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Identifying of Flash Flood-Prone Areas Based upon the Physical Characteristics of Semi-Arid Basins (Case Study of Wadi Baysh Basin, Southwest Saudi Arabia)

[1]Jalal M. Basahi, [2,3]Milad H. Masoud and [2]Syed F. Zaidi

[1]Department of Hydrology and Water Resource Management, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah-Saudi Arabia
[2]Water Research Center, King Abdulaziz University, Jeddah Saudi Arabia
[3]Hydrology Department, Desert Research Center-Cairo-Egypt

Abstract: Water shortage became a clear natural phenomenon which causes many problems and worries for many countries especially arid and semi-arid regions. Saudi Arabia is one of the biggest countries in the Middle East which also suffers from scarcity of water resources. Rainfall considers the main source of water for drinking and agricultural purposes especially in the southwest region of Saudi Arabia. Nowadays the government of Saudi Arabia is doing a big effort for optimal and maximum utilization of the natural water resources especially the flash flood hazard which is resulting from the heavy rainfall events. Forecasting the flash flood and identifying the flood-prone areas are very difficult tasks especially in arid regions due to the scarcity of historical data of rainfall and corresponding runoff. So, to overcome the problem of data shortage, this study is an attempt to identify the flood-prone areas in Wadi Baysh basin based upon the integration between geographic information systems (GIS) and physiographic features of the hydrographic basins. Wadi Baysh basin is one of the major significant basins of Jazan province in southwest of Saudi Arabia which is an important agricultural area of about 7300 km^2. Its main channel runs from northeast to southwest and discharging to the Red Sea. The catchment area of Wadi Baysh is about which is about 0.4 % of the total area of KSA, with length about 115 km, rising in the Asir Mountains and discharging to the Red Sea. The area receives annual rainfall ranging from 100 mm to 380 mm with estimated annual rainfall volume ranging from 0.73 BCM to 2.8 BCM. Morphometric analysis of Wadi Baysh basin and its sub-basins is based mainly on the physiographic features and morphometric parameters. These analyses were performed by tracing the drainage network using digital elevation model (30 m resolution DEM) and topographic maps (1:50,000 scale). The prevailing parameters such as basin area, flow accumulation, flow direction and stream ordering are prepared using ArcHydro Tool. Surface Tool in ArcGIS-10 software and ASTER (DEM) were used to create different thematic maps such as DEM, slope aspect and hillshade maps. Thirty five morphometric parameters were estimated and interlinked to produce nine effective parameters for evaluation of the flash flood risk in the study area. These nine parameters which have direct and indirect impact upon the basin's hydrologic behavior and time of concentration and are considering as a controlling factors of the flooding prone area. Based on the effective morphometric parameters, the flash flood risk of Wadi Baysh basin and its sub-basins were identified and classified into three categories (High, medium and low risk degree).

Key words: Flash floods · Basin · Hydrology · Baysh · DEM

INTRODUCTION

The morphometric characteristics of the hydrographic basins represent the final resultant of the interaction of geology, topography and climate influence. Characteristics of hydrographic basins consider as the most fundamental geomorphic features for hydrogeological studies and management of water resources for sustainable development especially in arid regions.

Corresponding Author: Jalal M. Basahi, Department of Hydrology and Water Resource Management, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah-Saudi Arabia.
E-mail: jbasahi@kau.edu.sa.

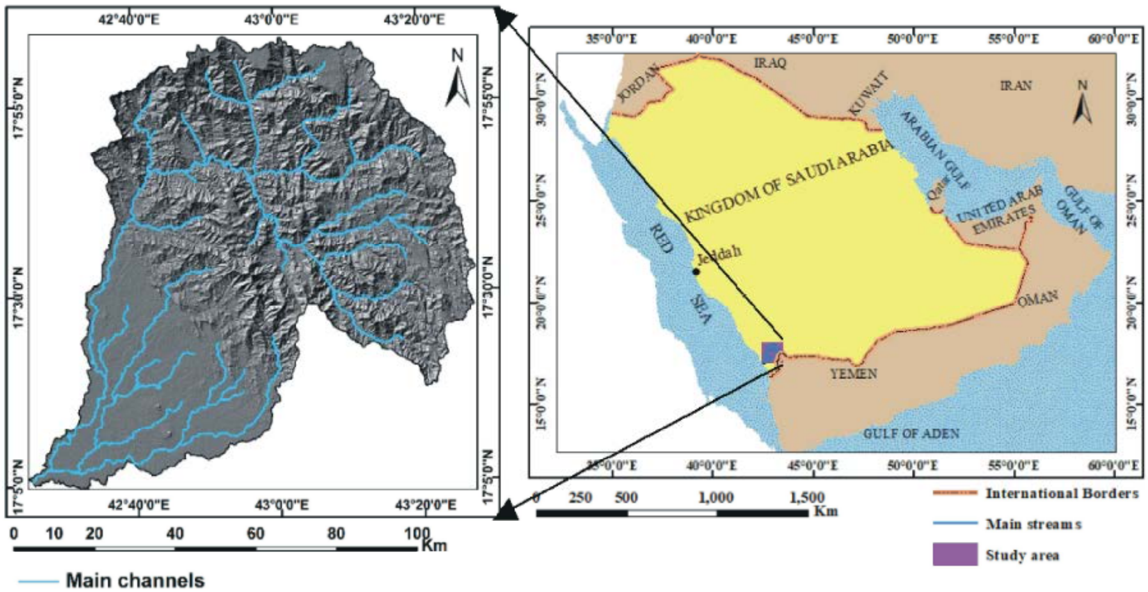

Fig. 1: Location map of Wadi Baysh basin

Comprehensive study and analysis of the drainage basin characteristics are very helpful for exploring the history of geomorphology, evolutions, features of landforms and basin tributaries which consider the most important controlling factors of the flash flood accumulation.

Morphometric analysis of Wadi Baysh basin and its sub-basins is based mainly on the physiographic features and morphometric parameters. These analyses were performed by tracing the drainage network using digital elevation model (30 m resolution DEM) and topographic maps (1:50,000 scale) as shown in Fig. 1.

