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Research paper

Morphometric analysis using geospatial techniques for priotrization of the eastern Jeddah sub-watersheds to reduce the risk of flooding and soil erosion

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Abstract

The goal of this work is to prioritize Jeddah sub-watersheds using morphometric parameters, the Weighted Sum Approach (WSA), and GIS. Finding the sub-watershed that is most vulnerable to flooding and soil erosion is the goal of priotrizating these watersheds. Major catastrophic floods that struck Jeddah's watersheds in 2009 claimed 113 lives, destroyed 10,000 homes, and severely damaged 17,000 automobiles. At first, the subwatersheds and streams were generated using the GIS technique, and the morphometric parameters for the sub-watersheds were computed. For nine chosen morphometric parameters, the Pearson's cross-correlation matrix was run with a 5% significance threshold. Based on the value of the compound factor obtained from WSA, each sub-watershed was assigned a rank level and priority category (Very high, high, medium, low, very low). The results show that SWD-2 and SWD-4 are highly vulnerable to flooding in about 57% of all sub-watershed areas. These two sub-watersheds require emergency flood prevention measures. Sub-watersheds 2 and 4 (SWD-2 and SWD-4) were the main contributors to the devastating floods of 2009 that claimed many lives and destroyed many homes. This shows that although while WSA is straightforward, it nevertheless has a wide range of possible applications in all sub-watersheds that are susceptible to flash floods and soil erosion.

Keywords: *Jeddah Sub-Watersheds; Flood Mitigation; Morphometric Characteristics ; Priotrization; Soil Erosion; Weighted Sum Approach*.

1. Introduction

A morphometric analysis of measuring a watershed is considered the most satisfactory method for understanding the hydrological behavior of catchments with their responses to rainfall. At the watershed scale, the natural cycle of rainfall-runoff relationship is thought to be a rather complex phenomenon (Kumar et al., 2012; Aher et al., 2014; Al-Juaidi, 2018; Al-Juaidi et al., 2018; Al-Juaidi 2020). Watershed runoff generation can be linked to morphological characteristics (Kumar et al., 2012; Aher et al., 2014; Al-Juaidi 2023).

Integrated watershed management has been widely accepted as an effective management approach that can lessen the detrimental consequences of soil erosion on freshwater supplies, climate change, and agricultural productivity (Al-Shutayri and Al-Juaidi, 2019; Al-Juaidi and Attia 2020; Al-Juaidi 2019a; Al-Juaidi 2019b; Al-Juaidi 2019c; Al-Juaidi et al., 2010; Al-Juaidi et al., 2011a). The morphometric analysis of Jeddah sub-watersheds is carried out to gain a better understanding of the dynamics of hydrological behavior, as well as to validate natural resource processes and put them under our control (Al-Juaidi et al., 2014; Al-Juaidi 2017; Al-Juaidi and Hegazy 2017; Al-Juaidi et al., 2011b). In other words, it is critical to examine the morphometric of watersheds in relation to landuse and soil in order to develop better water resource action plans.

The plans include identifying discharge and recharge zones and assisting in the prioritization of watersheds based on their rapid response to rainfall. Furthermore, morphometric analysis aids in understanding the relationship between watershed characteristics and drainage pattern, as well as comparing the various watersheds formed in various geological and climatic regimes (Kandpal et al., 2017; Khan et al., 2011). The most satisfying method is morphometric analysis of a watershed. Morphometric analysis does not necessitate a thorough understanding of the relationship between the various features of the watershed's drainage pattern. Morphometric analysis allows for the comparison of various watersheds formed in various geologic and climatic regimes (Kumar et al., 2012; Meshram and Sharma 2015; Malik et al., 2019). Prior studies prioritized sub-watersheds based on compound parameter value by taking a simple arithmetic average of preliminary priority ranks for final prioritization of sub-watersheds. In previous studies, all morphometric parameters were given equal weight, which may not be accurate or correct. Because each sub-watershed has its own characteristics, the importance of all input constraints should not be equal when delineating flood hazard in highly vulnerable areas.

