Bifurcation Ratio (88.68%) are relatively low from different stream orders. The estimated main

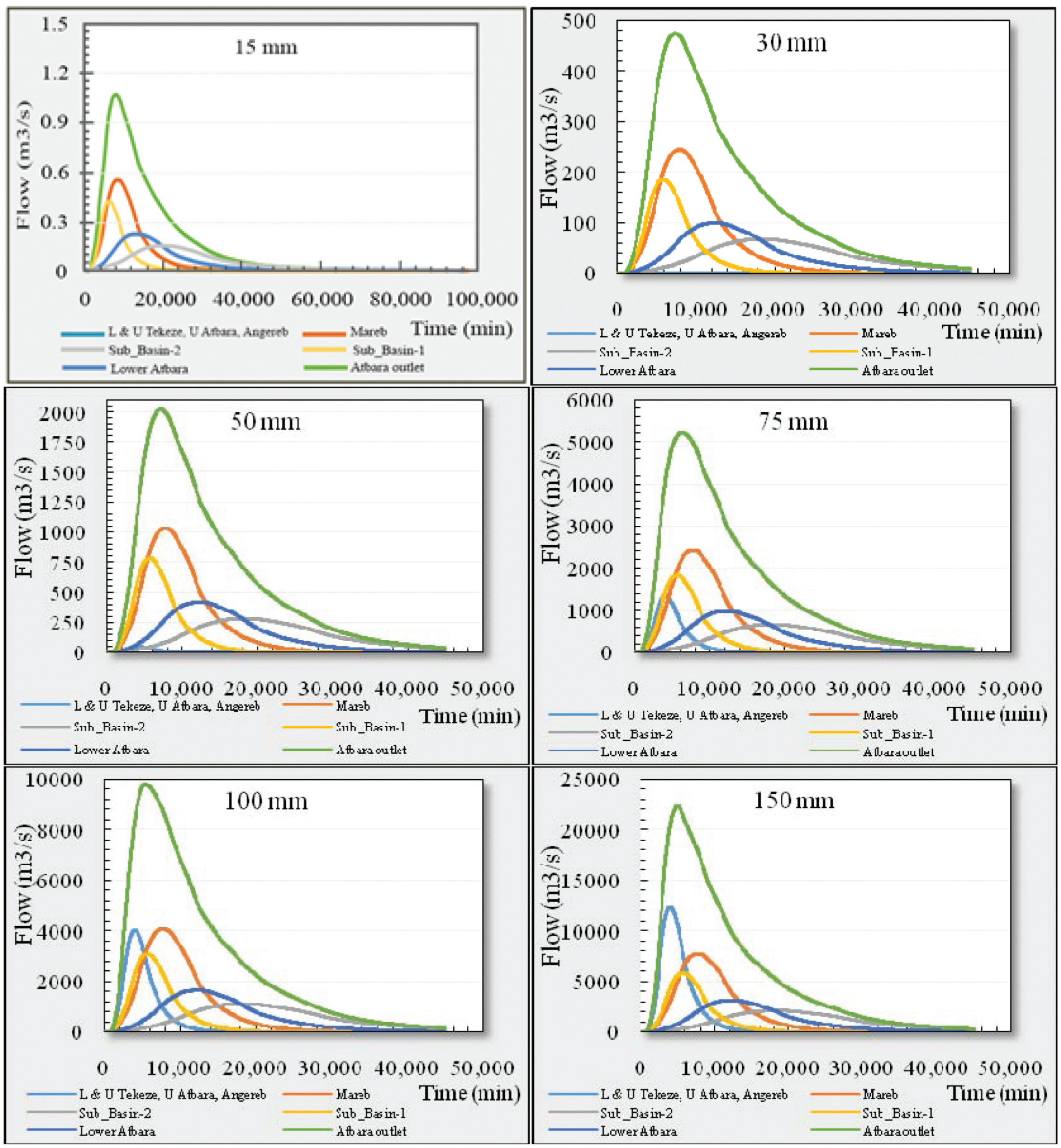

Fig. 6. Outlet Hydrograph created by HEC—HMS modelingfor Atbara River for each precipitation rate.

Table 1. Hydrograph curve of Atbara River and its sub-basins.

