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Morphometric Analysis and Flash Floods Assessment as A Tool for Rainwater-Harvesting and Runoff Hazard Management in Asir Region, Saudi Arabia

By

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Abstract

Flash floods are a continual hazard in Asir, and they can do significant damage to the region. The ASTER DEM, GIS, and geomorphic field data used in this study to predict flash floods for streams and basins are discussed. It was possible to undertake a quantitative evaluation of 37 watersheds on the Asir escarpment by using recovered and calculated morphometric characteristics and mathematical equations in this study. The techniques discussed above, Shamy's strategy for decisive the morphometric hazard degree, and morphometric investigation of the drainage basin and curve number were employed in the study (CN). Sub-basins at high and severe risk of flooding were identified and illustrated using geographic information systems (GIS). The research discusses management issues that may solve by using rainfall and runoff in the most efficient manner possible. Various management options for the basin's water resources are forecasted in this research using modeling geographic information systems (GIS). A map (A) shows the expected areas of runoff risk and water harvesting and (B) the planned dams' peak discharge (Qp) for each basin under consideration.

Keywords: Flash Flood; Hydrologic Analysis; Water Resources Management; Rainwater Harvesting

1- Introduction

When it comes to hydrological phenomena in dry environments, one of the most devastating natural disasters is flash flooding. Despite the reality, it is uncommon; they are common in dry locations, where they may cause one-of-a-kind and catastrophic catastrophes that risk both human life and property. Flaming rivers represent a significant threat to manufactured infrastructure along and across wadi streams, including dams, bridges, culverts, wells, roads, and highways, among other structures. Flash floods may occur when extremely dry or near-dry riverbeds get inundated with water because of the heavy rains over a brief time concise amount in terms of duration (Subyani & Al-Dakheel, 2009; Fathy, I.,2021). Generally speaking, floods are more common in wet regions. However, they may occur in dry and semi-arid places as well. Because they do not need measurable hydrologic data, GIS techniques are an integral part of the hydrologic modeling process. They are also being used more often to explore the hydrologic behavior of basins in order to validate certain essential aspects of sustainable water resource management, such as the amount of water that is available. However, since dry regions have a dearth of hydrologic data, estimating the likelihood of a flood is an extremely challenging endeavor. In order to assess whether or not there will be flooding in the future, it is essential to conduct an analysis of the topography of drainage basins using geoinformatics methods and field information. The hydrological characteristic of the watershed and the geomorphic procedures generated by massive rainstorms are predicted by applying suitable assessment factors described in detail below (Annis A.; et al., 2019). "Flash floods" are a term that is often used to describe flooding caused by a quick, high-peak discharge created by severe thunderstorms with a narrow region of effect (Farhan & Ayed, 2017). According to a study conducted by Bui, D.T. et al. (2019), the flood map and return interval are two important constrictions that must be met by flood risk reduction strategies.

According to (Blöschl, 2005), watershed modeling with sparse data results in the inability to derive hydrologic parameters for runoff molding, which are required to calibrate observed data, forcing the employment of other methodologies. Rainfall and runoff data are significant hydrologic variables in natural disaster studies during the twentieth century, particularly for inundating and mapping flash floods in desert drainage networks throughout the last century. In spite of the paucity of quantitative hydrological information in the region, the Wadi's topography and geomorphic properties were crucial for flooding caused by flash floods (Şen, 2012).

It is becoming increasingly standard practice to employ models of surface water in order to explore the hydrologic responses of watersheds to changes in land use (for example, shifts in land cover), climate change, and other structural variables (Tasdighi et al., 2018). Countries that experience dry or semi-arid climates have significant environmental, economic, and political challenges as a result of the risks posed by runoff and flash floods. Weather and hydrogeological conditions, the nature of wadi boundaries, their drainage network systems, and the types of rock unit that are contained within them all play an important role when it comes to determining the extent of the impact that flood flash environmental hazards have in dry mountainous locations. Access to water divides and basin streams may be gained via a variety of different approaches. Field excursions, GIS implementations, topographical and geological maps, and GIS tools are some of the strategies that fall under this category (Maidment & Morehouse, 2002; Masoud, 2015; Muzamil, A. R., 2022).

Using morphometric analysis of drainage basins, we may learn more about their hydrological characteristics, which can be used for hydrological prospecting and mapping flood-prone regions, among other things. Arc GIS software will be used to create flood risk maps that will illustrate the process of analyzing drainage systems and basin geometries, performing drainage texture analysis, and computing relief morphometric parameters, all of which will be demonstrated (Yousif & Bubenzer, 2015; Eseosa, H. I., 2022).

It has been shown that ASTER DEM data and GIS may be used to prioritize watersheds with the aim of preserving soil and water resources. Watershed systems are made up of hydrological, geological, geomorphological, and biological elements. Basic, linear, and areal form and relief features of a watershed are presented to calculate the morphometrics of a watershed (Horton, 1932, 1945; Strahler, 1952, 1964; Das, S., 2019).

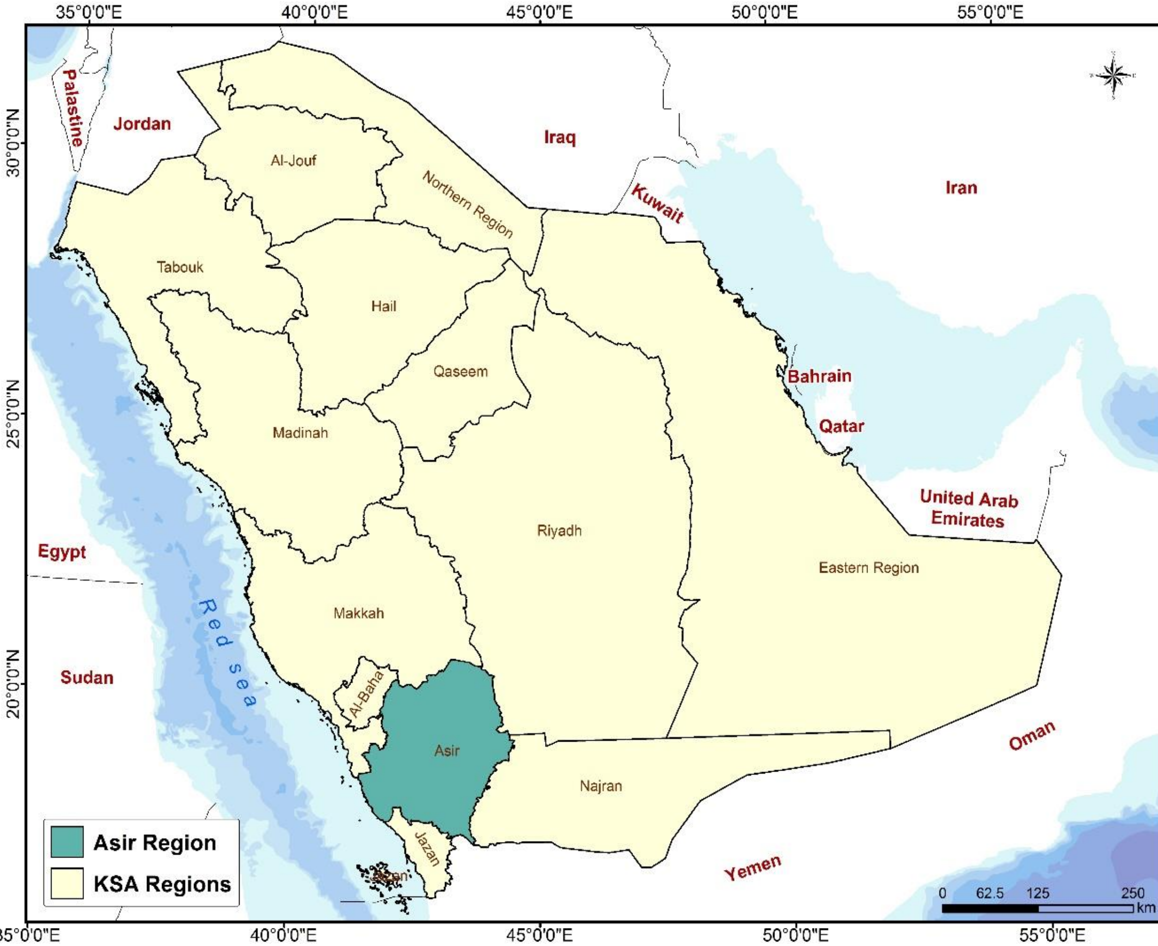
According to the World Bank, increased migration to new and attractive places, such as the Asir Region, may arise from economic success in line with Saudi Arabia's 2030 goal, in addition to the Asir development strategy "Qimam and Shem." Because of its geographic position and hydrological importance, the researched region is considered one of the most promising for a range of business ventures. Due to the increased danger of flooding in the Asir Region, the region's infrastructure, including roads and buildings, and other structures, may become increasingly susceptible to destruction. These necessitate the development of a revolutionary system that detects flash flood dangers and the resulting anxiety in society and analyses the quantity of runoff in the Asir region's key hydrographic sub-basins (based upon hydrologic models, as well as the GIS techniques). Last but not least, this study aims to build a credible scenario for flood management while also protecting the infrastructure and human habitations of the intended area from harm caused by floods.

This was accomplished using surface water models and GIS methodologies to estimate the degree of crucial vulnerability as well as excessive danger in each of the many study areas and to avoid heavy losses if any structural support, such as dams and reservoirs, is built in the Asir region, which has a history of devastating floods. A multi-criteria analysis (MCA) model based on a GIS was introduced for dam sites. Engineers and decision-makers in natural resource conservation may consider this study's findings.

2- Study Area

Asir' or 'Aseer' is a province in southwest Saudi Arabia, named after a confederation of tribes (Fig.1) (Som & Al-Kassem, 2013). Yemen is just a few kilometers over the border. The capital city is Abha. Mount Sawdah, which stands over 3,000 meters above sea level in Abha, is one of the country's highest peaks, receiving more rain than the rest of the country. The highlands get an average of 300-500 millimeters (12-20 inches) of rain each year, with some rain in the summer. The highlands have the most significant daily temperature changes in the globe. Mornings may be relatively chilly and foggy, but afternoons can reach 30 °C (85 °F) (Som & Al-Kassem, 2013). Consequently, the majority of Asir is covered in dense coniferous forest, although the ridges remain dry.

This pre-Cambrian continent of igneous and metamorphic rocks, which was produced during the pre-Cambrian epoch, has a geological structure that is extraordinarily complicated (both in age and origin). Rock may be classified according to its geological age and structural characteristics (MUSLIMS & Khan). Situated in western Asir is the Arab Shield, which includes a piece of the Tihama lowlands and the Arab shelf, located in the northeast. Aeolian shield and shelf are both igneous and metamorphic rocks, but the Arabian shield and shelf are composed of sedimentary rocks and geological formations produced as a consequence of slightly inclined sedimentary strata to the east and northeast. The drainage system of the kingdom of Asir, according to some estimates, has the most flowing tributaries in the country, which come in a range of forms and combinations. These tributaries may be divided into two major groups based on the Asir heights of their watersheds, which act as a hydrological divide between the two groups. In the second category, valleys that flow into the Tihama Plain and the Red Sea basin belong to the inland to the east and are generally characterized by sand veins or clusters of sand grains (Al-Zahrani, 2006). During the flash floods that ravaged Abha's Wadi Dhala in 1402 AH (1982 AD), the Asir area was hit the worst by the floodwaters (Mahsoub, 2009)



Reference: *KSA Administrative information, Updated Guidebook of the Population Names Manual during the 1442 AH agricultural census's planning phases.*

Fig.1: *Map showing the research area's location.*

3- Research Method:

For the purpose of quantitative morphometric study, the Asir watersheds were investigated using ArcGIS Pro 2.6, ASTER DEM, and topo-sheets at a ratio of 1: 50,000. The ASTER DEM is included in the Geo Tiff format, which may be downloaded for free and is also accessible. Arc GIS and the applications that go along with it are used to scan topographic sheets, georeference the data, and convert it to the WGS1984 zone 36 N projection system. This is done because the general accuracy of the ASTER DEM satisfies the parameters that are required.