Three consecutive flash floods that hit the Eastern Jeddah Sub-watersheds in 2009, 2011, 2012, and 2021 are estimated to have cost the city 2.6 billion USD in losses. In 2009, there were 113 flood-related deaths, 10,000 demolished homes, and 17,000 automobiles that were severely damaged (Youssef et al., 2016; Dano 2020). Subwatersheds 2 and 4 (SWD-2 and SWD-4) were the main contributors to the devastating floods of 2009 that claimed many lives and destroyed many homes. Wadi Qus and Wadi Muraikh are the names of SWD-2 and Subwatershed-4, respectively. According to Al-Saud (2015), Jeddah has implemented a number of flash flood mitigation strategies, including (a) large-scale ponds, stormwater drainage systems, and cleaning plans for open channels that are already present at the outlets of watersheds. Smaller-scale ponds, stormwater drainage systems, and open channel cleaning plans are also in place. These open channels serve the purpose of redirecting stormwater away from watersheds' exits and toward the Red Sea.

These flood mitigation measures, however, fall short if they don't incorporate strategies that will enable communities to respond appropriately and in plenty of time to lessen the post-flood stage (e.g., early warning system). The water authorities in Saudi Arabia intend to implement a plan for managing flood catastrophes that includes an early warning system and quick action in the event of flooding (Al-Juaidi 2020; Al-Juaidi 2023). Therefore, identifying the sub-watershed that responds to flooding more quickly will lessen the threat of flooding in Eastern Jeddah. Choosing the sub-watershed that is most susceptible to flooding can free up valuable time for efficient planning, design, and completion of the early warning system for flash flood mitigation. This work was carried out in two steps: (i) estimating the morphometric parameters of the sub-watersheds east of Jeddah city using GIS techniques, and (ii) indicating the sub-watersheds using the weighted sum approach (WSA) and determining their category and priority rank for conservation management and planning.

2. Study area

The study area is in the eastern part of Jeddah city, Mecca province, and the western region of Saudi Arabia (see Figure 1). Eastern Jeddah sub-watersheds are located between 39° 15′ 00″ E and 39° 30′ 00″ E, as well as 21° 22′ 0″ N and 21° 35′ 0″ N. The sub-watersheds have a total area of 208.42 km^2 and elevations above sea level ranging from 38 to 400 m (Al-Juaidi 2023). The most critical events occurred in the fourth quarters of 2009 and 2010, as well as in the first month of 2011. The precipitation from these three events ranged between 70 and 170 mm. In the east, the mountain slopes range from flat to medium.

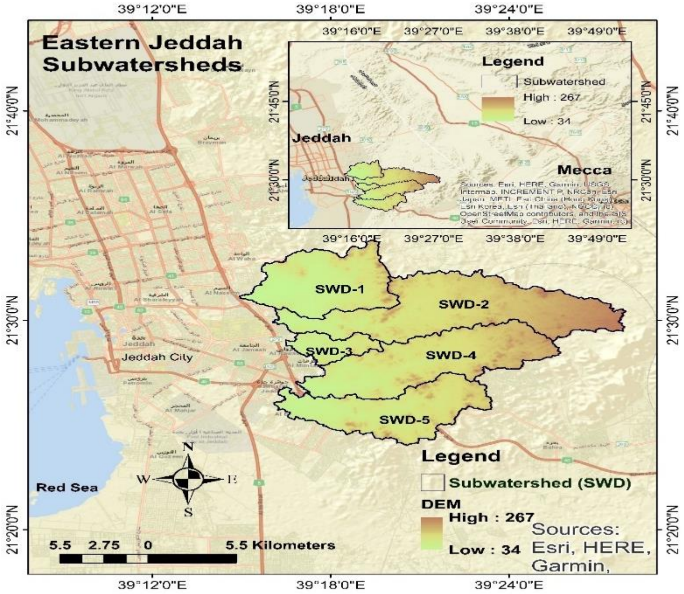

Fig. 1: Study Area (Eastern Jeddah Sub watersheds).