Atbara River Sub-basins	Peak discharge (m^3/s)	Time of peak (days)	Total W. volume flow (× 1000m^3)	Peak discharge (m^3/s)	Time of peak (days)	Total W. volume flow (×1000m^3)	Peak discharge (m^3/s)	Time of peak (days)	Total W. volume flow (×1000m^3)
	precipitation rate 15 mm			precipitation rate 30 mm			precipitation rate 50 mm		
Lower Tekeze	0	0	0	0	0	0	18.9	03Jul	4629
Upper Tekeze	0	0	0	0	0	0	19.6	03Jul	4515.4
Upper Atbara	0	0	0	0	0	0	3.6	05Jul	1331.5
AngerebRiver	0	0	0	0	0	0	6.8	04Jul	1915.2
Lower Atbara	0.2	10Jul	201	99	09Jul	90548.3	417.2	09Jul	381697.5
MarebRiver	0.5	06Jul	300	244.9	06Jul	135606.6	1032.4	06Jul	571636.1
Sub-basin1	0.4	05Jul	160.2	185.6	05Jul	72182	782.6	05Jul	304276
Sub-basin2	0.1	04Jul	207	66.7	14Jul	93303.6	281.2	13Jul	393312
Atbara River	1.1	06Jul	868.9	475.9	06Jul	391640.5	2023.3	05Jul	1663312.8
	precipitation rate 75 mm			precipitation rate 100 mm			precipitation rate 150 mm		
Lower Tekeze	529.7	03Jul	130049.9	1598.1	03Jul	392448.3	4900.6	03Jul	1202962
Upper Tekeze	548.6	03Jul	126858.2	1655.1	03Jul	382816.8	5075.8	03Jul	1173439
Upper Atbara	102.4	04Jul	37409	309.1	04Jul	112888.1	947.6	04Jul	346033.2
AngerebRiver	190.9	04Jul	53806	576.1	04Jul	162369	1766.2	04Jul	497706
Lower Atbara	979	09Jul	895556	1641.7	09Jul	1501871	3124.3	09Jul	2858077
MarebRiver	2422.4	06Jul	1341199	3581.8	06Jul	1983150	7730.9	06Ju	4280301.4
Sub-basin1	1836.4	05Jul	713906.1	3079.7	05Jul	1197239	5860.8	04Jul	2278360
Sub-basin2	659.8	13Jul	922806.6	1106.5	13Jul	1547571	2105.6	13Jul	2945045
Atbara River	5228.1	05Jul	4221591	9809.4	04Jul	7546428.6	22399.3	04Jul	15581924

channel length (CL) of Atbara River is 1390.914 km. The longest (CL) is 898.984 km computed in Mareb River, while the shortest is 323.393 km in Angereb River. The variations of geological and structural setting along Atbara River drainage systems control the values of their main channel length. The Sinuosity of Atbara River is 1.622 and for its sub-basins vary from 1.530 to 2.022. Atbara River and all its sub-basins consider as meandering channels, where their sinuosity values are more than 1.5 indicate long travel time of water flow along the watersheds to the outlet with a good water flow potentiality. The Rho coefficient (r) of Atbara River is 0.497. Sub-basins of high (r) values as Mareb River, upper Atbara, Tekeze River characterized by presence of good chance for water accumulation during the periods of floods and increase possibility for groundwater recharging.

Basin Geometry

The area of Atbara River basin is 231829.785 km^2 and for its sub-basins vary from 10384.846 (Upper Atbara River) to 66867.573 km^2 (Tekeze River). The area of all mentioned basins classified as large basins whereas their areas are more than 100 km^2 Horton (1945). Basin length of Atbara River is 857.4 Km and for its sub-basins vary from 203.2 to 553.2 km. The travel time of surface runoff (specially the flood waves passing through) for MarebRiver, TekezeRiver, sub-basin2 are the greatest that gives a good potentiality for groundwater recharge than the shortest travel time once. Basin perimeter and Basin width of Atbara River basin are 4415.580 and 270.39km respectively. The elongation Ratio values (vary from 0.448 to 0.641 km) indicates that all basins are elongated shape. The calculated drainage texture (Dt) of Atbara River is 154.401 km^{-1} and for its sub-basins vary from 35.11 to 91.64 km^{-1}. According to (Dt) values, the Atbara River sub-basins have drainage textures of very fine class controlled by the change in lithological, relief, climate, and rainfall conditions along Atbara River basin and its flow path.