The prevailing parameters such as basin area, flow accumulation, flow direction and stream ordering are prepared using ArcHydro Tool. Surface Tool in ArcGIS-10 software and ASTER (DEM) were used to create different thematic maps such as DEM, slope aspect and hillshade maps (Fig. 1). Thirty five morphometric parameters were estimated and interlinked to produce nine effective parameters for evaluation of the flash flood risk in the study area based on the references as shown in Table 1.

These nine parameters have direct and indirect impact upon the basin's hydrologic behavior and time of concentration and are considering as a controlling factors of the flooding prone area. Based on the effective morphometric parameters of the study basin flash flood risk of Wadi Baysh basin and its sub-basins were identified and classified into three categories (High, medium and low risk degree).

Location: Wadi Baysh basin is located in Jazan province which lies on south-western side of Saudi Arabia, is located between longitudes 42° 24’ to 43° 27’ E and latitudes 17° 05` to 18° 03` N. The catchment area of Wadi Baysh basin is about 7300 km2 rising in the Asir mountains and discharging to the Red Sea, as shown in Fig. (1).

Geomorphology: Wadi Baysh basin is an important part of Jazan province which is located in Tihama – Asir region, which is narrow coastal strip along the Red Sea. This region extends from Yemen in the south to about 250 km northward with a width ranges from 2 km to 120 km at Asir Mountains. Wadi baysh basin shows different relief characteristics with an elevation is ranging between 0 at the Red Sea Coast and 2980 at the water divide as shown in Fig. (2) and could be classified into three regions as follows:

- The coastal plain lies between the Sabkhas along the Red Sea coast and the foothills with variation width ranges between 20 km and 60 km. Usually, the coastal plain is flooded by flash flood through the main channels of the Wadis are crossing towards the Red Sea. This area is covered by alluvial soil which is good for recharging the shallow aquifer of groundwater [1, 2].
- The foothills which are located between the coastal plain and mountainous range with width ranges from 20 km to 60 km with an elevation about ranges from 0 m to 300 above mean sea level. This area is gently

Table 1: Geo-morphometric parameters formulas

Morphometric Parameters		Formula	Reference	
Drainage Network	1	Stream order ($_u$)	Hierarchical Rank	[12, 13]
	2	Stream number (N_u)	Nu = N1+ N2 + N3+…..Nn	[12]
	3	Stream length (L_u)	Lu= L1+L2+...... Ln	[10]
	4	Bifurcation ratio (Rb)	$Rb = Nu/$ Nu +	[10, 13]
	5	weighted mean bifurcation ratio (WMRb)	$WMRb = \frac{\sum(Rbu/Rbu+1)(Nu+Nu+1)}{\sum N}$	[14]
	6	Main channel Length (MC)	GIS software Analysis	
	7	Main channel index (MCi)	Ci = (Main channel length) / (Maximum straight of the main channel)	[15]
	8	Sinuosity (Si)	$Si = VL/LB$	[16]
Basin Geometry	9	Watershed Area (A)	GIS software Analysis	[17]
	10	The basin length (LB)	GIS software Analysis	[17]
	11	The basin perimeter (Pr)	GIS software Analysis	[17]
	12	Basin Width (W)	$W = A/LB$ (Km)	[10]
	13	Circularity ratio (Rc)	$Rc = 4\pi A/Pr^2$	[18]
	14	Elongation ratio (Re)	$Re = (2\sqrt{A/\pi}/LB$	[17]
	15	Texture ratio (Rt)	$Rt = \Sigma Nu/Pr$	[11]
	16	Form factor ratio (FFR)	$FFR = A/LB^2$	[10]
	17	Inverse shape form (Sv) or Shape factor ratio (Sf)	$Sv = LB^2.A$	[10]
	18	Basin shape index (Ish)	$Ish = 1.27A/LB^2$	[19]
	19	Compactness ratio (S_H)	$S_H = Pr/2(\sqrt{\pi A})$	[11]
Drainage texture	20	Stream Frequency (F)	$F = \sum_{i=1}^{K} Nu/A$	[10, 11]
	21	Drainage density (D)	$D = \Sigma Lu/A$	[10, 11]
	22	Drainage Intensity (Di)	Di = F/D	[20]
	23	Length of overland flow (Lo)	$Lo = 1/2\ D$	[11]
	24	Infiltration Number (FN)	FN = (F)(D)	[20]
	25	Drainage pattern (Dp)	Stream network using GIS software Analuysis	[10]
Relief characteristics	26	Maximum elevation (H_{max})	GIS software Analysis using DEM	
	27	Minimum elevation (H_{min})	GIS software Analysis using DEM	
	28	Relief (Rf)	Rf = Highest elevation-Lowest elevation	[12]
	29	Internal relief (E)	E= (E85-E10)	[12]
	30	Mean Elevation (Hm)	GIS software Analysis using DEM	
	31	Relief ratio (Rr)	$Rr = (Rf/LB)100$	[17]
	32	Slope index (SI %)	$SI = (E/0.75VL)100$	[21]
	33	Mean basin slope (Sm)	GIS software Analysis using DEM	
	34	Ruggedness number (Rn)	$Rn = Rf.D$	[22]
	35	Hypsometric Integral (HI)	$HI = (Elev - Elevmin)/Elev_{max} - Elev_{min})$ Elev is the mean elevation, $Elev_{max}$. is the maximum elevation and $Elev_{min}$ is the minimum elevation,	[23]

sloping and partly plateaus and is covered with boulders, rocks and depressions which are largely filled with alluvial materials having good water holding capacity. Most of the Wadi tributaries originate in the Asir Mountains cross the foothills to the coastal plain.

- The Asir Mountains extends east of the coastal plain from north to south parallel to the Red Sea with an abruptly altitude about more than 3000 m. These mountains are cut by deep Wadis, meandering towards the coastal plain, which provides communications within the mountains. The major Wadis are occurred in Jazan province.

Geology: Geology is very important and directly impacts to surface and groundwater by governing the hydraological behavior of the hydrographic basins such as basin shape, basin tributaries, surface runoff flow direction and groundwater recharge of shallow aquifer.