There are many different methods to display georeferenced data maps and tabular and supplemental data. A feature is a collection of descriptive data included inside a geographic information system layer. Analyzing digital remote sensing data using ERDAS Imagine and ENVI, and ARC GIS and statistical tools, the researchers were able to acquire the findings of lithological, structural, and geometric analyses. GIS approaches have been developed to extract stream networks from digital elevation models (DEMs) (Omran et al., 2011; Zhang et al., 2009).

Table .1: *Morphometric variables and their mathematical and statistical formula*

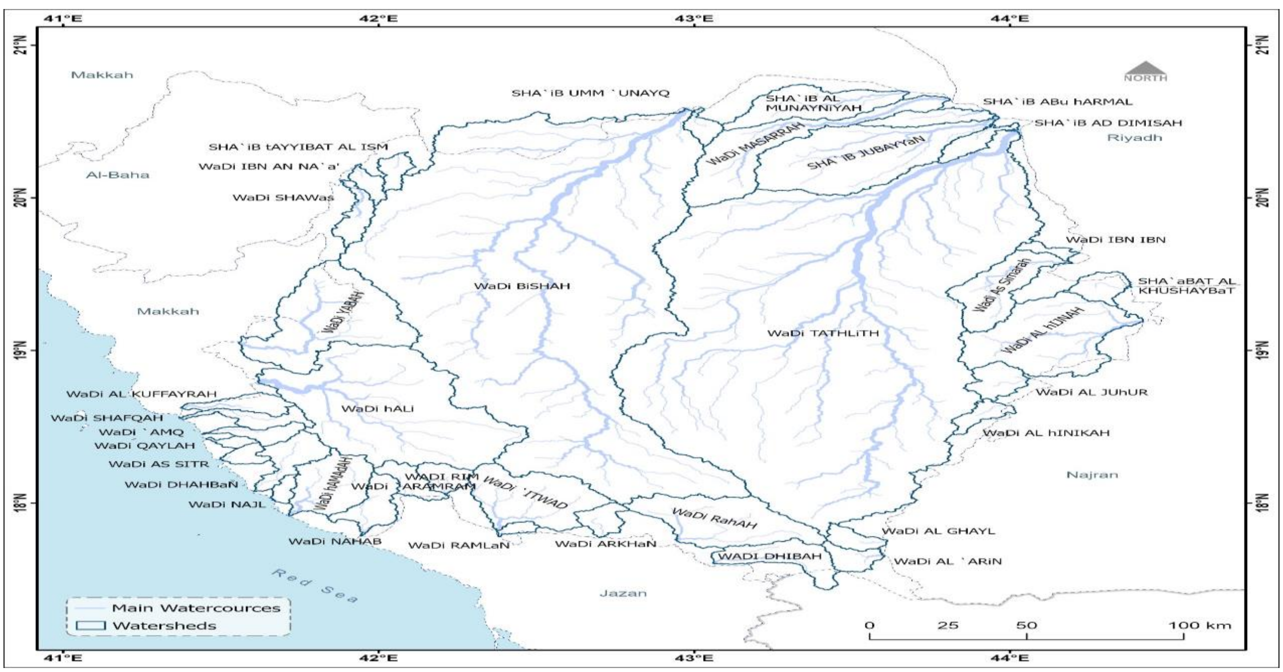
Morphometric Parameters	Formula/Definition	References
	Drainage network	
Stream order (u)	Hierarchical rank	
No. of streams (Nu)	N = N1 + N2 + ⋯ + Nn	(Strahler, 1952)
Stream length (Lu) km	Lu = L1 + L2 + ⋯ + Ln (km)	(Strahler, 1964)
Mean stream length (Lsm) km	Lsm = Lu/Nu (km)	(Horton, 1945)
Stream length ratio (RL)	RL = Lu/Lu−1, where Lu = the total stream length of order "u," Lu−1 = the total stream length of its next lower order	(Horton, 1945)
Bifurcation ratio (Rb)	Rb = Nu/Nu+1, where Nu = total no. of stream segments of order "u", Nu+1 = no. of segments of the next higher order	
Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratio of Strahler all orders	(Strahler, 1952)
Basin geometry		
Basin Length (Lb) km	GIS Software Analysis	(Schumm, 1956)
Basin area (A) km2		(Schumm, 1956)
Basin perimeter (P) km	GIS Software Analysis	(Schumm, 1956)
Form factor (ratio) (Rf)	$Rf = A/Lb^2$	(Horton, 1932)
Elongation ratio (Re)	$Re = 1.128 \sqrt{A} / Lb$	(Schumm, 1956)
Shape factor (Bs)	$Bs = Lb^2/A$	(Horton, 1945)
Lemniscate ratio (k)	$K = L^2/4A$	(Ivanova et al., 2012)
Circularity ratio (Rc)	$Rc = 4*\pi* A/p^2$	(Strahler, 1964)
Drainage texture (Dt)	Dt = Nu/P, where Nu = Total no. Streams of all orders, P = perimeter (km)	(Horton, 1945)
Drainage texture analysis		
Stream frequency (Fs)	Fs = Nu/A	(Horton, 1945)
Drainage density (Dd) km/km2	Dd = Lu/A	(Horton, 1945)
Drainage intensity (Di)	Di = Fs/Dd	(Faniran, 1968)
Length of overland flow (Lo) km	Lo = 1/2 Dd	(Horton, 1945)
Relief characteristics		
Basin relief (Bh) or total relief (H) m	Bh = h − h1, where, h = maximum height (m), h1 = minimum height (m	(Hadley & Schumm, 1961)
Relief ratio (Rr)	Rr = H/Lb, Where H = total relief, Lb = basin length	(Strahler, 1964)
Ruggedness number (Rn)	Rn = Dd∗(Bh/1000)	(Strahler, 1964)

Dissection index (Dis)	Dis = Bh/Ra, where Ra = absolute relief	(Singh & Dubey, 1994)
Hypsometric curve (HC)	HC is achieved by plotting the proportion of the total height (h/H) against the basin's total area (a/A), where H is the total relief height, and a is the basin's total area above a given line of elevation h.	(Strahler, 1964)
Hypsometric integral (Hi)	Hi= (H -H)/ (H- h), where H= the weighted mean elevation H = maximum elevation h = minimum elevation	(Strahler, 1952)

4- Results And Discussion

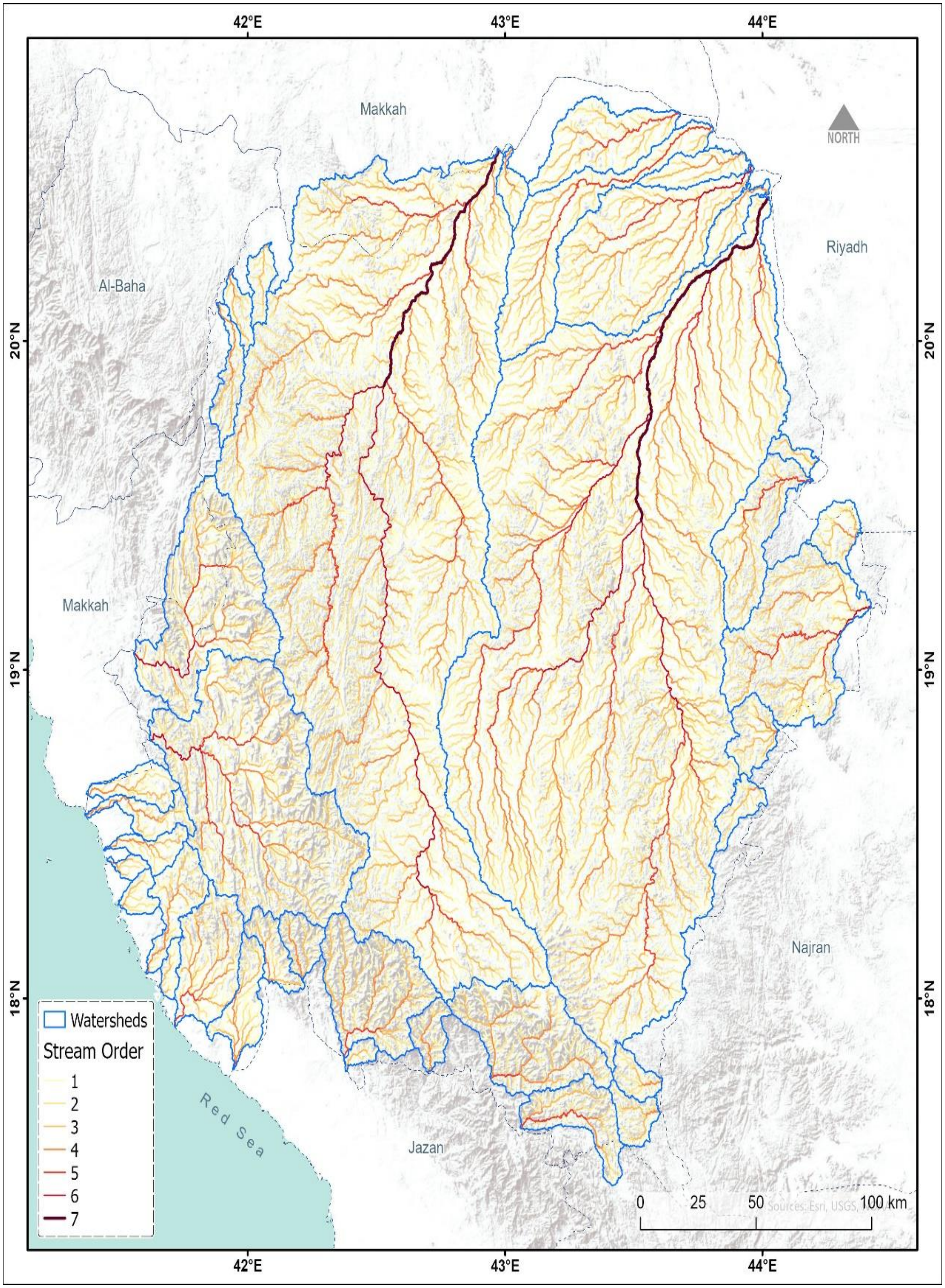
4-1- Morphometric Analysis of Hydrographic of the Streams and Basins of the Study Area:

Thirty-two morphometric variables were used to assess the relief features, geometry, drainage network, and texture of 37 watersheds on the Asir escarpment. The drainage system on dip slopes is naturally dendritic to sub dendritic, while the drainage system on faulted-erosional slopes is trellis-like. The Asir watersheds are rated in this article using Strahler's hierarchical ranking approach, described in detail elsewhere. This basin is characterized as a seventh-order basin due to the dendritic drainage design that it has (Fig. 2 Watersheds for basins and sub-basins and Fig. 3 Drainage and stream order of study area). Table 1 shows the morphometric features of several objects. The morphometric parameters that were acquired are reported in Table 2. Table.3 provides measurements for individual basins, while Table.4 contains geomorphological/morphological metrics for streams and basins. Table.3 contains measurements for individual basins. This stream morphometric analysis example will show how to do the following: (Table 5).