The estimated texture ratio (Rt) of Atbara River is 77.626 km^{-1} and for its sub-basins vary from 17.638 to 46.053 km^{-1}. According to (Rt) values and Morisawa (1958) classification, the texture ratio of Atbara River basin and its sub-basins vary from medium texture (upper Atbara River), to soft texture (total Atbara River, Angereb River, Tekeze

River, Mareb River, sub-basin1, and sub-basin2). Lemniscate ratio, basin shape index, and compactness coefficient of Atbara River basin are 3.171, 0.401, and 2.588 km^{-1} respectively. The results that established from of the sub-basins boundaries map are corresponding with the interpretations of circularity ratio, lemniscate ratio, basin shape index, and compactness coefficient. They indicated elongated sub-basins shape which give a good chance for groundwater recharge due to basins length, therefore the runoff passes have great distance from the basins divide to their discharged at their outlets.

Drainage texture

The stream frequency for total Atbara River is 2.941 km^{-2} and for its sub-basins ranged between 2.817 km^{-2} (upper Atbara River basin) and 3.104 km-^{2} (sub-basin1). Stream frequencies have limited variation may be due to near similarity of their characteristics as relief, infiltration rate, lithology, conditions of erosion, and rainfall. The drainage density of Atbara River is 1.793 km^{-1} and for its sub-basins vary from 1.591 to 1.958km^{-1}. High drainage density at Atbara basin describe a rapid hydrologically response to the rainfall events and highly dissected drainage basin while low drainage density means slow or little hydrogeological response. Drainage Intensity, overland flow, infiltration number of Atbara River basin are 1.64 km^{-1}, 0.897 km^{-1} and 5.274 km^{-3} respectively. High drainage intensity sub-basins as Tekezes River, Angereb River, and upper Atbara River give a good chance of surface water runoff or flood waves passing through. The basin of high length of overland flow values, has high total stream length of all orders in a unite basin area. The higher values of the infiltration number indicate the lower infiltration characteristics and consequently the higher surface runoff. The form factor ratio (Fr) of Atbara River is 0.315 and for its sub-basins vary from 0.157 to 0.323. The low (Fr) values for all basins indicate elongated in their shapes with flow for longer duration. Dendritic pattern is the main pattern in most of Atbara River basin and its sub-basins as shown in Fig. 7.

Relief characteristics

The processing analysis results of the DEM show that basin relief varies greatly where the lowest relief is found to be 320 m. above mean sea level (a.m.s.l.) and the highest relief is 4529 m.a.m.s.l

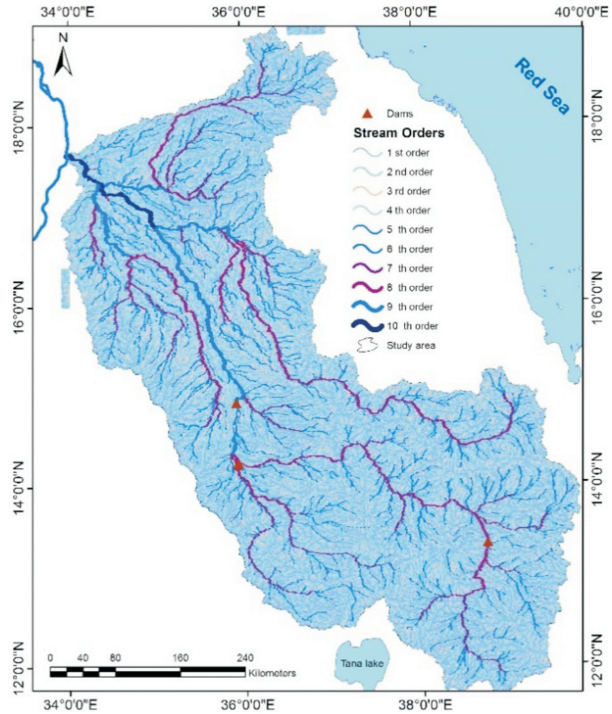

Fig. 7. Stream orders map of Atbara basin.

(Table 2). The outer water divides of most Atbara River basin characterized by presence of high relief and steep slope. Basin relief play an important role of the hydrological and physiographic characteristics of drainage watersheds, where high relief sub-basins as Tekeze River (4529 m), Angereb River (3046 m), and upper Atbara River (2809 m) have high runoff with low infiltration conditions. The lowest relief characterized sub-basins as Mareb River (350 m), sub-basin1 (334 m), and sub-basin2 (341 m). The basin relief, Relief Ratio, Ruggedness number, Hypsometric integral, and dissection index of Atbara basin are 994.67 m, 320, 7.548, 0.16, and 4209 respectively.