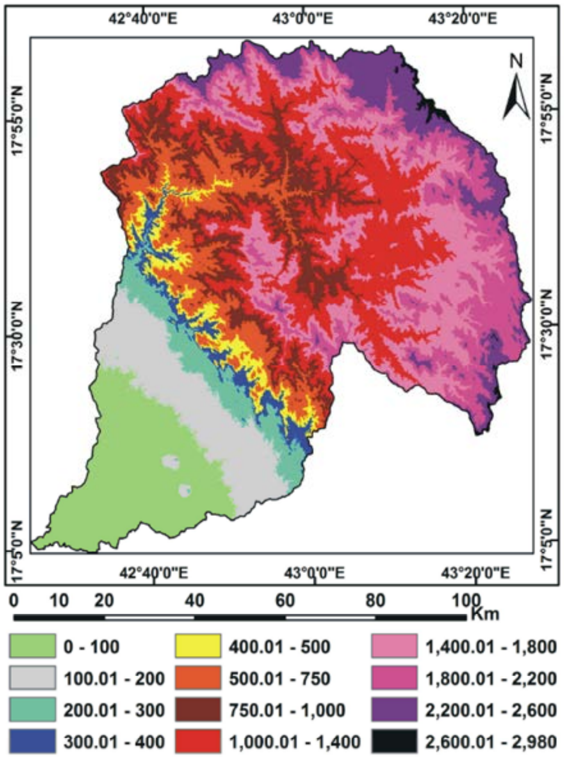

Fig. 2: Digital Elevation Model (DEM) of Wadi Baysh basin

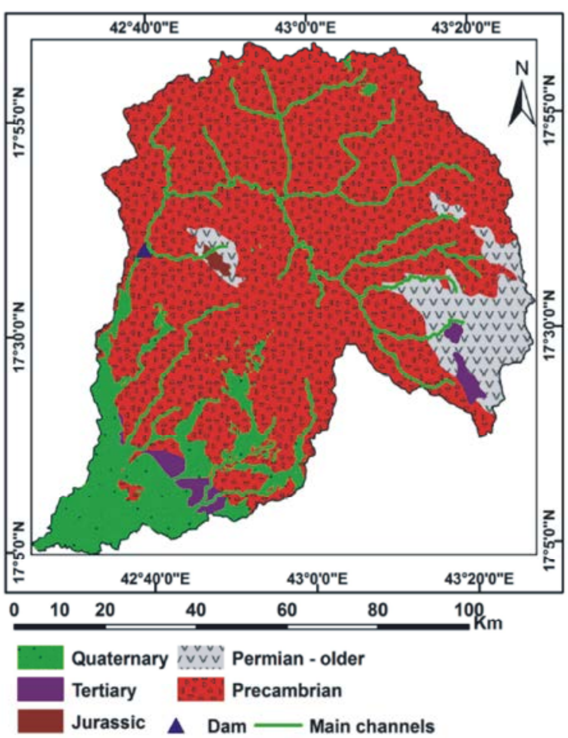

Fig. 3: Geological map of Wadi Baysh basin

Geologically, the Kingdom of Saudi Arabia can be classified into two structural sectors as follow:

- Western sector, which is called Arabian Shield and considers as a part of the Precambrian crust and is mostly outcropping but locally overlain by Tertiary volcanic rocks.
- Eastern sector, which is entitled the Arabian Shelf and comprises of a large thickness sedimentary covering of the Arabian tectonic plate.

Geologically, Wadi Baysh basin is a part of Arabian Shield which is located in Wadi Baysh quadrangle of Asir and Tihama province. This quadrangle includes geologic times from Late Proterozoic (Precambrian) to the Holocene as shown in Fig. (3). Wadi Baysh basin is characterized by a presence of predominant of an older ensimatic volcanic arc complex and a young of Andean type volcanic arc complex [3].

[3], classified the southern Arabian Shield into a series of generally north trending tectonic belts that are bonded by major structural breaks as follows:

- Proterozoic sedimentary, volcanic, metamorphic and intrusive rocks (Precambrian).
- Paleozoic and Mesozoic rocks.
- Tertiary rocks.
- Quaternary rocks and alluvial terrace deposits

The Precambrian series are exposed all along the north eastern flank of the Red Sea. Many volcanic intrusions, dyke swarms and flows that happened during the progress of the Red Sea rifting are characteristic of the Jazan Plain.

Palaeozoic and Mesozoic sediments occur as capping to the basement, but in some places they are preserved in down-faulted beds. In the study area only a few remnants on the ancient cover remain on the basement of it.

Tihama Asir fronts upon a pronouncedly flat coast, broken only by the slight 50 m elevation of the Jazan salt diapir (intrusion). The area adjacent to the coast is taken up by a Sabkhah zone, virtually as long as the coast and with a width up to several kilometers. Beneath the ground surface are alternate layers of silty, clayey sediments and evaporation products with a high salt content owing to the high groundwater level and the high rate of evaporation [4]. The Sabkhah area must have been largely flooded during high rainfall intensity and gradually follows a slight but distinct rise between the Wadis and can be traced in the alluvial accumulation plain of the middle terrace.

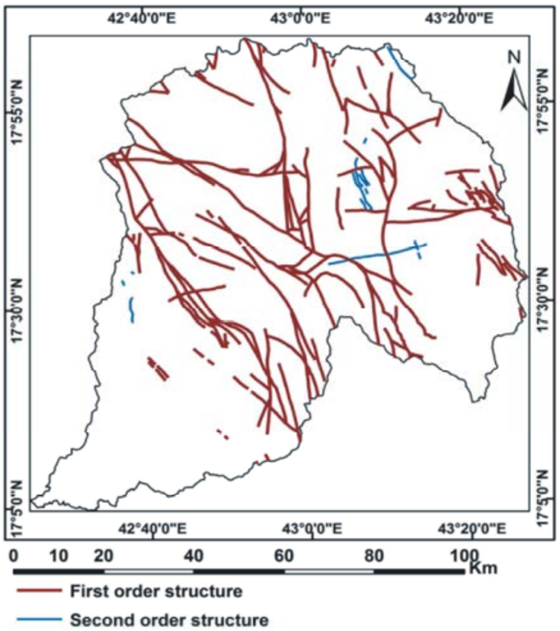

Fig. 4: Lineaments of Wadi Baysh basin

Tertiary formations occur beneath of the coastal plain and tend to outcrop in the foothills. They include: clay and marls locally associated with evaporates, limestone, detrital sediment of continental origin such as sand and gravel and basalts.