Reference: *Delineation from SRTM 3 Arc Second DEM using ArcGIS Pro 2.6 spatial analysis*

Fig. 2: *Watersheds for basins and sub-basins of the study location.*



Reference: *Delineation from SRTM 3 Arc Second DEM using ArcGIS Pro 2.6 spatial analysis*
Fig. 3: *Drainage and stream order of study area.*

Table .2: *Surface drainage network and stream order for basins and sub-basins of the study area*

Basin	Number of Streams Stream order (U)							Total	Stream Length (km) Stream order (U)							Total
	1	2	3	4	5	6	7		1	2	3	4	5	6	7	
SHA`aBAT AL- KHUSHAYBAT	75	36	12	4	0	0	0	127	139.6	38.4	41.9	13.3	0.0	0.0	0.0	233
SHA`iB ABu BARMAL	94	34	12	4	0	0	0	144	131.3	50.1	40.3	29.9	0.0	0.0	0.0	251
SHA`iB AD DIMISAH	49	22	6	4	0	0	0	81	82.6	56.4	18.0	22.7	0.0	0.0	0.0	180
SHA`iB AL- MUNAYNiYAH	250	96	27	12	5	0	0	390	385.5	157.7	104.6	27.3	47.6	0.0	0.0	723
SHA`iB JUBAYYaN	562	220	66	24	10	6	0	888	998.0	456.7	303.4	145.9	61.6	31.2	0.0	1997
SHA`iB TAYYIBAT AL- ISM	45	18	3	0	0	0	0	66	80.8	38.5	29.2	0.0	0.0	0.0	0.0	149
SHA`iB UMM `UNAYQ	39	18	12	4	0	0	0	73	70.4	33.3	8.7	19.8	0.0	0.0	0.0	132
WaDi `AMQ	48	24	12	4	0	0	0	88	86.5	38.1	31.6	27.5	0.0	0.0	0.0	184
WaDi `ARAMRAM	71	28	12	8	5	0	0	124	100.9	56.8	33.8	18.7	0.6	0.0	0.0	211
WaDi `ITWAD	321	142	42	16	5	0	0	526	465.8	234.5	143.0	88.2	27.0	0.0	0.0	959
WaDi AL- ARiN	59	26	9	4	0	0	0	98	97.9	51.9	29.6	8.9	0.0	0.0	0.0	188
WaDi AL -GHAYL	44	18	6	4	0	0	0	72	93.0	53.1	10.3	12.3	0.0	0.0	0.0	169
WaDi AL -HIJNAH	527	234	75	20	10	6	0	872	863.7	430.5	228.2	104.2	75.8	21.3	0.0	1724
WaDi AL- HINIKAH	47	18	9	4	0	0	0	78	85.6	45.0	17.9	4.0	0.0	0.0	0.0	153
WaDi AL- JUhUR	84	44	18	8	5	0	0	159	141.8	70.2	57.9	14.3	1.1	0.0	0.0	285
WaDi AL- KUFFAYRAH	69	30	6	4	0	0	0	109	110.1	69.3	32.5	22.7	0.0	0.0	0.0	235
WaDi ARKHaN	52	26	9	4	0	0	0	91	89.9	42.4	7.9	29.0	0.0	0.0	0.0	169
Wadi As Simarah	227	112	33	16	5	0	0	393	340.4	206.6	100.9	40.1	47.3	0.0	0.0	735
WaDi AS SITR	39	14	6	4	0	0	0	63	63.0	40.8	14.1	2.0	0.0	0.0	0.0	120
WaDi BiSHAH	4798	2124	666	172	45	12	7	7824	8124.5	4172.2	1936.5	1111.2	371.5	304.3	115.3	16135
WaDi DHAHBaN	114	54	18	4	0	0	0	190	181.2	80.6	55.0	42.4	0.0	0.0	0.0	359
WADI DHIBAH	149	66	24	12	5	0	0	256	201.0	107.5	61.0	28.8	43.5	0.0	0.0	442
WaDi Hali	1020	452	135	40	15	6	0	1668	1585.7	781.6	406.0	215.7	133.5	38.0	0.0	3161
WaDi Hamadah	194	96	39	16	5	0	0	350	341.5	172.7	92.5	97.4	24.4	0.0	0.0	728
WaDi IBN AN NA`a'	41	26	9	4	0	0	0	80	55.3	37.8	26.7	10.8	0.0	0.0	0.0	131
WaDi IBN IBN	25	10	3	0	0	0	0	38	43.0	17.3	24.9	0.0	0.0	0.0	0.0	85
WaDi MASARRAH	367	146	33	12	5	0	0	563	637.7	288.4	181.2	44.0	112.9	0.0	0.0	1264
WaDi NAHAB	101	46	21	8	5	0	0	181	192.3	96.1	68.9	39.2	3.1	0.0	0.0	400
WaDi NAJL	22	12	6	4	0	0	0	44	58.2	9.9	19.9	0.3	0.0	0.0	0.0	88
WaDi QAYLAH	20	10	6	4	0	0	0	40	22.4	17.9	14.2	6.0	0.0	0.0	0.0	60

WaDi RahAH	**351**	**148**	**39**	**12**	**5**	**0**	**0**	**555**	**541.2**	**246.7**	**94.1**	**121.7**	**14.9**	**0.0**	**0.0**	**1019**
WaDi RAMLaN	**20**	**8**	**3**	**0**	**0**	**0**	**0**	**31**	**33.5**	**8.9**	**15.5**	**0.0**	**0.0**	**0.0**	**0.0**	**58**
WADI RIM	**59**	**28**	**9**	**4**	**0**	**0**	**0**	**100**	**77.7**	**44.6**	**20.4**	**27.3**	**0.0**	**0.0**	**0.0**	**170**
WaDi SHAFQAH	**72**	**30**	**9**	**4**	**0**	**0**	**0**	**115**	**97.2**	**58.1**	**29.6**	**45.1**	**0.0**	**0.0**	**0.0**	**230**
WaDi SHAWas	**70**	**30**	**9**	**4**	**0**	**0**	**0**	**113**	**110.3**	**46.4**	**36.3**	**36.1**	**0.0**	**0.0**	**0.0**	**229**
WaDi TATHLITH	**5364**	**2258**	**768**	**232**	**75**	**24**	**7**	**8728**	**9238.8**	**4701.9**	**2318.1**	**1319.9**	**684.2**	**258.9**	**157.9**	**18680**
WaDi YABAH	**528**	**242**	**87**	**24**	**10**	**6**	**0**	**897**	**867.9**	**429.0**	**218.3**	**71.7**	**56.4**	**45.1**	**0.0**	**1688**

Table. 3: *Morphometric variable basins of the study area*

Basin	Basin Area (mk2)	Basin Length	Basin Width	Perimeter Length (km)	Gradient (longest path)	Circulatory ratio (Rc)	Elongation Ratio (Re)	Form Factor (Ff)	Compactness coefficient (Cc)	Length/Width Ratio	Leminescate ratio
SHA`aBAT AL KHUSHAYBaT	317.22	22.08	14.37	91.78	36.97	0.47	0.27	0.23	1.45	2.57	1.08
SHA`iB ABu HARMAL	371.81	44.51	8.35	128.67	59.29	0.28	0.18	0.11	1.88	7.10	2.36
SHA`iB AD DIMISAH	256.36	35.81	7.16	119.94	50.06	0.22	0.18	0.10	2.11	6.99	2.44
SHA`iB AL- MUNAYNiYAH	1015.31	66.87	15.18	191.04	93.27	0.35	0.19	0.12	1.69	6.14	2.14
SHA`iB JUBAYYAN	2541.16	95.53	26.60	291.66	135.12	0.38	0.21	0.14	1.63	5.08	1.80
SHA`iB TAYYIBAT AL-ISM	201.64	30.47	6.62	89.98	43.63	0.31	0.18	0.11	1.79	6.59	2.36
SHA`iB UMM `UNAYQ	181.98	27.73	6.56	81.62	41.31	0.34	0.18	0.11	1.71	6.29	2.34
WaDi `AMQ	253.15	34.76	7.28	100.75	51.27	0.31	0.18	0.10	1.79	7.04	2.60
WaDi `ARAMRAM	308.99	26.42	11.69	108.53	34.02	0.33	0.29	0.27	1.74	2.91	0.94
WaDi `ITWAD	1473.67	48.87	30.16	207.77	76.85	0.43	0.28	0.25	1.53	2.55	1.00
WaDi AL `ARiN	263.21	22.24	11.83	84.84	34.70	0.46	0.26	0.22	1.48	2.93	1.14
WaDi AL -GHAYL	225.43	23.46	9.61	76.08	34.79	0.47	0.27	0.23	1.45	2.57	1.08
WaDi AL- HIJNAH	2280.85	67.89	33.60	268.52	120.39	0.28	0.18	0.11	1.88	7.10	2.36
WaDi AL- HINIKAH	225.55	27.38	8.24	95.04	37.43	0.22	0.18	0.10	2.11	6.99	2.44
WaDi AL -JUhUR	376.66	22.81	16.51	101.15	39.88	0.35	0.19	0.12	1.69	6.14	2.14

WaDi AL-KUFFAYRAH	**331.44**	**37.82**	**8.76**	**109.58**	**54.61**	**0.38**	**0.21**	**0.14**	**1.63**	**5.08**	**1.80**
WaDi ARKHAN	**263.17**	**25.76**	**10.21**	**82.73**	**40.58**	**0.31**	**0.18**	**0.11**	**1.79**	**6.59**	**2.36**
Wadi As Simarah	**1013.50**	**61.25**	**16.55**	**197.30**	**105.67**	**0.34**	**0.18**	**0.11**	**1.71**	**6.29**	**2.34**
WaDi AS SITR	**158.99**	**18.28**	**8.70**	**64.74**	**23.45**	**0.31**	**0.18**	**0.10**	**1.79**	**7.04**	**2.60**
WaDi BiSHAH	**21797.04**	**283.57**	**76.87**	**1044.95**	**430.85**	**0.33**	**0.29**	**0.27**	**1.74**	**2.91**	**0.94**
WaDi DHAHBAN	**507.99**	**47.59**	**10.68**	**152.27**	**70.92**	**0.43**	**0.28**	**0.25**	**1.53**	**2.55**	**1.00**
WADI DHIBAH	**686.05**	**44.71**	**15.34**	**156.91**	**79.02**	**0.46**	**0.26**	**0.22**	**1.48**	**2.93**	**1.14**
WaDi HALi	**4790.81**	**97.94**	**48.92**	**408.60**	**169.67**	**0.47**	**0.27**	**0.23**	**1.45**	**2.57**	**1.08**
WaDi HAMAdAH	**971.84**	**51.52**	**18.86**	**169.68**	**78.69**	**0.28**	**0.18**	**0.11**	**1.88**	**7.10**	**2.36**
WaDi IBN AN NA`a'	**178.03**	**30.20**	**5.90**	**84.32**	**39.84**	**0.22**	**0.18**	**0.10**	**2.11**	**6.99**	**2.44**
WaDi IBN IBN	**115.21**	**21.33**	**5.40**	**71.56**	**33.99**	**0.35**	**0.19**	**0.12**	**1.69**	**6.14**	**2.14**
WaDi MASARRAH	**1656.45**	**116.19**	**14.26**	**339.26**	**179.31**	**0.38**	**0.21**	**0.14**	**1.63**	**5.08**	**1.80**
WaDi NAHAB	**485.10**	**46.82**	**10.36**	**145.12**	**67.91**	**0.31**	**0.18**	**0.11**	**1.79**	**6.59**	**2.36**
WaDi NAJL	**119.64**	**19.98**	**5.99**	**62.88**	**27.66**	**0.34**	**0.18**	**0.11**	**1.71**	**6.29**	**2.34**
WaDi QAYLAH	**83.95**	**17.82**	**4.71**	**49.77**	**24.04**	**0.31**	**0.18**	**0.10**	**1.79**	**7.04**	**2.60**
WaDi RAhAH	**1613.20**	**50.96**	**31.66**	**222.67**	**70.54**	**0.33**	**0.29**	**0.27**	**1.74**	**2.91**	**0.94**
WaDi RAMLAN	**90.91**	**15.57**	**5.84**	**49.10**	**23.69**	**0.43**	**0.28**	**0.25**	**1.53**	**2.55**	**1.00**
WADI RIM	**278.24**	**24.31**	**11.45**	**78.70**	**34.27**	**0.46**	**0.26**	**0.22**	**1.48**	**2.93**	**1.14**
WaDi SHAFQAH	**316.85**	**45.90**	**6.90**	**147.57**	**73.66**	**0.47**	**0.27**	**0.23**	**1.45**	**2.57**	**1.08**
WaDi SHAWAS	**330.27**	**48.84**	**6.76**	**139.92**	**68.92**	**0.28**	**0.18**	**0.11**	**1.88**	**7.10**	**2.36**
WaDi TATHLITH	**24478.27**	**301.52**	**81.18**	**970.75**	**438.85**	**0.22**	**0.18**	**0.10**	**2.11**	**6.99**	**2.44**
WaDi YABAH	**2489.91**	**68.30**	**36.46**	**300.76**	**119.76**	**0.35**	**0.19**	**0.12**	**1.69**	**6.14**	**2.14**