Slope map for the study created from ASTER DEM by using Surface Analysis Tool in ArcGIS-10.5 (Fig. 8). The mean basin slope of Atbara basin is 7.44^{o}. The highest slope has been observed at basins Tekeze River, upper Atbara River, and Angereb River while the lowest slope has been observed at basins Mareb River, sub-basin1, and sub-basin2. A steep slope increases stream flow velocity and allows faster removal of the runoff from the watershed, thereby reduces time of concentration and causes erosion as at basins of Tekeze River, upper Atbara River, and Angereb River.

Table 2. Morphometric parameters of Atbara River and its sub-basins.

Sl.	Parameters		Units	Upper Atbara River	Angereb River	Tekeze River	Mareb River	Sub-basin1	Sub-basin2	Total Atbara River
Drainage network										
1	Stream Order	Sμ	–	7	8	8	9	9	9	10
2	Stream number	Nμ	–	29259	41709	190286	142759	88913	98221	681771
3	Stream Length Min	$L\mu_{Min}$	Km	0.030055	0.030037	0.029918	0.022708	0.029268	0.029635	0.006786
4	Stream Length Max	$L\mu_{Max}$	Km	6.115428	4.707754	7.257979	7.080116	6.90585	6.439327	10.62546
5	Stream Length	Lμ	Km	16895.81	23804.26	106410.4	89057.03	56071.88	65648.59	415723.38
6	Mean Stream Length	L_{sm}	Km	0.529	0.507	0.495	0.597	0.612	0.679	0.558
7	Stream Length Ratio	RL	–	0.963	0.963	0.956	0.994	1.009	1.002	0.984
8	Mean Bifurcation R.	Rbm	–	1.802	2.132	1.879	3.038	2.095	2.031	2.298
9	weighted mean B, R.	WMRb	–	1.660	1.609	1.637	2.185	1.585	1.587	1.620
10	Main Channel Length	CL	Km	410.851	323.393	825.675	898.984	511.394	595.582	1390.914
11	Sinuosity	Si	–	2.022	1.530	1.768	1.625	1.552	1.577	1.622
12	Rho Coefficient	ρ	–	0.607	0.488	0.544	1.038	0.513	0.542	0.497
Basin Geometry										
13	Watershed Area	A	Km^2	10384.85	14434.79	66867.57	48112.73	28643.52	33548.07	231829.79
14	Basin perimeter	Pr	Km	833.364	844.997	2076.295	2376.803	1475.492	1502.905	4415.580
15	Basin length	LB	Km	203.2	211.4	467.1	553.2	329.5	377.6	857.4
16	Basin Width	W	Km	51.11	68.28	143.15	86.97	86.93	88.85	270.39
17	Circularity Ratio	Rc	–	0.188	0.254	0.195	0.107	0.165	0.187	0.149
18	Elongation Ratio	Re	Km	0.566	0.641	0.625	0.448	0.580	0.547	0.634
19	Drainage Texture	Dt	km^{-1}	35.110	49.360	91.647	60.063	60.260	65.354	154.401
20	Texture ratio	Rt	km^{-1}	17.638	24.798	46.053	30.168	30.307	32.842	77.626
21	Lemniscate ratio	K	–	3.976	3.096	3.263	6.361	3.790	4.250	3.171
22	Basin shape index	Ish	–	0.319	0.410	0.389	0.200	0.335	0.299	0.401
23	Compactness ratio	SH	km^{-1}	2.307	1.985	2.266	3.058	2.460	2.315	2.588
Drainage textur										
24	Drainage Frequency	(F)	km^{-2}	2.817	2.889	2.846	2.967	3.104	2.928	2.941
25	Drainage density	(D)	km^{-1}	1.627	1.649	1.591	1.851	1.958	1.957	1.793
26	Drainage Intensity	(Di)	km^{-1}	1.732	1.752	1.788	1.603	1.586	1.496	1.640
27	Length of overland f.	Lo	km^{-1}	0.813	0.825	0.796	0.926	0.979	0.978	0.897
28	Infiltration Number	FN	km^{-3}	4.584	4.765	4.529	5.492	6.077	5.729	5.274
29	Form Factor Ratio	Fr	–	0.252	0.323	0.306	0.157	0.264	0.235	0.315
Relief Aspects										
30	Max. elevation	H_{max}	m	2809	3046	4529	3269	1527	677	4529
31	Minimum elevation	H_{min}	m	501	503	469	350	334	341	320
32	Basin Relief	Rf	m	1007.77	1089.41	1659.62	844.46	569.31	444.02	994.67
33	Mean Elevation	Hm	m	0.011	0.012	0.009	0.005	0.004	0.001	0.005
34	Relief Ratio	Rr	–	501	503	469	350	334	341	320
35	Max slope	S_{max}	deg.	77.970	76.090	78.920	75.430	67.310	48.950	78.920
36	Mean basin slope	Sm	deg.	8.46	9.46	12.93	5.53	4.06	2.23	7.44
37	Ruggedness number	Rμ	–	3.755	4.194	6.461	5.403	2.335	0.658	7.548
38	Hypsometric Integral	HI	–	0.220	0.231	0.293	0.169	0.197	0.307	0.160
39	Dissection Index	DI	–	0.822	0.835	0.896	0.893	0.781	0.496	0.929
40	Internal relief	(E)	m	820	895	910	940	340	105	830
41	Slope index	SI%	–	0.266	0.369	0.147	0.139	0.089	0.024	0.080