3. Methodology

The steps of the methodology are as follows: (1) Stream and boundary order delineation using GIS. In this study, the digital elevation model (DEM) of the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) with a resolution of 30 m × 30 m (downloaded from https://earthexplorer.usgs.gov) was used to delineate the boundary and stream of the eastern Jeddah watershed (see Figures 1 and 2). (2) Determine the linear, areal, and shape morphological characteristics of the sub watersheds. (3) Initial prioritization of sub-watersheds based on morphological traits. (4) The WSA method was then used to rank and categorize sub-watersheds in order of priority for conservation planning and management.

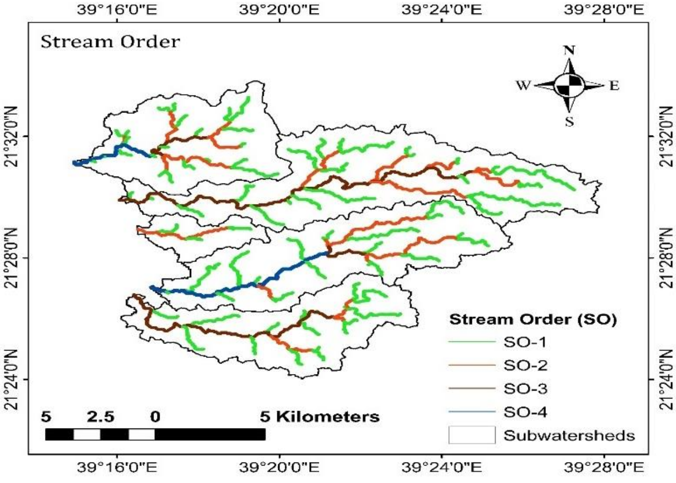

Fig. 2: Stream Order and Eastern Jeddah Sub Watersheds.

3.1. Morphometric analysis

The morphometric analysis describes the geometry of watersheds and streams. It aids in comprehending the linear aspects of the drainage network, the areal aspects of the watershed, and the relief aspects of the stream network (Strahler 1964). The primary process in watershed morphometric analysis is stream ordering (u). Stream ordering is the process of delineating existing streams along the watershed boundary. Horton (1945) and Strahler (1952) proposed that stream networks and watershed order be extracted from the watershed's digital elevation model map (see Figure 1).

The morphometric parameters are primarily used to describe causative factors that have a direct impact on surface runoff and sediment loss from a watershed. Morphometric parameters are divided into three types: linear, areal, and shape. Table 1 displays the morphometric factors watershed area (A), watershed perimeter (P), stream order (u), stream length (L_u), mean stream length, texture ratio (R_t), basin length (L_b), bifurcation ratio (R_b), circularity ratio (R_c), drainage density (D_d), stream frequency (F_s), mean surface flow length (Lom), shape factor (F_f), compactness coefficient (C_c), and elongation ratio (R_e). Table 1 displays the formulas for all morphometric factors considered in this work.

The form factor (F_f) is defined as the ratio of the basin's axial width to its axial length, or the basin area squared to its axial (maximum) length. If the shape factor is greater than 0.7854, it indicates that the watershed is circular. Lower form factor values indicated a longer watershed (Strahler 1952). The ratio of total stream length of all orders to total watershed area is known as drainage density (D_d).

The lowest drainage density value indicates highly permeable subsurface material and soil covered with dense low relief vegetation, whereas the highest value indicates impervious subsurface material with surplus vegetation and high relief.