Table. 4: *Geomorphological and morphological variables of the streams and basins of the study area*

Basin	H	h	Mean Elevation	Drainage density (Dd)	Gradient Ratio (Gr)	Basin relief (H)	Relative relief (Rhp)	Relief ratio ((Rh)) (Dimensionless)	Ruggedness Number (HD)	Texture Ratio	Stream Maintenance	Hypsometric Integral	Geometrc Number
SHA`aBAT AL - KHUSHAYBAT	1367	994	1100	0.73	0.010	373	4.1	0.017	0.27	1.07	1.36	0.45	43.48
SHA`iB ABu HARMAL	919	776	841	0.68	0.002	143	1.1	0.003	0.10	0.90	1.48	0.53	210.51
SHA`iB AD DIMISAH	893	776	842	0.70	0.002	117	1.0	0.003	0.08	0.53	1.43	0.54	214.44
SHA`iB AL- MUNAYNiYAH	1167	802	933	0.71	0.004	365	1.9	0.005	0.26	1.63	1.40	0.47	130.41
SHA`iB JUBAYYAN	1330	781	952	0.79	0.004	549	1.9	0.006	0.43	2.41	1.27	0.40	136.73
SHA`iB tAYYIBAT AL- ISM	1745	1293	1455	0.74	0.010	452	5.0	0.015	0.33	0.61	1.36	0.56	49.66
SHA`iB UMM `UNAYQ	1136	990	1034	0.73	0.004	146	1.8	0.005	0.11	0.65	1.38	0.53	137.92
WaDi `AMQ	850	0	297	0.73	0.017	850	8.4	0.024	0.62	0.65	1.38	0.44	29.67
WaDi `ARAMRAM	1529	167	462	0.68	0.040	1362	12.5	0.052	0.93	0.85	1.47	0.54	13.24
WaDi `ITWAD	2980	232	1192	0.65	0.036	2748	13.2	0.056	1.79	1.98	1.54	0.69	11.57
WaDi AL `ARIN	2660	2018	2307	0.72	0.019	642	7.6	0.029	0.46	0.90	1.40	0.51	24.79
WaDi AL- GHAYL	2737	1983	2258	0.75	0.022	754	9.9	0.032	0.56	0.74	1.34	0.57	23.29
WaDi AL- HIJNAH	1786	1040	1337	0.76	0.006	746	2.8	0.011	0.56	2.52	1.32	0.50	68.78
WaDi AL- HINIKAH-	2074	1502	1728	0.68	0.015	572	6.0	0.021	0.39	0.63	1.48	0.54	32.38
WaDi AL- JUhUR	1806	1364	1544	0.76	0.011	442	4.4	0.019	0.33	1.14	1.32	0.41	39.08
WaDi AL- KUFFAYRAH	784	-1	192	0.71	0.014	785	7.2	0.021	0.56	0.79	1.41	0.37	34.09

WaDi ARKHaN	**2563**	**370**	**1079**	**0.64**	**0.054**	**2193**	**26.5**	**0.085**	**1.41**	**0.83**	**1.56**	**1.37**	**7.55**
Wadi As Simarah	**1660**	**1041**	**1313**	**0.73**	**0.006**	**619**	**3.1**	**0.010**	**0.45**	**1.52**	**1.38**	**2.37**	**71.79**
WaDi AS SITR	**484**	**-5**	**185**	**0.75**	**0.021**	**489**	**7.6**	**0.027**	**0.37**	**0.76**	**1.33**	**3.37**	**28.20**
WaDi BiSHAH	**2990**	**995**	**1640**	**0.74**	**0.005**	**1995**	**1.9**	**0.007**	**1.48**	**5.87**	**1.35**	**4.37**	**105.22**
WaDi DHAHBAN	**896**	**-2**	**314**	**0.71**	**0.013**	**898**	**5.9**	**0.019**	**0.64**	**0.97**	**1.41**	**5.37**	**37.48**
WADI DHIBAH	**2674**	**890**	**1670**	**0.64**	**0.023**	**1784**	**11.4**	**0.040**	**1.15**	**1.24**	**1.55**	**6.37**	**16.14**
WaDi HALi	**2984**	**87**	**861**	**0.66**	**0.017**	**2897**	**7.1**	**0.030**	**1.91**	**3.19**	**1.52**	**7.37**	**22.30**
WaDi HAMADAH	**1386**	**-2**	**266**	**0.75**	**0.018**	**1388**	**8.2**	**0.027**	**1.04**	**1.53**	**1.33**	**8.37**	**27.82**
WaDi IBN AN NA`a'	**1821**	**1357**	**1529**	**0.73**	**0.012**	**464**	**5.5**	**0.015**	**0.34**	**0.69**	**1.36**	**9.37**	**47.75**
WaDi IBN IBN	**1347**	**996**	**1146**	**0.74**	**0.010**	**351**	**4.9**	**0.016**	**0.26**	**0.43**	**1.35**	**10.37**	**44.99**
WaDi MASARRAH	**1387**	**801**	**1048**	**0.76**	**0.003**	**586**	**1.7**	**0.005**	**0.45**	**1.34**	**1.31**	**11.37**	**151.31**
WaDi NAHAB	**1027**	**10**	**164**	**0.82**	**0.015**	**1017**	**7.0**	**0.022**	**0.84**	**0.92**	**1.21**	**12.37**	**37.92**
WaDi NAJL	**400**	**-1**	**98**	**0.74**	**0.014**	**401**	**6.4**	**0.020**	**0.30**	**0.49**	**1.35**	**13.37**	**36.80**
WaDi QAYLAH	**481**	**-1**	**160**	**0.72**	**0.020**	**482**	**9.7**	**0.027**	**0.35**	**0.56**	**1.39**	**14.37**	**26.63**
WaDi RAHAH	**2989**	**602**	**1666**	**0.63**	**0.034**	**2387**	**10.7**	**0.047**	**1.51**	**1.98**	**1.58**	**15.37**	**13.48**
WaDi RAMLAN	**986**	**179**	**433**	**0.64**	**0.034**	**807**	**16.4**	**0.052**	**0.51**	**0.51**	**1.57**	**16.37**	**12.31**
WADI RIM	**1995**	**351**	**898**	**0.61**	**0.048**	**1644**	**20.9**	**0.068**	**1.00**	**0.98**	**1.64**	**17.37**	**9.03**
WaDi SHAFQAH	**898**	**0**	**270**	**0.73**	**0.012**	**898**	**6.1**	**0.020**	**0.65**	**0.62**	**1.38**	**18.37**	**37.10**
WaDi SHAWas	**2276**	**1411**	**1723**	**0.69**	**0.013**	**865**	**6.2**	**0.018**	**0.60**	**0.64**	**1.44**	**19.37**	**39.19**
WaDi TATHLITH	**2970**	**791**	**1488**	**0.76**	**0.005**	**2179**	**2.2**	**0.007**	**1.66**	**7.03**	**1.31**	**20.37**	**105.60**

WaDi YABAH	**2713**	**113**	**740**	**0.68**	**0.022**	**2600**	**8.6**	**0.038**	**1.76**	**2.28**	**1.47**	**21.37**	**17.81**

Table. 5: *Morphometric analysis of streams of the study area*

Basin	Stream Frequency (Fs)	Drainage Density (D)	Infiltration Number	Overland flow	Mean Bifurcation ratio (Rbm)	Weighted Bifurcation Ratio (Rb)	Stream Slope (Degree)	Stream Maintenance
SHA`aBAT AL-KHUSHAYBAT	0.40	0.73	0.29	0.37	4.04	2.36	2.57	1.36
SHA`iB ABu HARMAL	0.39	0.68	0.26	0.34	2.87	2.74	1.36	1.48
SHA`iB AD DIMISAH	0.32	0.70	0.22	0.35	2.46	2.44	1.82	1.43
SHA`iB AL-MUNAYNiYAH	0.38	0.71	0.27	0.36	2.70	2.77	1.50	1.40
SHA`iB JUBAYYAN	0.35	0.79	0.27	0.39	2.54	2.74	1.64	1.27
SHA`iB TAYYIBAT AL-ISM	0.33	0.74	0.24	0.37	4.25	3.26	3.40	1.36
SHA`iB UMM `UNAYQ	0.40	0.73	0.29	0.36	2.22	2.02	1.41	1.38
WaDi `AMQ	0.35	0.73	0.25	0.36	2.33	2.06	2.22	1.38
WaDi `ARAMRAM	0.40	0.68	0.27	0.34	1.99	2.23	5.37	1.47
WaDi `ITWAD	0.36	0.65	0.23	0.33	2.87	2.58	10.87	1.54
WaDi AL- `ARiN	0.37	0.72	0.27	0.36	2.47	2.36	6.28	1.40
WaDi AL-GHAYL	0.32	0.75	0.24	0.37	2.31	2.39	4.40	1.34
WaDi AL-HIJNAH	0.38	0.76	0.29	0.38	2.56	2.58	4.58	1.32
WaDi AL-hINIKAH	0.35	0.68	0.23	0.34	2.29	2.32	3.84	1.48

WaDi AL- JUhUR	**0.42**	**0.76**	**0.32**	**0.38**	**2.05**	**2.03**	**2.52**	**1.32**
WaDi AL- KUFFAYRAH	**0.33**	**0.71**	**0.23**	**0.35**	**2.93**	**2.84**	**2.22**	**1.41**
WaDi ARKHaN	**0.35**	**0.64**	**0.22**	**0.32**	**2.38**	**2.20**	**12.02**	**1.56**
Wadi As Simarah	**0.39**	**0.73**	**0.28**	**0.36**	**2.67**	**2.41**	**3.77**	**1.38**
WaDi AS SITR	**0.40**	**0.75**	**0.30**	**0.38**	**2.21**	**2.41**	**2.19**	**1.33**
WaDi BiSHAH	**0.36**	**0.74**	**0.27**	**0.37**	**3.38**	**2.67**	**3.74**	**1.35**
WaDi DHAHBAN	**0.37**	**0.71**	**0.26**	**0.35**	**3.20**	**2.52**	**3.75**	**1.41**
WADI DHIBAH	**0.37**	**0.64**	**0.24**	**0.32**	**2.35**	**2.33**	**7.95**	**1.55**
WaDi HALi	**0.35**	**0.66**	**0.23**	**0.33**	**2.83**	**2.63**	**6.70**	**1.52**
WaDi HAMADAH	**0.36**	**0.75**	**0.27**	**0.37**	**2.53**	**2.21**	**3.47**	**1.33**
WaDi IBN AN NA`a'	**0.45**	**0.73**	**0.33**	**0.37**	**2.24**	**1.98**	**3.58**	**1.36**
WaDi IBN IBN	**0.33**	**0.74**	**0.24**	**0.37**	**2.92**	**2.57**	**3.14**	**1.35**
WaDi MASARRAH	**0.34**	**0.76**	**0.26**	**0.38**	**3.02**	**2.96**	**1.56**	**1.31**
WaDi NAHAB	**0.37**	**0.82**	**0.31**	**0.41**	**2.15**	**2.17**	**1.69**	**1.21**
WaDi NAJL	**0.37**	**0.74**	**0.27**	**0.37**	**1.78**	**1.72**	**1.98**	**1.35**
WaDi QAYLAH	**0.48**	**0.72**	**0.34**	**0.36**	**1.72**	**1.69**	**2.08**	**1.39**
WaDi RAHAH	**0.34**	**0.63**	**0.22**	**0.32**	**2.95**	**2.77**	**11.86**	**1.58**
WaDi RAMLaN	**0.34**	**0.64**	**0.22**	**0.32**	**2.58**	**2.37**	**5.61**	**1.57**
WADI RIM	**0.36**	**0.61**	**0.22**	**0.31**	**2.49**	**2.32**	**9.62**	**1.64**
WaDi SHAFQAH	**0.36**	**0.73**	**0.26**	**0.36**	**2.66**	**2.56**	**3.49**	**1.38**
WaDi SHAWAS	**0.34**	**0.69**	**0.24**	**0.35**	**2.64**	**2.52**	**4.63**	**1.44**
WaDi TATHLITH	**0.36**	**0.76**	**0.27**	**0.38**	**2.97**	**2.63**	**2.38**	**1.31**
WaDi YABAH	**0.36**	**0.68**	**0.24**	**0.34**	**2.53**	**2.46**	**6.32**	**1.47**

4-2- Flash Flood Hazard Assessment Method:

Numerous ways have been taken. The most often used technique is morphometric evaluation, which entails the following:

1) El-Shamy's approach for assessing flooding hazard probability (El Shamy, 1992)
2) The morphometric ranking method (Youssef et al., 2011).
3) Wahid's flash flood rating method determines flash flood hazards (Wahid et al., 2016).
4) "Morphometric hazard degree assessment method" (Yousif & Bubenzer, 2015)
5) Analyses of the drainage basin and CN morphometrics to assess the likelihood of a flash flood (Perucca & Angilieri, 2011).