Conclusion

The integration between the hydrogeological modeling and morphometric analyses using HEC-HMS and GIS techniques were performed. The HEC-HMS model simulate runoff at the present precipitation rate 15, 30, and 50 mm. As well as it simulates other three scenarios in case of high precipitation rate according to any climate change effects (at 75, 100, and 150 mm). The modeling at precipitation

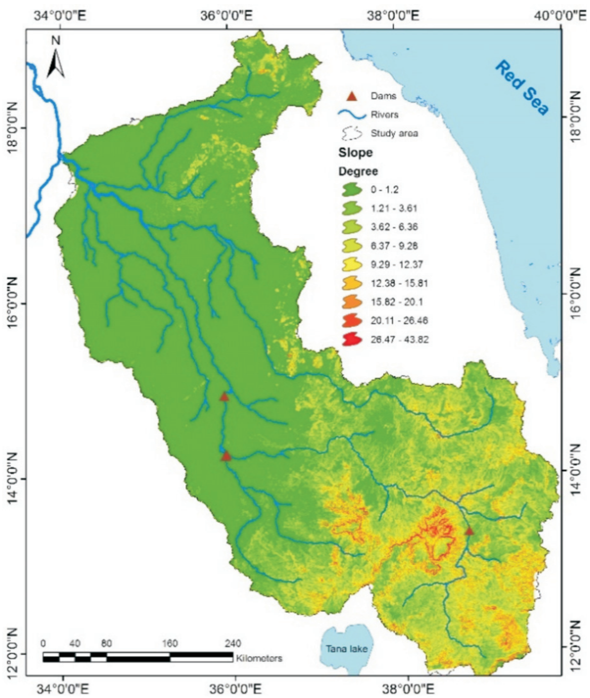

Fig. 8. Slope map of Atbara River.

rate 15 mm in 24 hours, the hydrographic curve and modeling results indicate that water volume at Atbara River basin is 868.9 × 1000 m^3 with peak discharge with water volume rate is 1.10 m^3/sec. Hydrographic curve in this model indicates that upper Tekeze, lower Tekeze, upper Atbara, and Angereb sub-basins has low water flow. While at Mareb River, lower Atbara River, sub-basin1, and sub-basin2 get high water flow (water volume are 300, 201, 160, and 207 X 1000 m^3 respectively). The modeling at precipitation rate equal 30, 50, 75, 100, and 150 mm, indicate water volume of 391641 X 1000, 1663313 X 1000, 4.22 X 10^9, 7.54 X 10^9, and 15.58 X 10^9 m^3 with peak discharge with water volume rate are 475.9, 2023.3, 5228, 9809.4, and 22399.3 m^3/sec respectively.

From the morphometric analysis, Atbara River watershed has total stream length 415723.376km and main channel length is 1390.914 km. The area, basin perimeter, basin width, stream frequency, drainage density, mean basin slope, and sinuosity of Atbara River basin are 231829.78 km^2, 4415.580km, 270.39 km, 2.941 km^{-2}, 1.793 km^{-1}, 7.44^o, and 1.622 respectively. Lemniscate ratio, basin shape index, compactness coefficient, drainage intensity, overland flow, infiltration number, basin relief, relief ratio, ruggedness number, hypsometric integral, and dissection index of Atbara River basin are 3.171, 0.401, 2.588 km^{-1}, 1.64 km^{-1}, 0.897 km^{-1}, 5.274 km^{-3}, 994.67 m, 320, 7.548, 0.16, 4209, 994.67 m, 320, 7.548, 0.16, and 4209 respectively.

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