Quaternary and alluvial deposits occur in the Wadi beds and also as extensive sheets covering much of the coastal plain, so that the only alluvium remaining on the shield is in the Wadis. The alluvial layers are thin, ranges from some meters up to more than 80 m. From the structural geology, Wadi Baysh basin is dissected by many major and minor structures which are very important and influence upon the groundwater recharge as shown in Fig. 4.

Methodology: Flash flood forecasting for arid and semi-arid regions is one of the challenges particularly for the ungauged Wadis with the scarcity of hydrological data such as Wadi Baysh basin. So, one of the objectives of this project is to identify, inventory and evaluate the hydrological characteristics of Wadi Baysh basin

Table 2: Geo-morphometric parameters and hazard degrees of Wadi Baysh

Geo-morphometric Parameter			Baysh Basin	Name of Sub-basins									
			Entire Basin	Sabya	Wusaa	Qura	Dafa	Dhibah	Atf	Al Khayi	Bishah	Arkhan	Amoud
Drainage Network	1	($_u$)	8	6	6	6	6	6	6	6	6	6	6
	2	(N_u)	20208.000	2427.000	2793.000	760.000	2170.000	1989.000	1414.000	855.000	1821.000	809.000	441.000
	3	(L_u)	13704.000	1740.500	2098.600	571.100	1360.000	1247.500	890.300	569.100	1173.100	518.400	290.000
	4	(Rb)	4.060	4.542	4.680	3.750	4.510	4.667	4.316	3.840	4.354	3.800	3.500
	5	(WMRb)	4.490	4.530	4.590	4.610	4.295	4.350	4.502	4.522	4.496	4.606	4.700
	6	(MC)	151.000	56.600	35.000	7.100	16.100	39.200	19.500	9.200	19.100	11.400	1.000
	7	(MCi)	1.610	1.370	1.361	1.164	1.150	1.400	1.393	1.180	1.104	1.425	1.300
	8	(Si)	1.160	0.928	0.550	0.224	0.378	0.980	0.527	0.291	0.636	0.495	0.070
Basin Geometry	9	(A)	7308.400	851.600	989.000	268.000	793.000	696.000	514.400	317.400	650.300	302.500	161.000
	10	(LB)	130.000	61.000	63.600	31.600	42.600	40.000	37.000	31.600	30.000	23.000	15.000
	11	(Pr)	485.000	297.200	275.000	147.000	180.400	222.500	177.300	149.00	210.000	117.000	60.000
	12	(W)	56.200	13.960	15.550	8.480	18.615	17.400	13.900	10.040	21.670	13.150	10.700
	13	(Rc)	0.390	0.121	0.164	0.156	0.306	0.176	0.205	0.179	0.185	0.277	0.560
	14	(Re)	0.740	0.539	0.558	0.585	0.746	0.744	0.692	0.636	0.959	0.853	0.950
	15	(Rt)	41.670	8.160	10.150	5.170	12.030	8.940	7.970	5.740	8.670	6.910	7.350
	16	(FFR)	0.430	0.229	0.244	0.268	0.437	0.435	0.375	0.318	0.722	0.571	0.720
	17	(Sv) or (Sf)	2.310	4.370	4.090	3.730	2.290	2.290	2.660	3.150	1.380	1.750	1.400
	18	(Ish)	0.550	0.290	0.310	0.341	0.555	0.552	0.477	0.404	0.917	0.726	0.910
	19	(S_H)	1.600	2.874	2.467	2.533	1.807	2.380	2.205	2.360	2.323	1.898	1.330
Drainage texture	20	(F)	2.770	2.850	2.824	2.835	2.736	2.850	2.750	2.690	2.800	2.674	2.700
	21	(D)	1.880	2.040	2.120	2.130	1.715	1.792	1.730	1.790	1.804	1.713	1.800
	22	(Di)	1.480	1.390	1.330	1.330	1.595	1.594	1.588	1.502	1.552	1.560	1.520
	23	(Lo)	0.270	0.245	0.235	0.235	0.291	0.279	0.289	0.278	0.277	0.291	0.278
	24	(FN)	5.190	5.820	5.990	6.040	4.693	5.122	4.757	4.830	5.050	4.583	4.930
	25	(Dp)	dendroid	dendroid	dendroid	dendroid	dendroid	dendroid	dendroid	dendroid	dendroid	dendroid	dendroid
Relief Characterizes	26	H_{max}	2980.000	2448.000	2457.000	1326.000	2749.000	2695.000	2980.000	2919.000	2580.000	2552.000	2450.000
	27	H_{min}	0.000	2.000	2.000	43.000	874.000	887.000	772.000	774.000	612.000	342.000	818.000
	28	(Rf)	2980.000	2446.000	2455.000	1283.000	1875.000	1808.000	2208.000	2145.000	1968.000	2210.000	1632.000
	29	(E)	1785.000	830.000	560.000	390.000	740.000	900.000	1350.000	1480.000	1280.000	1040.000	685.000
	30	(Hm)	1043.000	386.600	580.000	228.000	1695.000	1677.000	1753.400	1797.400	1666.000	1045.000	1388.000
	31	(Rr)	0.023	0.040	0.038	0.040	0.044	0.045	0.059	0.067	0.065	0.096	0.110
	32	(SI %)	0.016	0.019	0.021	0.073	0.061	0.030	0.092	0.214	0.089	0.121	0.910
	33	(Sm)	15.200	9.000	6.000	5.000	21.000	16.500	26.300	20.000	20.200	21.500	22.300
	34	(Rn)	5.590	4.999	5.210	2.733	3.215	3.240	3.821	3.846	3.550	3.787	2.940
	35	(HI)	0.350	0.160	0.240	0.140	0.440	0.440	0.440	0.480	0.540	0.320	0.350
Summation of Hazard degree				26.670	28.440	18.740	24.470	24.930	20.630	17.960	26.290	19.790	23.990
Hazard degree				5.000	5.000	1.000	4.000	4.000	2.000	1.000	4.000	1.000	3.000