4-2-1- El-Shamy's technique for assessing flooding risk probability:

In a study that was carried out by (El Shamy, 1992), the researchers determined how likely it was that flash floods would occur in a number of different subbasins by analyzing the connection between), stream frequency, drainage density (Dd, and the bifurcation ratio (Br) (Rb). A three-zone empirical diagram is depicted: zone (A) has a high risk of flash flooding, but a low groundwater recharge; zone (B) has a moderate risk of flash flooding but a moderate groundwater recharge; and zone (C) has a low risk of flash flooding but a high groundwater recharge. According to the graphic, Rb and Dd are responsible for determining the whole organization's overall risk level. If a sub-basin in the first image is located in zone B and zone (C) of the second figure, then the natural hazard that is presented by that sub-basin will be considered to be moderate (Youssef et al., 2009).

The calculation of the danger of flash flooding that is based on the link between Rb and Dd indicates that the nine sub-basins, including 4, 6, 7, 8, 11, 12, 14, 18, 23, 24, 27, 28, and 29 lie in zone (A) and indicate areas with a high risk of being affected by flooding caused by flash floods. Sub-basins 1, 2, 3, 9, 10, 13, 15, 16, 17, 21, 22, 25, 26, 30, 31, 32, 33, 34, 35, and 36 lie in zone (B), representing moderate susceptibility. Besides, sub-basins 5, 19, and 20 lie in zone (C), representing low susceptibility (Fig. 4 (A) and Table 6). Additionally, the seven sub-basins 6, 8, 14, 18, 24, 28, and 29 lie in zone (A), representing high susceptibility. Moreover, sub-basins 1, 2, 3, 4, 7, 9, 10, 11, 12, 13, 15, 16, 17, 21, 22, 23, 25, 27, 30, 31, 32, 34, and 35 lie in zone (B), representing moderate susceptibility. Finally, four sub-basins (5, 19, 20, and 26) lie in the zone (C), representing low susceptibility (Fig. 4 (B)). The findings of the relation among Rb and Dd and the link between Rb and Fs were integrated, and the results revealed that sub-basins 5, 19, and 20 had a low probability of being affected by flash floods in both of these relations. (Fig. 5). However, sub-basins 1, 2, 3, 4, 9, 10, 13, 15, 16, 17, 21, 22, 25, 26, 30, 31, 32, 33, 34, 35, 36, and 37 are of a moderate potential for flash flooding. Similarly, sub-basins 6, 7, 8, 11, 12, 14, 18, 23, 24, 27, 28, and 29 are of high proneness to sudden and severe flooding. Where there are in Table. 6: R b = Bifurcation Ratio, Fs = Stream Frequency, D d = Drainage Density, HD1 = Hazard degree R b vs. Fs, HD2 = Hazard degree R b vs. D d, and FHD = Final hazard degree from HD1 and HD2. L: low susceptibility for flash floods; M: moderate susceptibility for flash floods; and H: high susceptibility for flash floods.

Table. 6: *Hazard degree analysis for sub-basins of the study area (El-Shamy & El-Rayes, 1992)*

Basin	Basin No	Mean bifurcation ratio (Rbm)	Stream Frequency (Fs)	HD1	Dd	HD2	FHD
SHA'ABAT AL KHUSHAYBAT	1	4.04	0.40	M	0.73	M	M
SHA`iB ABu HARMAL	2	2.87	0.39	M	0.68	M	M
SHA`iB AD DIMISAH	3	2.46	0.32	M	0.70	M	M
SHA`iB AL MUNAYNiYAH	4	2.70	0.38	M	0.71	H	M
SHA`iB JUBAYYAN	5	2.54	0.35	L	0.79	L	L
SHA`iB tAYYIBAT AL ISM	6	4.25	0.33	H	0.74	M	H
SHA`iB UMM `UNAYQ	7	2.22	0.40	M	0.73	H	H
WaDi `AMQ	8	2.33	0.35	H	0.73	H	H
WaDi `ARAMRAM	9	1.99	0.40	M	0.68	M	M
WaDi `ITWAD	10	2.87	0.36	M	0.65	M	M
WaDi AL `ARiN	11	2.47	0.37	M	0.72	H	H
WaDi AL GHAYL	12	2.31	0.32	M	0.75	H	H
WaDi AL HIJNAH	13	2.56	0.38	M	0.76	M	M
WaDi AL HINIKAH	14	2.29	0.35	H	0.68	H	H
WaDi AL JUhUR	15	2.05	0.42	M	0.76	M	M
WaDi AL KUFFAYRAH	16	2.93	0.33	M	0.71	M	M
WaDi ARKHaN	17	2.38	0.35	M	0.64	M	M
Wadi As Simarah	18	2.67	0.39	H	0.73	H	H
WaDi AS SITR	19	2.21	0.40	L	0.75	L	L
WaDi BiSHAH	20	3.38	0.36	L	0.74	L	L
WaDi DHAHBAN	21	3.20	0.37	M	0.71	M	M
WADI DHIBAH	22	2.35	0.37	M	0.64	M	M
WaDi HALi	23	2.83	0.35	M	0.66	H	H
WaDi hAMADAH	24	2.53	0.36	H	0.75	H	H
WaDi IBN AN NA`a'	25	2.24	0.45	M	0.73	M	M
WaDi IBN IBN	26	2.92	0.33	L	0.74	M	M
WaDi MASARRAH	27	3.02	0.34	M	0.76	H	H
WaDi NAHAB	28	2.15	0.37	H	0.82	H	H
WaDi NAJL	29	1.78	0.37	H	0.74	H	H
WaDi QAYLAH	30	1.72	0.48	M	0.72	M	M
WaDi RAHAH	31	2.95	0.34	M	0.63	M	M
WaDi RAMLaN	32	2.58	0.34	M	0.64	M	M
WADI RIM	33	2.49	0.36	M	0.61	M	M
WaDi SHAFQAH	34	2.66	0.36	M	0.73	M	M
WaDi SHAWAS	35	2.64	0.34	M	0.69	M	M
WaDi TATHLiTH	36	2.97	0.36	M	0.76	M	M
WaDi YABAH	37	2.53	0.36	M	0.68	M	M

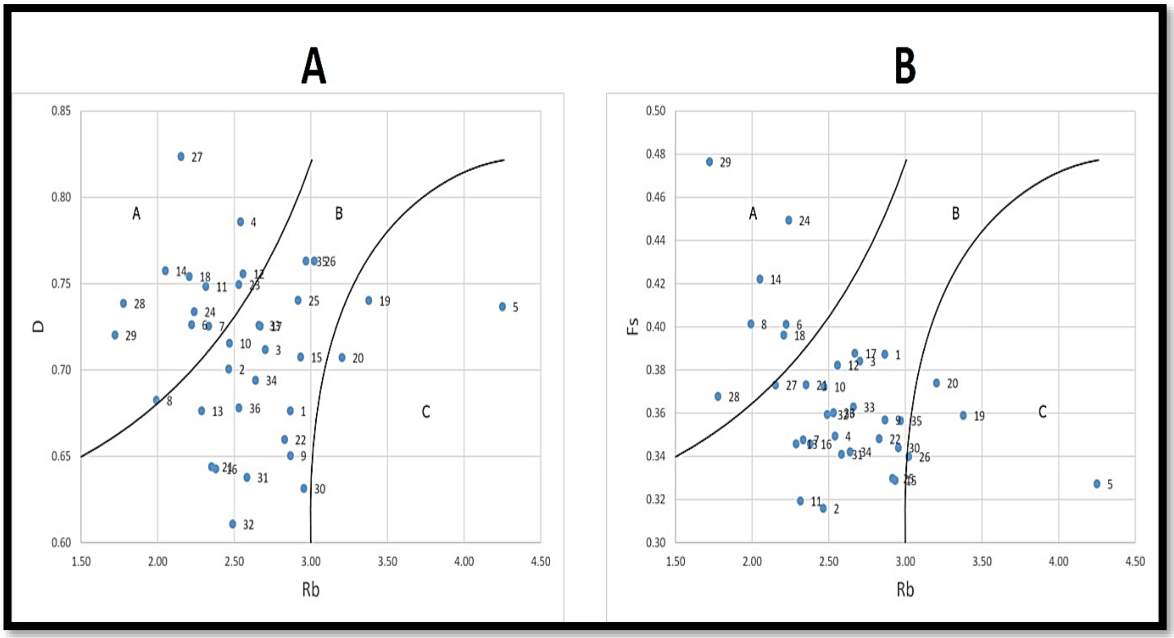
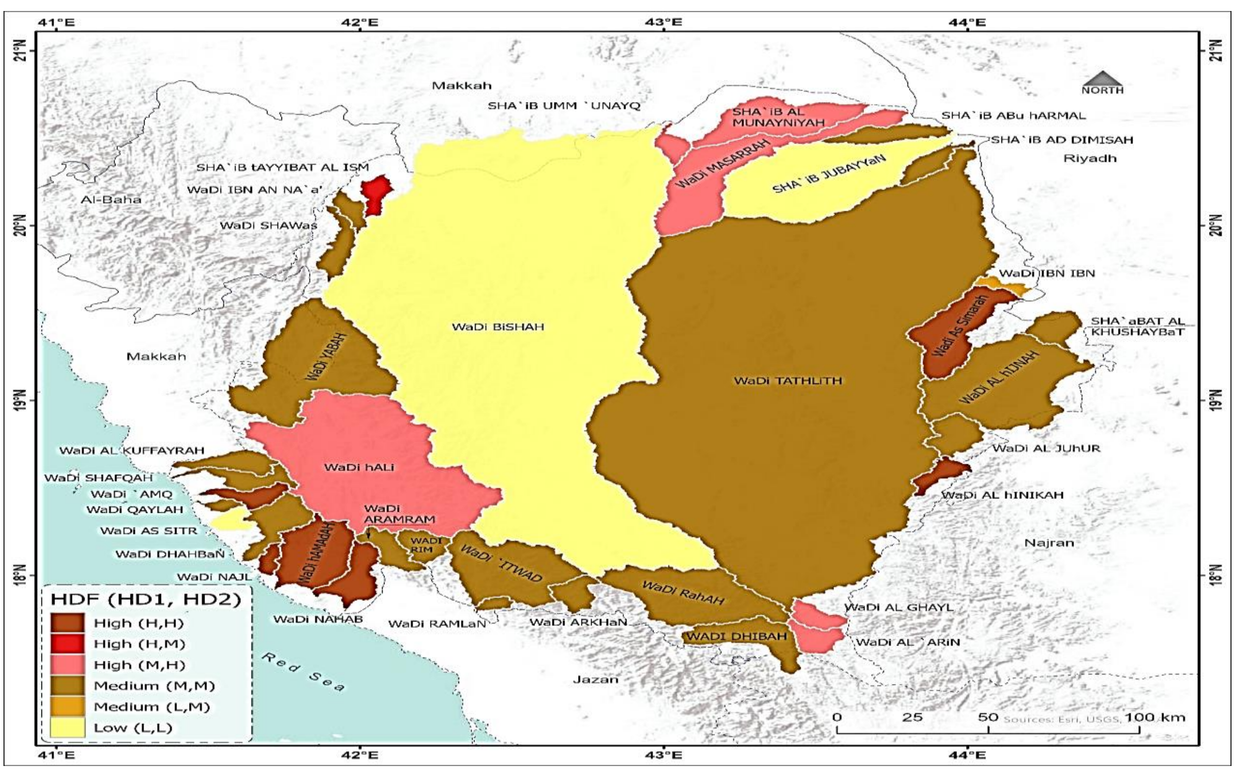