The drainage density indicates the development of channels in the watershed as well as the closeness of channel spacing. Drainage density is influenced by lithology, subsoil compactness, vegetation cover, and relief (Rai at al., 2014; Horton 1932; Smith 1950; Kumar et al., 2012). According to Smith (1950), drainage density is classified into five texture classes: (i) very coarse (2), (ii) coarse (2 to 4), (iii) moderate (4 to 6), (iv) fine (6 to 8), and (v) very fine (> 8) (Horton 1945). The total number of stream segments of all steam orders per unit area of the watershed is defined as stream frequency (Fs) (Horton 1932). The circularity ratio (R_c) is the ratio of the basin's area to the area of the circle with the same circumference as the basin (Miller 1953). A higher value (> 0.5) indicates that the geologic material is more circular and homogeneous. The lower value (0.5) indicates that the basin is elongated. The circularity ratio has a value between 0.2 and 0.8, or 1. The compactness coefficient (C_c) is the ratio of the basin perimeter to the perimeter of the basin's equivalent circular area (Horton 1945).

The elongation coefficient (R_e) is defined as the ratio of the diameter of a circle with the same area as the basin to the basin's maximum length (Schumn 1956). For a wide range of climatic and geologic conditions, its value ranges from 0.4 to 1.0 or ≤ 1.0. If the elongation ratio value is around 1.0, it indicates a region with very low relief, whereas 0.4 to 0.8 indicates a region with very high relief and a steep terrain slope. The texture ratio (R_t), also known as drainage texture, is defined as the total number of stream segments of all orders at the watershed's perimeter (Horton 1945).

Table 1: The Formula Used for Computation of Linear, Areal, and Shape Morphometric Parameters

Parameters	Parameters	Formula	References
Linear	Basin area ($\boldsymbol{A}$)	Area of watershed $(\boldsymbol{Km^2})$	
	Basin perimeter ($\boldsymbol{P}$)	Perimeter of watershed $(\boldsymbol{Km})$	
	Stream order ($\boldsymbol{u}$)	Hierarchical rank	
	Stream length ($\boldsymbol{L_u}$)	Length of stream $(\boldsymbol{Km})$	
	Mean stream length $(\overline{L_u})$	$(\overline{L_u}) = \frac{L_u}{N_u}$, Where $(\overline{L_u})$ is the mean stream length (km). $\boldsymbol{L_u}$ is the total length of stream of order $\boldsymbol{u}$, $\boldsymbol{N_u}$ is the total number of stream of order $\boldsymbol{u}$	
	Basin Length ($\boldsymbol{L_b}$)	$\boldsymbol{L_b = 1.312 \times A^{0.568}}$, $(\boldsymbol{km})$	(Strahler 1964) Nookaratnam et al. (2005)
	Bifurcation ratio ($\boldsymbol{R_b}$)	$\boldsymbol{R_b = \frac{N_u}{N_{u+1}}}$, where $\boldsymbol{N_{u+1}}$ is the number of stream segment of $(\boldsymbol{u+1})^{th}$ order	Schumm (1956)
Areal	Drainage density ($\boldsymbol{D_d}$)	$\boldsymbol{D_d = \frac{\sum L_u}{A}}, (\boldsymbol{km/km^2})$, where $\sum \boldsymbol{L_u}$ is the total length of stream of all orders (km)	Horton (1932)
	Stream frequency ($\boldsymbol{F_s}$)	$\boldsymbol{F_s = \frac{\sum N_u}{A}}, (\boldsymbol{1/km^2})$	Horton (1932)
	Drainage texture ($\boldsymbol{R_t}$)	$\boldsymbol{R_t = \frac{\sum N_u}{P}}, (\boldsymbol{1/km^2})$	Horton (1945)
	Mean length of overland flow ($\boldsymbol{L_o}$)	$\boldsymbol{L_o = \frac{1}{2D_d}}, (\boldsymbol{km})$	Horton (1945)
	Constant of channel maintenance (C)	$\boldsymbol{C = \frac{1}{D_d}}, (\boldsymbol{km})$	Schumm (1956)
	Infiltration number ($\boldsymbol{I_f}$)	$\boldsymbol{I_f = F_s \times D_d}$	Strahler (1952)
Shape	Form factor ($\boldsymbol{F_f}$)	$\boldsymbol{F_f = \frac{A}{L_b^2}}$	Horton (1932)
	Circularity ratio ($\boldsymbol{R_c}$)	$\boldsymbol{R_c = 4 \times \pi \times \frac{A}{P^2}}$	Miller (1953)
	Compactness coefficient ($\boldsymbol{C_C}$)	$\boldsymbol{C_c = 0.2821 \times \frac{P}{A^{0.5}}}$	Strahler (1964)
	Elongation ratio ($\boldsymbol{R_e}$)	$\boldsymbol{R_e = 1.128 \times \frac{\sqrt{A}}{L_b}}$	Schumm (1956)