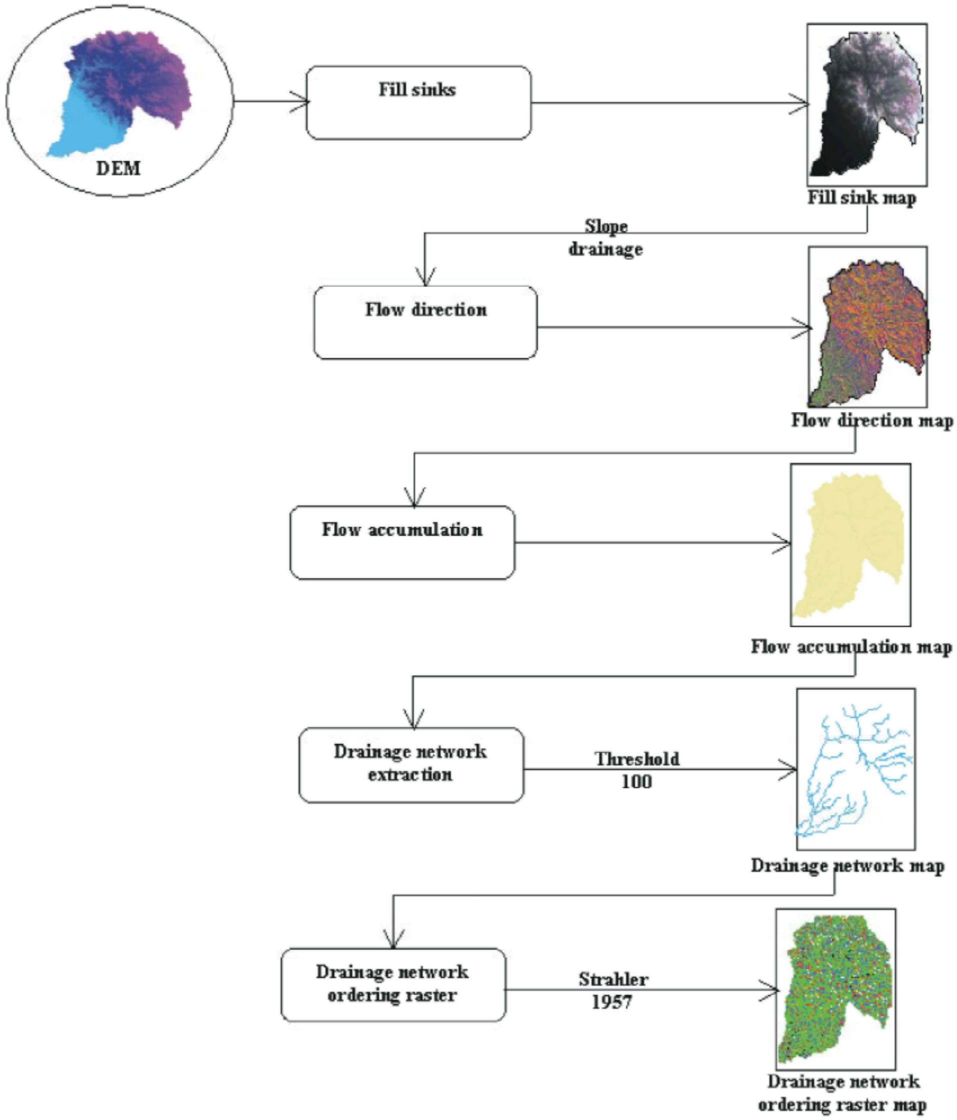

Fig. 5: Arc GIS 10.2 Flowchart for stream network, water divide extraction and mapping

depending on the physiographic features which influence on the surface runoff. Geo-morphometric features responsible about the hydrological behaviour of the hydrographic basin.

This study deals with the geo-morphometric features of Wadi Baysh basin with its effect for hydrologic characteristics based upon the integrations between geo-morphometric parameters and Geographic Information System (GIS). Basic information for this project was depending on the following:

- Digital Elevation Model (DEM 30 meter resolution) based upon ASTER data.
- Topography maps (1:250, 000).
- Geology maps (1:100, 000).

All the used data was confirmed and calibrated with field measurements.

Thirty five of geo-morphometric parameters were assessed and analysed using Arc Hydro and surface tools of Arc GIS 10 based on the equations and references as shown in Table 1 and Fig. 5. These 35 parameters were interconnected with each other to provide nine of high impact parameters for the evaluation the hazardous measure of flash flood for Wadi Baysh basin and its sub-basins (Table 2) as reported by [5-8] as shown in Fig. 5.

According to [9], the stream orders were traced and evaluated according to [10, 11] as shown in Tables 1 and 2. Geo-Morphometric characteristics of Wadi Baysh basin can be classified to four categories as follow; drainage network; basin geometry; drainage texture and relief characteristics.

RESULTS AND DISCUSSIONS

Drainage Network Characteristics: Wadi Baysh basin has 8th order and is classified into 10 sub-basins of 6th order (Table 2 and Fig. 6). It is clear that the highest frequency is in the first order streams while the lowest frequencies are in highest order. Total stream lengths for Wadi Baysh basin are 13704 km and it ranges from 290 km to 2793 km of Amoud and Wusaa sub-basins respectively. High negative correlations are observed among the order, number and length of the streams (Fig. 7), so, it could be concluded that the number and length of the streams are decreasing with increasing of stream orders.

Wadi Baysh basin and its sub-basins show a much closed range values of both bifurcation ratio (Rb) and weighted mean bifurcation ratios (WMRb). Values of Rb and WMRb are high and closed to 4, this shows the highly impact of the geologic structures controlling the drainage pattern. Limited range due to the similarity of lithology. Main stream length is measured using ArcGIS-10.2 and it is 151 km for Wadi Baysh basin. Main streams are ranging between 1 km and 56.6 km of Amoud and Sabya sub-basins respectively. Wide varieties of the main stream values are due to the structural control and amounts of surface runoff. Main stream index of Wadi Baysh and its sub-basins is ranging from 1.104 to 1.61 for Bishah sub-basin and Wadi Baysh basin respectively. Sinuosity parameter of Wadi Baysh and its sub-basin is ranging between 0.07 at Amoud sub-basin and 1.16 at Wadi Baysh. From these results it could be concluded that Amoud sub-basin has shorter travelling time of surface runoff flowing to the outlet, whereas whole Baysh basin and the other sub-basins have the longest travelling time which leads to high potentiality of groundwater recharge.