Fig. 4: *Flooding susceptibility for sub-basins of the study location, according to El-Shamy's technique, Rb vs. Dd (A) and Rb vs. Fs (B)*



Reference: *MCDM following El-Shamy Methodology using ArcGIS Pro 2.6 spatial analysis*
Fig. 5: *Flooding susceptibility for sub-basins of the research location, according to El-Shamy's technique, (R b vs. D d) layer superimposed on (R b vs. Fs) layer.*

4-2-3- Flash Flood Hazard Assessment Through Morphometric Examination of Drainage Basin and CN Technique

The NRCS CN method was adopted for the runoff analysis because of its efficiency and popularity. The annual net runoff quantities are estimated by the SCS-CN model, which represents the assumption of soil conservation service. As this hypothesis considers the type of soil, land uses, land cover, and soil moisture, these spatial variables are converted to CN, indicating the extent of soil absorption (ground cover) of the falling water before the surface runoff process where each land cover forks into four categories of soil: A, B, C, and D. The intersection of the relationship between the ground cover and the type of soil counts with the range. The standard spatial number (Zone), CN, is a variable that measures the net surface runoff depth (mm) and volume (m3) and calculates the actual surface runoff depth Q (USDA, 1986) as follows:

$$Q = ((P - la)^2)/((\mathrm{p} + \mathrm{La})\ S)$$

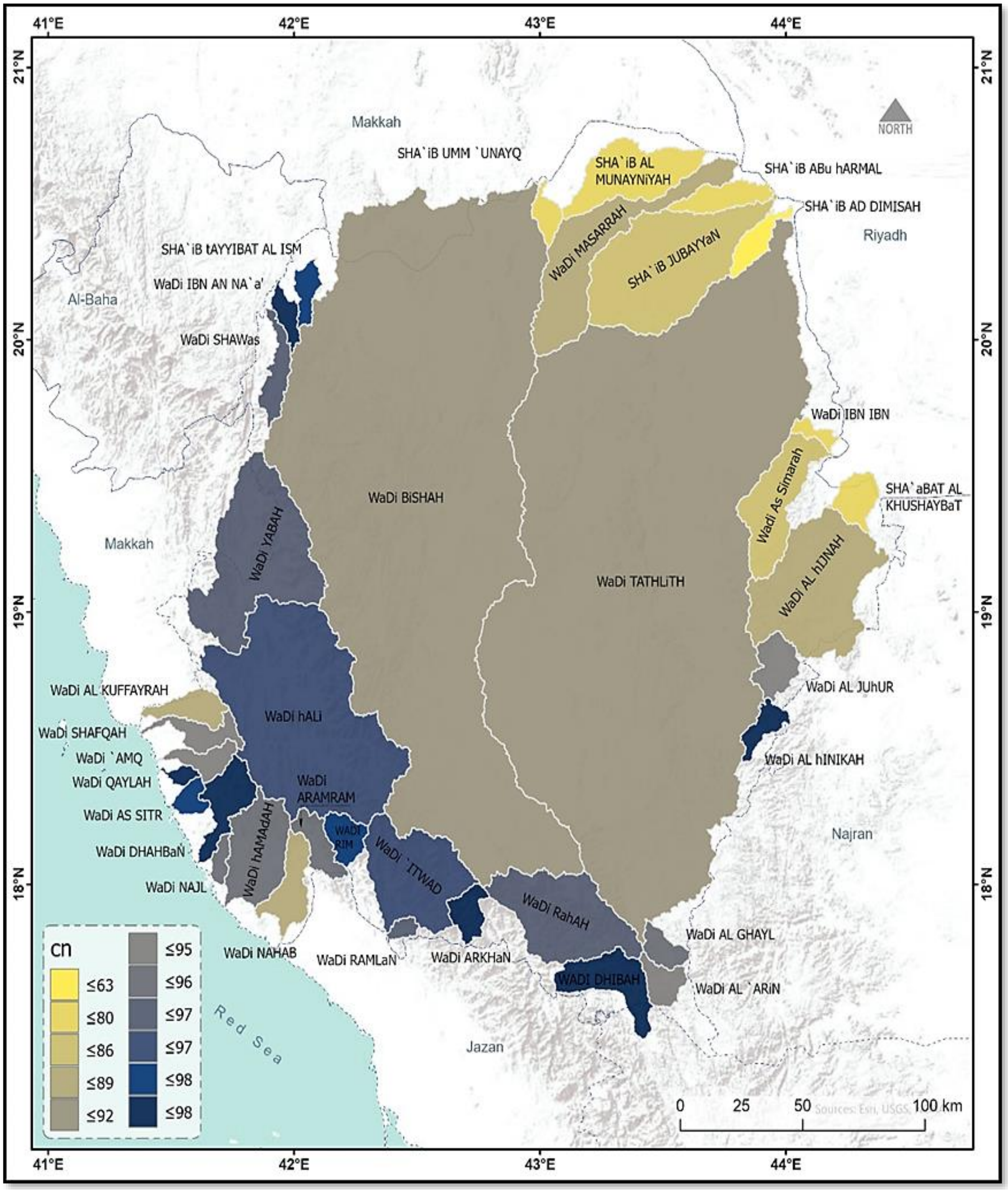
whereas:
Q = depth of runoff (inches).
P = Precipitation (inches).
La = pre-runoff losses such as plant leakage, reception, and evaporation (inches).
S = surface pool after the start of runoff (inches).
Since La is equivalent to one fifth (⅕) of the value of S and is determined as follows:
La = 0.25

S is calculated as follows:
$S = 1000/cN - 10$
After the algebra of the value of S, the equation for surface runoff becomes:
$Q = ((P - la)^2)/((\mathrm{p} + 0.85)\ )$
The input of the equation is in inches, so the equation must be reformulated by metric scales by multiplying the fixed numbers in the equation:
$S = 1000/cN - 10$
The equation is multiplied by 25.4 to be converted from inches to millimeters, so the formula for the equation becomes as follows:
$S = 25{,}400/cN - 254$

The surface runoff volume (m 3) is calculated by the surface runoff depth, multiplying the runoff depth value (height) in the basin area (with the unit of depth and area in meters and square meters standardized) and the CN values and their average for the ground cover. The annual surface runoff depth (mm) and volume (thousand m3) are calculated. The annual precipitation rate reaches about 123 mm annually. This rate and the annual runoff volume (m 3) are the crucial criteria for classifying the degree of severity of the basins in Asir. Table. 7, Fig. 6, and Fig. 7 show the annual runoff depth (mm) and volume (thousand m3) for each sub-basin.

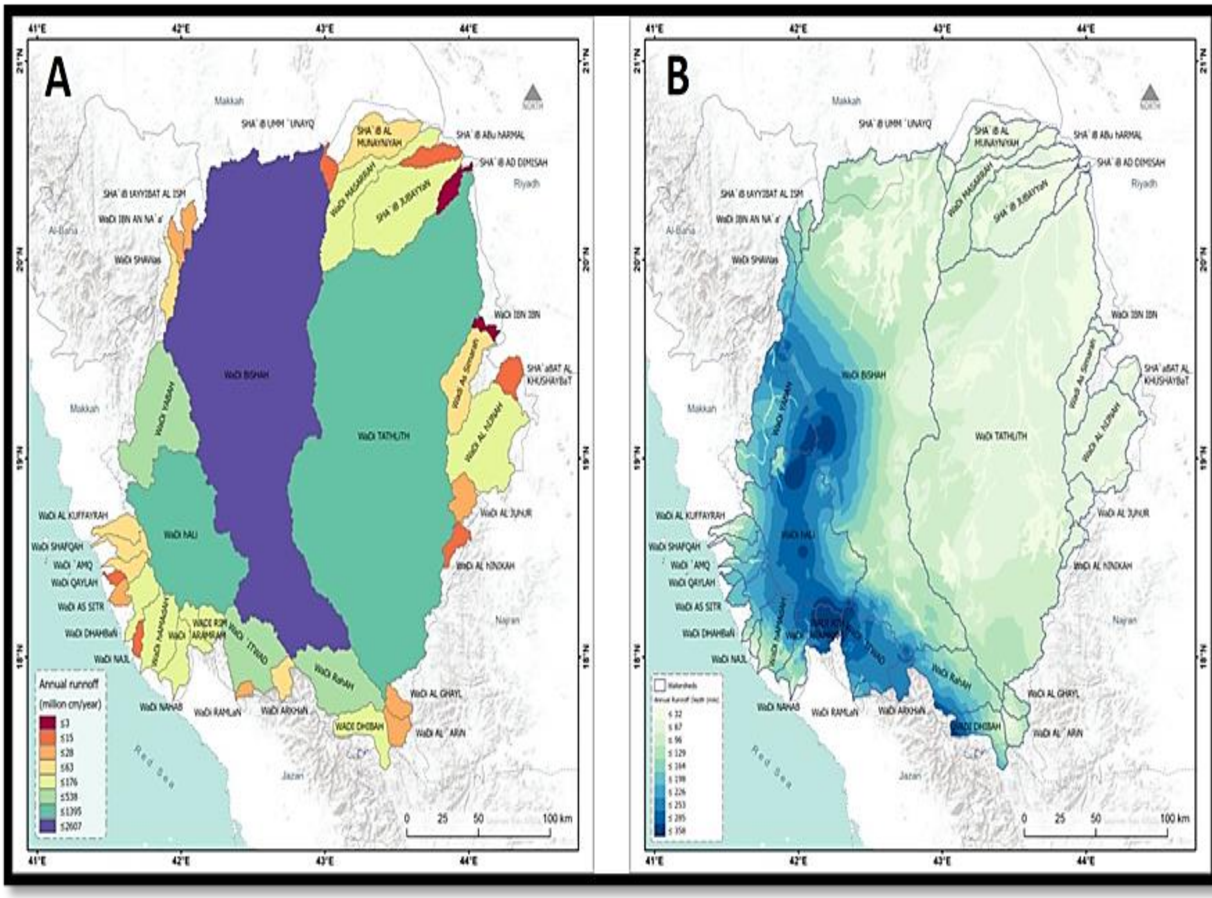
Table. 7: *Estimated net annual runoff depth and annual runoff volume*

Watershed Name	Weighted Mean CN	Annual Precipitation (mm)	Runoff Depth (mm)	Runoff Volume (mcm)
SHA`ABAT AL-KHUSHAYBAT	78.22	54.76	25.35	8.04
SHA`iB ABu HARMAL	78.51	61.13	27.18	10.11
SHA`iB AD DIMISAH	62.87	55.95	9.70	2.49
SHA'iB AL -MUNAYNiYAH	77.77	76.33	36.33	36.89
SHA`iB JUBAYYAN	83.54	70.82	43.88	111.51
SHA`iB TAYYIBAT AL ISM	97.68	133.41	126.96	25.60
SHA`iB UMM `UNAYQ	79.55	90.37	52.56	9.56
WaDi `AMQ	94.71	196.31	181.32	45.90
WaDi `ARAMRAM	95.70	281.01	267.86	82.77
WaDi `ITWAD	97.21	256.25	247.90	365.32
WaDi AL `ARIN	93.62	85.49	68.50	18.03
WaDi AL -GHAYL	95.74	105.07	93.20	21.01
WaDi AL- HIJNAH	89.05	64.21	47.71	108.81
WaDi AL- HINIKAH	98.00	72.22	66.55	15.01
WaDi AL- JUHUR	94.69	70.86	59.50	22.41
WaDi AL KUFFAYRAH	87.78	138.69	109.30	36.23
WaDi ARKHAN	97.90	245.70	239.48	63.02
Wadi As Simarah	85.83	58.07	35.41	35.89
WaDi AS SITR	97.68	185.59	179.16	28.49
WaDi BiSHAH	92.35	137.46	119.62	2607.37
WaDi DHAHBaN	98.00	206.95	201.33	102.28
WADI DHIBAH	98.00	174.06	167.91	115.19
WaDi HALI	97.08	241.88	233.23	1117.35
WaDi HAMADAH	95.01	195.40	180.98	175.88
WaDi IBN AN NA`a'	98.00	150.45	144.64	25.75
WaDi IBN IBN	78.89	53.89	24.36	2.81
WaDi MASARRAH	89.31	82.08	61.74	102.26
WaDi NAHAB	86.78	199.43	162.52	78.84
WaDi NAJL	95.84	104.92	97.22	11.63
WaDi QAYLAH	97.94	181.29	175.45	14.73
WaDi RAHAH	96.67	179.95	170.11	274.42
WaDi RAMLAN	96.45	210.19	200.30	18.21
WADI RIM	97.60	320.94	313.74	87.29
WaDi SHAFQAH	93.70	173.38	157.54	49.92
WaDi SHAWAS	96.39	197.59	186.67	61.65
WaDi TATHLITH	91.51	72.07	56.99	1395.08
WaDi YABAH	96.55	226.23	216.03	537.89



Reference: *Land resources map of MOMRA 2022 and HYSOGs250m soil groups using ArcGIS Pro 2.6 spatial analysis*

Fig.6: *Annual runoff (mm) for sub-basins of the study area.*



Reference: *SCS method, MEWA rainfall stations (1978-2022), land resources map of MOMRA 9, and HYSOGs250m soil groups using ArcGIS Pro 2.6 spatial analysis*

Fig. 7: *The annual surface runoff volume (A) and annual runoff depth (B) for the study area basins.*

4-2-3- The Morphometric Hazard Degree:

For the purpose of doing the necessary morphometric analysis and determining the level of danger for the subbasins, the evaluation approach known as the Morphometric Hazard Degree was used. The findings of the technique are shown in Table 8 for both watersheds according to a ranking score comprised of eleven morphometric parameters. The Geographic Information System was used to create the flood risk map. Fig. 8 displays the +sub-basin flooding hazard degree of the research location. Figure 8 depicts a cluster of waterways that may be broken down into three categories: high, very high, and extreme. The accumulation of risk degree values for the sub-basins is displayed by the following five categories of vulnerability to flash floods:

1) Low flooding susceptibility (Shallow hazard).
2) Moderate flooding susceptibility (low hazard).
3) High flooding susceptibility (Moderate hazard).
4) Very high flooding susceptibility (High hazard).
5) Extreme flooding susceptibility (Very high hazard).

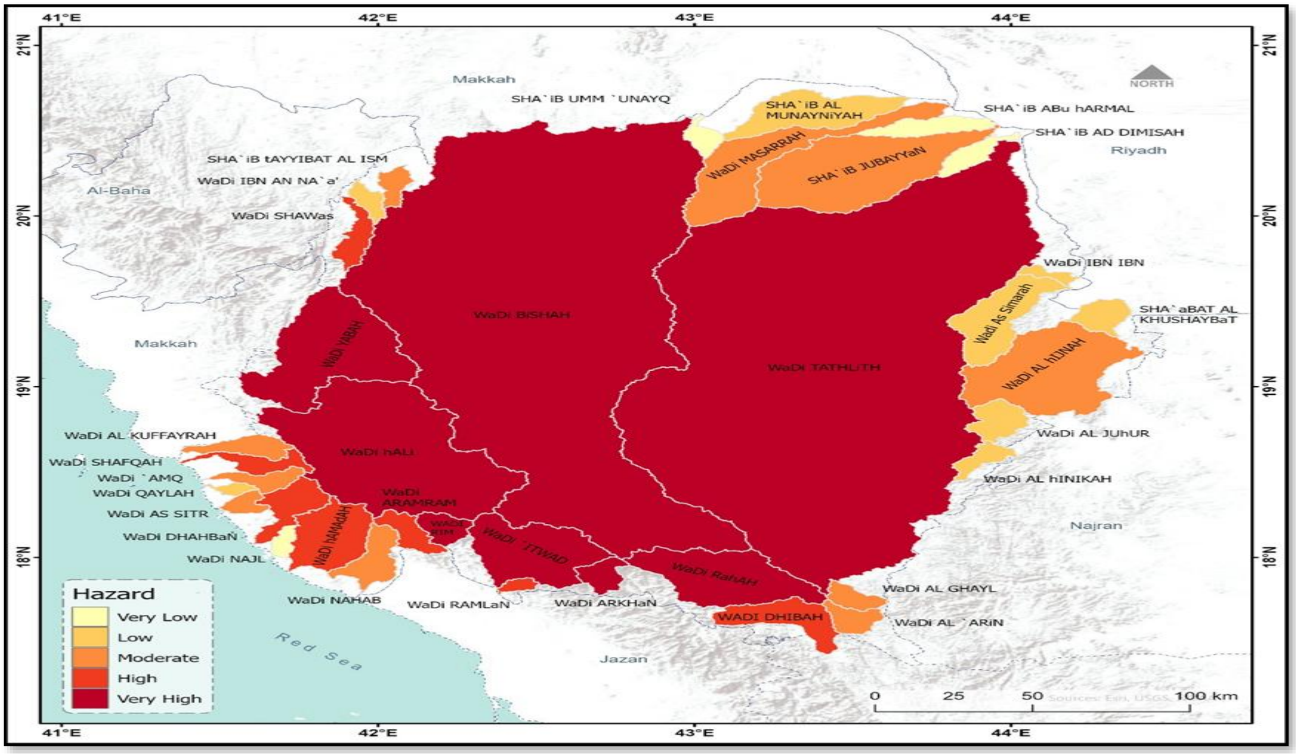
Table. 8: *Hazard quantity of the effective variables of the studied 37 watersheds of the study area*

Watershed Name	Basin No	Water Speed (m/s)	Annual Runoff Depth (mm)	Basin Area (mk2)	Gradient (longest path)	Circulatory ratio (Rc)	Drainage Density (D)	Weighted Bifurcation Ratio (Rb)	Stream Slope (Degree)	basin relief (H)	Relative relief (Rhp)	Hazards	Classification of Watershed hazard degree
SHA`ABAT AL-KHUSHAYBaT	1	1.87	1.21	1.04	1.13	5	3.33	2.71	1.45	1.37	1.48	1.82	Low hazard
SHA`iB ABu hARMAL	2	1	1.23	1.05	1.34	1.93	2.23	3.68	1	1.04	1.02	1.53	Very low hazard
SHA'iB AD DIMISAH	3	1.65	1	1.03	1.26	1	2.69	2.91	1.17	1	1	1.48	Very low hazard
SHA`iB AL -MUNAYNiYAH	4	1.26	1.35	1.15	1.67	3.02	2.90	3.74	1.05	1.36	1.15	1.78	Low hazard
SHA`iB JUBAYYaN	5	1.58	1.45	1.40	2.07	3.43	4.29	3.67	1.11	1.62	1.14	2.06	Moderate hazard
SHA`iB tAYYIBAT AL ISM	6	2.07	2.54	1.02	1.19	2.43	3.37	5	1.76	1.48	1.63	2.29	Moderate hazard
SHA`iB UMM `UNAYQ	7	1.3357	1.56	1.02	1.17	2.91	3.17	1.84	1.02	1.04	1.12	1.51	Very low hazard
WaDi `AMQ	8	1.86	3.26	1.03	1.27	2.43	3.15	1.94	1.32	2.05	2.17	2.08	Moderate hazard
WaDi `ARAMRAM	9	3.32	4.40	1.04	1.10	2.70	2.35	2.38	2.50	2.79	2.81	2.66	High hazard
WaDi `ITWAD	10	4.97	4.13	1.22	1.51	4.29	1.74	3.27	4.57	4.78	2.92	3.40	Very high hazard
WaDi AL `ARiN	11	3.01	1.77	1.03	1.11	4.78	2.97	2.70	2.85	1.75	2.03	2.21	Moderate hazard
WaDi AL-GHAYL	12	2.46	2.10	1.02	1.11	5	3.59	2.77	2.14	1.92	2.40	2.26	Moderate hazard

WaDi AL-hIJNAH	13	2.55	1.50	1.36	1.93	1.93	3.72	3.26	2.21	1.91	1.28	2.14	Moderate hazard
WaDi AL -hINIKAH	14	2.15	1.75	1.02	1.13	1	2.23	2.60	1.93	1.65	1.79	1.78	Low hazard
WaDi AL-JUhUR	15	1.96	1.65	1.05	1.16	3.02	3.76	1.86	1.44	1.47	1.53	1.78	Low hazard
WaDi AL-KUFFAYRAH	16	1.78	2.31	1.04	1.30	3.43	2.82	3.92	1.32	1.96	1.97	2.15	Moderate hazard
WaDi ARKHaN	17	5	4.02	1.03	1.16	2.43	1.60	2.30	5	3.99	5	3.24	Very high hazard
Wadi As Simarah	18	2.42	1.34	1.15	1.79	2.91	3.16	2.83	1.91	1.72	1.34	1.96	Low hazard
WaDi AS SITR	19	1.59	3.23	1.01	1	2.43	3.69	2.82	1.31	1.53	2.03	2.09	Moderate hazard
WaDi BiSHAH	20	2.25	2.45	4.56	4.92	2.70	3.43	3.48	1.89	3.70	1.15	3.10	Very high hazard
WaDi DHAHBAN	21	2.43	3.52	1.07	1.46	4.29	2.81	3.10	1.90	2.12	1.77	2.42	High hazard
WADI DHIBAH	22	4.24	3.08	1.10	1.53	4.78	1.62	2.62	3.47	3.40	2.63	2.78	High hazard
WaDi HALI	23	3.83	3.94	1.77	2.41	5	1.92	3.39	3.01	5	1.96	3.25	Very high hazard
WaDi HAMADAH	24	2.47	3.25	1.14	1.53	1.93	3.61	2.32	1.79	2.83	2.13	2.38	Moderate hazard
WaDi IBN AN NA`a'	25	2.22	2.77	1.01	1.16	1	3.31	1.74	1.83	1.50	1.71	1.90	Low hazard
WaDi IBN IBN	26	2.15	1.19	1.01	1.10	3.02	3.43	3.23	1.67	1.34	1.62	1.86	Low hazard
WaDi MASARRAH	27	1.39	1.68	1.26	2.50	3.43	3.86	4.23	1.07	1.67	1.12	2.12	Moderate hazard
WaDi NAHAB	28	1.66	3.01	1.06	1.44	2.43	5	2.22	1.12	2.29	1.94	2.22	Moderate hazard