Basin Geometry Characteristics: Wadi Baysh basin and its sub-basins belong to large basin area, where it is more than 100 km2 (Table 2). Basin length of Wadi Baysh is 130 km, whereas for the sub-basins is ranging between 15 km and 63.6 km of Amoud and Wusaa sub-basins respectively. Wusaa sub-basin has maximum of travelling time with high potential for groundwater recharging than Amoud sub-basin of minimum travel time. Perimeter of Wadi Baysh basin is 485 km, whereas for its sub-basins it is ranging between 60 km of Amoud and 297.2 km of

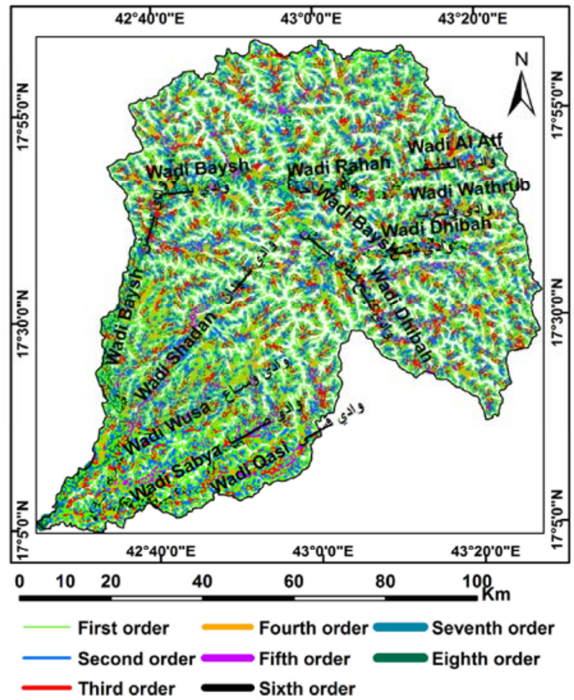

Fig. 6: Stream order of Wadi Baysh basin

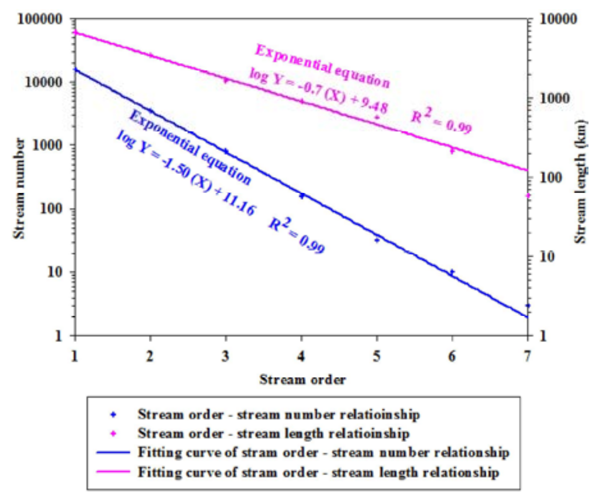

Fig. 7: Graphical representation of relationships between order, number and length of streams in Wadi Baysh basin

Sabya sub-basins (Table 2). Width of Wadi Baysh basin is 56.2 km, whereas for its sub-basin it is ranging between 8.48 km and 18.62 km for Qura and Dafa sub-basins respectively. Smaller value of basin width indicates more longitudinal shape which leads to more recharging of groundwater than those of higher ones.

Values of the circularity ratio for Wadi Baysh and its sub-basins show narrow range of variations and ranges between 0.12 for Sabya sub-basin and 0.56 for Amoud sub-basin (Table 2), which is an indication of elongated form having high potentialities of groundwater recharge. Limited variations of elongation ratios have been observed due to lithological and geological structures. It is ranging between 0.539 and 0.959 for Sabya and Bishah sub-basins respectively. As stated by [11], texture ratio (Rt) of Wadi Baysh basin is 41.67 km-1, whereas for its sub-basins it is ranging between 5.17 km-1 and 12.03 km-1 for Qura and Dafa sub-basins respectively. Based on [24], Rt could be classified into three following categories:

- Coarse Rt (<6.4 km-1)
- Intermediate Rt (6.4-16 km-1)
- Fine Rt (6.4-16 km-1)

Wadi Baysh basin is characterized by fine texture, while Qura and Al Khayi sub-basins are coarse texture, whereas the rest of sub-basins are intermediate texture (Table 2). [25] reported that to analyze basin characteristics, the importance of Rt factor cannot be neglected because of its relation with the lithological properties, infiltration rate and slope of the catchment.

Basins with small value of Rt have a high potential for recharging of groundwater than the others of high value of Rt. High value of Rt is due to the composition of hard rocks with no possibility for groundwater recharge which leads to high potential of surface runoff [26].

[10] stated that the form factor ratio (FFR) is a numerical parameter responsible about the basin shape and its value ranges between 0.1 and 0.8. FFR of the Wadi Baysh basin and its sub-basins have a large scale of variation and it ranges between 0.224 and 0.722 of Wusaa and Bishah sub-basins respectively, whereas FFR of the entire Wadi Baysh basin is 0.43. Basin of high value of FFR having circular shape can produce a hydrograph with large peak over its entire area than the basin of the same size with a low FFR [27]. [28] concluded that FFR is an important controlling feature of the water course which enters the main stream.

Values of the inverse shape form Sv for Wadi Baysh and its sub-basin range from 1.38 to 4.37 for for Bishah and Sabyah sub-basins respectively. Sv values are indications of basin length, where the higher value represents elongated basin with high potential for recharging groundwater.

The calculated values of basin shape index (Ish) for Wadi Baysh and its sub-basin range between 0.29 and 0.917 for Sabya and Bishah sub-basins respectively. High values of Ish are indicator for longitudinal basin lead to high potentiality of groundwater recharge, whereas basins of lower values produce more surface runoff with risk of flash floods. Compactness ratios (SH) of Wadi Baysh and its sub-basin range between 1.33 and 2.87 for Amoud and Sabya sub-basins respectively. Basins having low value of SH characterized by elongated shape with less erosion which give good chance for groundwater recharge, whereas basins of higher value are characterized by circular and high erosion which leads to high flash flood hazard.