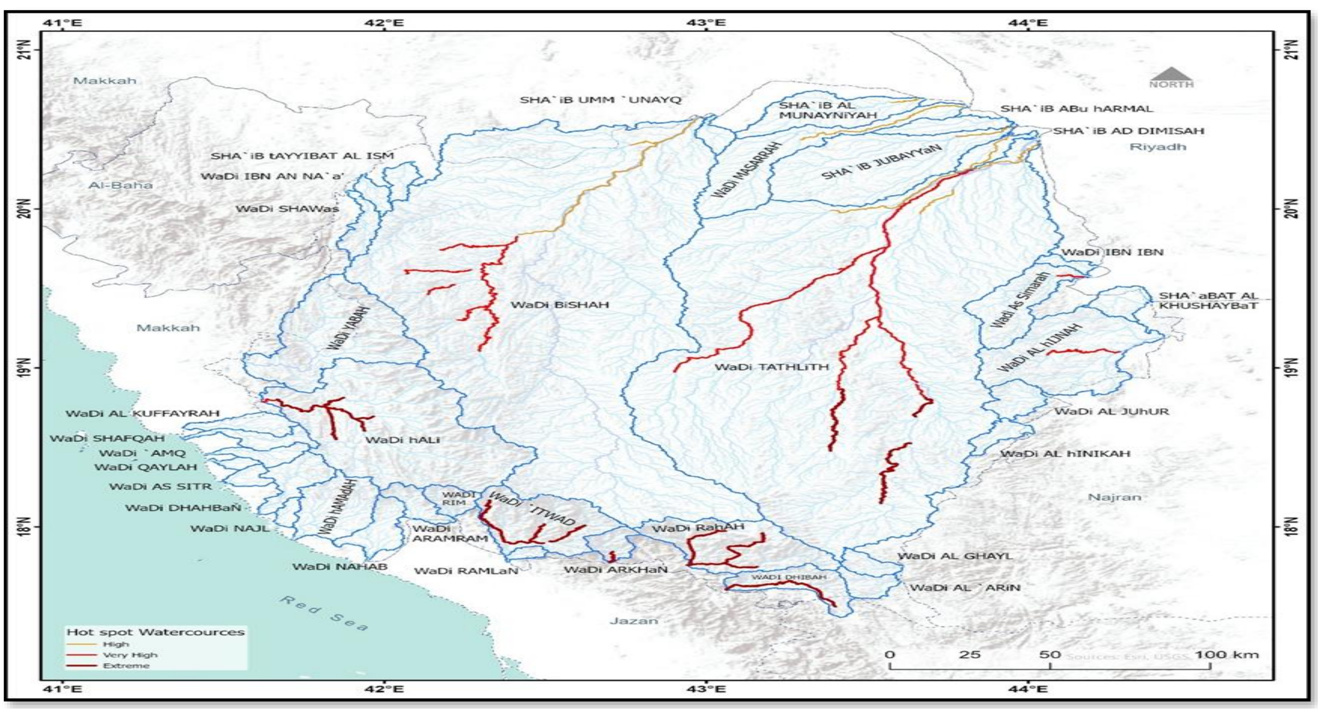
WaDi NAJL	**29**	**1.35**	**2.15**	**1.01**	**1.04**	**2.91**	**3.40**	**1.06**	**1.23**	**1.41**	**1.85**	**1.64**	**Very low hazard**
WaDi QAYLAH	**30**	**1.61**	**3.18**	**1**	**1.01**	**2.43**	**3.06**	**1**	**1.27**	**1.52**	**2.36**	**1.84**	**Low hazard**
WaDi RAHAH	**31**	**4.81**	**3.11**	**1.25**	**1.45**	**2.70**	**1.39**	**3.74**	**4.94**	**4.27**	**2.53**	**3.11**	**Very high hazard**
WaDi RAMLAN	**32**	**3.03**	**3.51**	**1.01**	**1.01**	**4.29**	**1.51**	**2.71**	**2.60**	**1.99**	**3.42**	**2.46**	**Moderate hazard**
WADI RIM	**33**	**4.86**	**5**	**1.03**	**1.10**	**4.78**	**1**	**2.61**	**4.10**	**3.20**	**4.12**	**3.21**	**Very high hazard**
WaDi SHAFQAH	**34**	**2.53**	**2.94**	**1.04**	**1.48**	**5**	**3.16**	**3.22**	**1.80**	**2.12**	**1.80**	**2.40**	**High hazard**
WaDi SHAWAS	**35**	**3.06**	**3.33**	**1.04**	**1.44**	**1.93**	**2.56**	**3.10**	**2.23**	**2.08**	**1.82**	**2.37**	**Moderate hazard**
WaDi TATHLITH	**36**	**1.94**	**1.62**	**5**	**5**	**1**	**3.86**	**3.39**	**1.38**	**3.97**	**1.20**	**2.95**	**High hazard**
WaDi YABAH	**37**	**3.70**	**3.71**	**1.39**	**31.9**	**3.01**	**2.26**	**2.97**	**2.86**	**4.57**	**2.20**	**2.97**	**High hazard**

Regarding the 37 sub-basins of the study area watershed (Table. 8 and Fig. 9), sub-basins nos. 2, 3, and 7 have shallow hazards and the lowest overall values. Sub-basins nos. 1, 4, 14, 15, 18, 25, 26, and 30 have intermediate score values, and sub-basins nos. 5, 6, 8, 11, 12, 13, 16, 19, 24, 27, 28, 32, and 35m demonstrate moderate flooding vulnerability. On the other hand, the sub-basins with the numbers 9, 21, 22, 34, 36, and 37 all have high overall score values, which indicates that they are highly hazardous sub-basins with a high potential for flooding. The total score value that is greatest belongs to the sub-basins numbered 10, 17, 20, 23, 31, and 33. Since of this, they are the most hazardous subbasins because they are most susceptible to flooding. For this reason, the defense of the town is an absolute need.



Reference: *MCDM using ArcGIS Pro 2.6 spatial analysis*

Fig.8: *The study area's sub-basins flooding hazard degree according to the morphometric hazard degree assessment technique.*



Reference: *Delineation from SRTM 3 Arc second DEM Using ArcGIS Pro 2.6 spatial analysis.*

Fig.9: *Hot spot of watercourses in the study location.*

4-3- Water-resources management in the Asir region:

As a result of water scarcity, contamination, and the need to establish development projects, there is an urgent need for reliable alternatives that address the following objectives: (1) management of surface runoff effects, (2) optimum effectiveness in the utilization of runoff and rainfall, and (3) contamination protection of water resources.

Rainwater harvesting and runoff management:

Water harvesting systems aid in the prevention of surface runoff risks, the gathering of rainwater for future use, and the refilling of aquifers by collecting rainfall. Rather than relying on rainfall to refill aquifers, runoff might be collected and utilized as a direct water source for storage facilities. Retardation dams, in contrast to reservoirs and lakes, which provide direct storage, may provide indirect storage by allowing runoff water to organically infiltrate the soil profile behind them (El Osta et al., 2021).

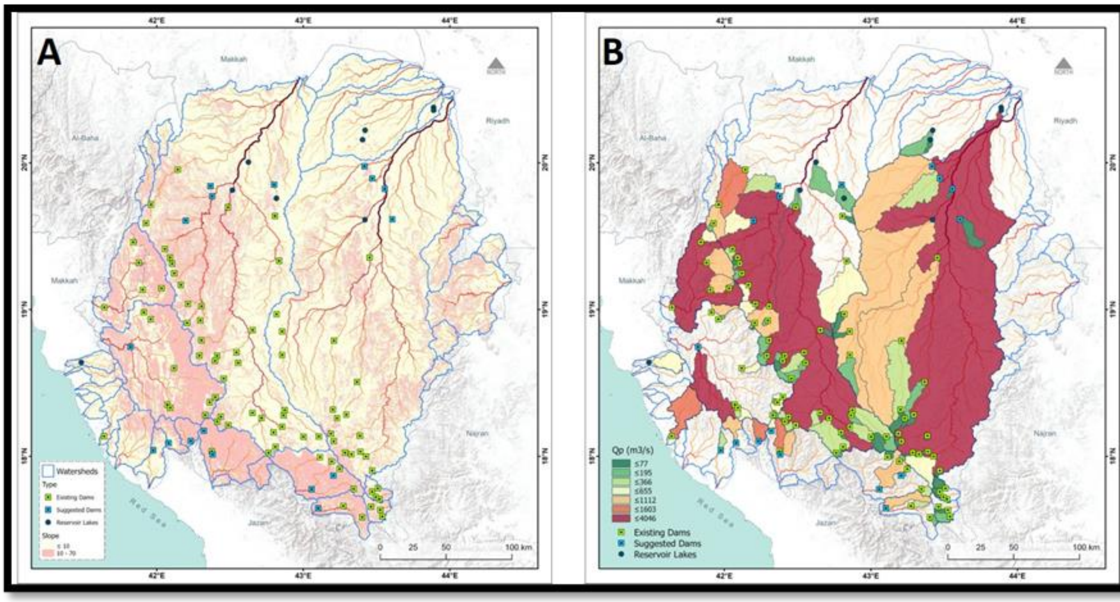
After doing a thorough investigation, ArcGIS is used to find the locations that have been identified. This kind of terrain is characterized by the topographical parameters, slope, slope, elevation, and drainage density, and Geological maps were used to generate geomorphology, lithology, and lineament layers of the region, which are important in deciding site suitability analysis for dams. Ideally, slopes should be less than 10 degrees at these places. Figures 10A and 10B show potential locations for the suggested water harvesting and runoff hazard management systems, respectively. Water resources may be managed in several different ways.

Retardation dams:

In order to improve infiltration, raise the amount of natural recharge to aquifers, and reduce peak discharge, it is possible to create retardation dams upstream of subbasins from local materials. This will allow for increased natural recharge to aquifers. Therefore, this will reduce runoff concerns in downstream regions. They may be able to get work.

Reservoirs:

The construction of reservoirs along the key streams in the sub-basin is going to be planned so that water can be stored, the natural recharging of aquifers can be increased, and the risks associated with runoff farther downstream can be reduced. It is possible to absorb and store between 77 & 98 percent of runoff water for future use in certain situations. The harvested runoff water volumes using existing dams, recommended dams, and proposed reservoirs were about 53.50 MCM, 25.30 MCM, and 21.20 MCM, respectively, for a 123 mm precipitation total (see Figure 1). (Table 9).



Reference: *MCDM hydrology analysis ArcGIS Pro 2.6*

Fig.10: *(A) guide map shows the potential areas for the suggested alternatives for runoff hazard management and water harvesting and (B) peak discharge (Qp) of the proposed dams.*

Table. 9: *Calculated total volumes of annual collected runoff water*

Sub-basin	Calculated harvested annual runoff water volume (mcm)			
	Existing Dams	Suggested Dams	Suggested Reservoirs	Grand Total
SHA`iB AD DIMISAH	0.00	0.00	728.99	728.99
SHA`iB JUBAYYAN	0.00	0.00	13.75	13.75
WADI `ARAMRAM	0.00	38.42	0.00	38.42
WADI `ITWAD	40.98	44.00	0.00	84.98
WADI AL `ARIN	6.88	0.00	0.00	6.88
WADI AL GHAYL	9.20	0.00	0.00	9.20
WADI AL KUFFAYRAH	0.00	0.00	30.45	30.45
WADI BISHAH	1384.98	627.68	15.12	2027.78
WADI DHAHBAN	98.72	0.00	0.00	98.72
WADI DHIBAH	9.93	38.07	0.00	48.00
WADI HALi	100.90	168.14	0.00	269.04
WADI NAHAB	0.00	11.67	0.00	11.67
WADI RAHAH	12.01	48.40	0.00	60.42
WADI RIM	0.00	42.42	0.00	42.42
WADi TATHLITH	295.02	151.76	192.90	639.68
WADI YABAH	518.00	0.00	0.00	518.00
Grand Total	2476.63	1170.55	981.21	4628.39
%	53.50	25.30	21.20	100

5- Conclusion

The Asir region is a viable investment location. As discussed in the article, one option for solving long-term sustainability management difficulties is to increase the efficiency with which runoff and rainfall are used. Flood hazard and flood susceptibility mapping using geographic information systems (GIS) identify areas at risk of flooding. In order to evaluate flood risk, three morphometric analysis methodologies were used in combination with a Geographic Information System (GIS). Sub-basins are prone to flooding in varying degrees: low, moderate, high, very high, and severe, depending on their location. Flood danger maps generated utilizing geographic information systems (GIS) and histomorphometric data assist decision-makers in taking the appropriate actions before, during, and after a catastrophe. Individual or collaborative initiatives to reduce peak discharge and boost natural and artificial recharge and water harvesting may be undertaken to reduce the dangers of surface runoff and its consequences. Using adequately installed and maintained rainwater collecting systems to preserve more than 77 percent of runoff water.

Recommendations on measures in basins and streams of the study encompass:

1. Assessing the effectiveness and long-term consequences of measures to mitigate runoff dangers and collect rainwater for future use.
2. Construction of micro dams and stream channelization to alleviate flooding in the upper reaches of significant wadis and Construction of delay dams manufactured in the same overhead sewers.
3. Digging artificial ponds at the mouth of the main valleys.
4. Attempts are being made to reduce the frequency of floods.
5. Storage tank drilling is essential along high-risk valleys.
6. It's indeed necessary to be a firm grasp of the climate of the research location before deciding how to manage the study area's groundwater.

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