Drainage Texture: Wadi Baysh and its sub-basins are characterized by limited variations of stream frequency values which range between 2.67 km-2 and 2.85 km-2 for Arkhan, Sabya and Dhibah sub-basins respectively (Table 2). Drainage density values (D) range between 1.71 km-1 and 2.13 km-1 of Arkhan and Qura sub-basins respectively. The higher drainage density values are indicators of heavy resultant runoff from high intensity rainfall. Whereas a lower drainage densities values demonstrate that Wadi Baysh basin composed of fractured hard rocks which lead to groundwater recharging. Wadi Baysh basin and its sub-basins have a drainage intensity values range between 1.33 and 1.595 for Wusaa and Dafa sub-basins respectively.

Wadi Baysh basin and its sub-basins have a limited values of overland flow (Lo) are ranging between 0.235 km and 0.291 km for for Wusaa, Qura Dafa and Arkhan sub-basins respectively (Table 2). Lower values of Lo indicate that the flash flood is concentrated faster than those having higher values.

Infiltration number (FN) considers as an indicator of the infiltration behavior of the drainage basin of high relief, fractured hard rocks. FN values of Wadi Baysh and its sub-basins range between 4.583 and 6.04 of Arkhan and Qura sub-basins respectively. Basins of lower FN have higher infiltration rate which leads to high potentiality of groundwater recharge. [29] reported that drainage patterns (Dp) help to determine erosion cycle phase and display the impact of slope, lithology and structural geology [30]. Wadi Baysh basin and its sub-basins are characterized by dendritic drainage patterns.

Relief Characteristics: Wadi Baysh basin is characterized by high relief with an elevations range between 0 to 2980 m above mean sea level. All the relief characteristics are tabulated in Table 2.

Slope of main channel (SI %) is an important factor which controlling the surface runoff behavior. SI % of Wadi Baysh basin is ranging between 0.016 and 0.91 for Wadi Baysh basin and Amoud sub-basin respectively (Table 2).

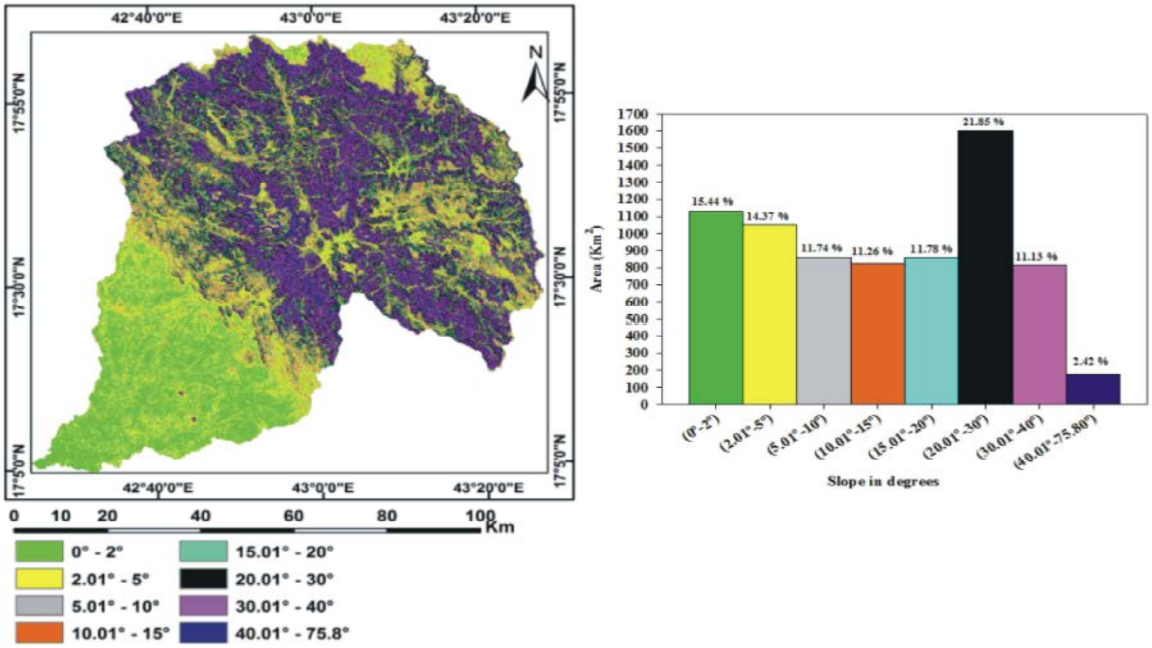

Fig. 8: Slope map and its histogram of Wadi Baysh basin

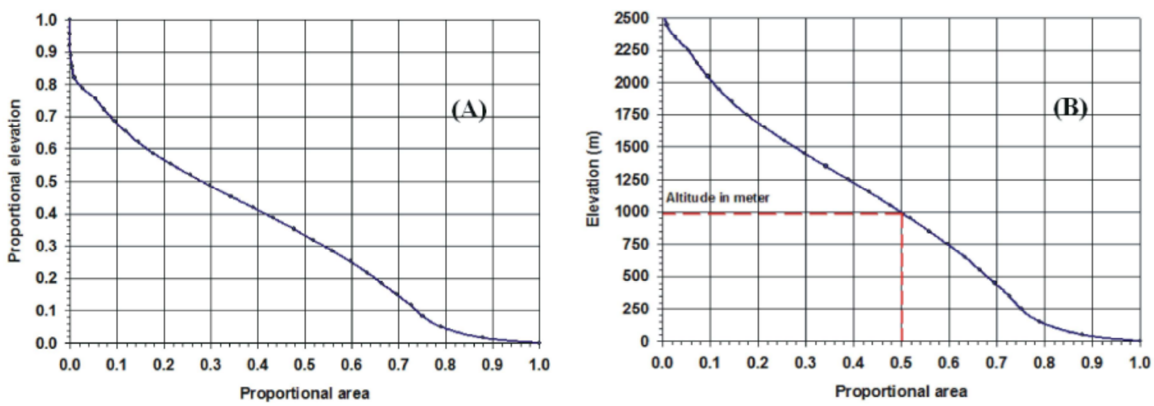

Fig. 9: Hypsometric curve (A) and Altitude curve (B) of Wadi Baysh basin

Mean basin slope (Sm) is very important morphometric parameter which is controlling the hydrologic behavior of the drainage basin. Mean slope values of Wadi Baysh basin and its sub-basins are shown in Table 2 and Fig. 8.

According to several researchers of hydrogeology such as [13, 25, 31-36], the hypsometric curves are important relationship which reflects the development of the shape, geomorphological features and geological tectonics of the study basin.

According to [13, 37] there are three shapes of the hypsometric curves as follow:

- Young hypsometric curve (convex upward curves),
- Mature hypsometric curve (S-shaped curves) and
- Old hypsometric curve (concave upward curves)

Wadi Baysh basin is characterized by concave upward curves hypsometric curve, old stage of (Fig. 9 a & b). [38] calculated the hypsometric integral (HI) to evaluate the erosion process of the basin through different geologic times. The HI values of Wadi Baysh were tabulated in Table 2.

Flash Flood Hazard Evaluation: Flash flood potentiality is depending on morphometric characteristics of drainage basin and rainfall intensity. The morphometric characteristics play the essential role for the flash flood hazard, where these parameters reflect the influence of geology, topography and climate on the drainage basin [39, 40].

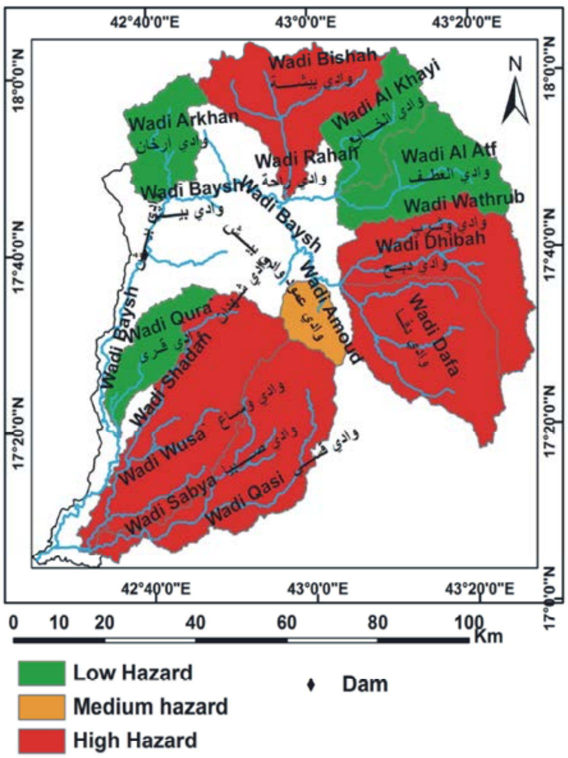

Fig. 10: Hazard degree map of Wadi Baysh basin

Evaluation of the flash flood hazard for Wadi Baysh sub-basins is depending upon nine effective geo-morphometric parameters having a direct influence upon flooding. These effective geo-morphometric parameters are watershed area (A), drainage density (D), stream frequency (F), shape index (Ish), slope index (SI), relief ratio (Rr), ruggedness ratio (Rn), texture ratio (Rt) and weighted mean bifurcation ratio (WMRb). All these parameters have a direct proportional relationship with the hazard geo-morphometric parameters except for the WMRb which has an inverse proportion. The hazard degree is calculated based on [41, 7, 8] using the following equations (1 and 2):

$$Hazard\ \text{degree} = \frac{4(\text{X-X}_{\text{min}})}{(\text{X}_{\text{max}}\text{-X}_{\text{min}})} + 1 \qquad (1)$$

$$Hazard\ \text{degree} = \frac{4(\text{X-X}_{\text{max}})}{(\text{X}_{\text{min}}\text{-X}_{\text{max}})} + 1 \qquad (2)$$

where X represents the geo-morphometric parameter of the sub-basin, Xmax represents the maximum value of the geo-morphometric parameter overall study sub-basins and Xmin is the minimum value.

From the calculated values (Table 2 and Fig. 10), the sub-basins of Wadi Baysh could be classified into three categories as follow:

Low hazard degree category includes Qura, Atf, Al Khayi and Arkhan sub-basins which have high potentialities of groundwater recharge.

Medium hazard degree group: includes Amoud sub-basin, is characterized by mild potentiality of surface runoff and recharging of groundwater.

High hazard degree group: includes Sabya, Wusaa, Dafa, Dhibah and Bishah sub-basins, this means that these sub-basins have very high potentialities for accumulating of surface runoff with short time of concentration.

CONCLUSIONS AND RECOMMENDATIONS

Wadi Baysh is a representative basin in southwest part of Saudi Arabia which annually receives rainfall ranges from 140 mm to 380 mm that causes flash floods periodically.

Basin morphometric parameters are playing significant controlling roles of surface runoff accumulation and flash flood evaluations for the arid and semi-arid ungauged basins. Flash flood hazard assessment is very important for the drainage basin management which will help in maximize of water use and minimize of water lose. Based upon the integration between morphometric parameters and geo-informatics technique, it could be concluded that the hydrologic behavior of Wadi Baysh and its sub-basins is influenced by the geomorphology, geology, soil cover and land use. Based on the shape of hypsometric curve it is a clear that Wadi Baysh basin is characterized by concave upward curve of old stage which leads to high potentiality of flash flood.

Sub-basins of Wadi Baysh could be classified into three categories as follow:

- *Low hazard degree category* includes Qura, Atf, Al Khayi and Arkhan sub-basins which have high potentialities of groundwater recharge.
- *Medium hazard degree category:* includes Amoud sub-basin, is characterized by mild potentiality of surface runoff and recharging of groundwater.
- *High hazard degree category:* includes Sabya, Wusaa, Dafa, Dhibah and Bishah sub-basins, this means that these sub-basins have very high potentialities for accumulating of surface runoff with short time of concentration.

Due to the lack of data, researchers recommend that a telemetric station and recorder for rainfall and runoff should be installed at the Wadi Baysh Dam for measuring the rainfall depth and recording the corresponding level and volume of the water in the lake.

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