3.2. Preliminary priority of sub-watersheds

The preliminary priority of sub-watersheds has been evaluated according to the morphological characteristics based on (i) linear parameters including bifurcation ratio (R_b); (ii) areal parameters including drainage density (D_d), stream frequency (F_s), mean overland flow length

(L_{om}); and (iii) shape parameters including shape factor (F_f), circularity ratio (R_c), compactness coefficient and elongation ratio (R_e). Linear parameters and areal parameters are directly related to soil erodibility. As a result, the greater the value of these parameters, the greater the erodibility potential (Aher et al., 2014; Malik et al., 2019). For each of the five sub-watersheds, the highest value of linear and aerial parameters was assigned priority rank number one, the second highest value was assigned priority rank number two, and so on.

Table 2: Details of Linear Parameters of All Eastern Jeddah Sub-Watersheds

Sub-Watershed Name	Linear parameters										
	A (km^2)	P (km)	Stream order					N_u	L_u (km)	$\bar{L}_u (km)$	L_b (km)
			1	2	3	4	5				
SWD-1	38.25	32.43	23	6	2	1	0	32	35.937	1.12	10.396
SWD-2	67.30	64.54	22	6	1	0	0	29	72.692	2.51	14.330
SWD-3	10.89	22.13	4	1	0	0	0	5	7.780	1.56	5.093
SWD-4	52.70	48.51	21	5	2	1	0	29	51.575	1.78	12.471
SWD-5	39.29	42.92	16	3	1	0	0	20	34.830	1.74	10.556

3.3. Weighted sum approach (WSA)

The mathematical expression of the composite factor is shown in Equation (1) below according to Aher et al. (2014).

$$CF = PPR_{mp} \times W_{mp} \quad (1)$$

where CF is the composite factor, PPR_{mp} is the preliminary priority rank based on the morphometric parameter, and W_{mp} is the morphometric parameter weight obtained through cross-correlation analysis. The final ranking was based on the composite factor, with the lowest value receiving priority rank 1, the next lowest receiving priority rank 2, and so on for all sub-watersheds.

4. Results and discussions

To evaluate the characteristics and properties of the drainage networks, morphometric analyses were performed for the selected eastern Jeddah sub-watersheds. Morphometric analysis was performed on all sub-watersheds by quantifying linear, areal, and shape parameters. Linear parameters (basin area, perimeter, stream order, stream length, mean stream length, mean stream length, basin length, and bifurcation ratio), areal parameters (drainage density, stream frequency, texture ratio, and mean overland flow length), and shape parameters were identified (shape factor, circularity ratio, and compaction coefficient and elongation ratio).

Tables 2 and 3 show the quantitative values of the linear, areal, and shape parameters. The highest value of linear and aerial parameters was given rank 1, while the lowest value was given the lowest rank in preliminary priority ranking (see Table 4). The shape parameters with the lowest values were assigned rank one, while the shape factors with the highest values were assigned the highest rank. The Strahler (1964) system is used to analyze the stream orders.

4.1. Linear parameters

The linear aspects of the channel system are stream length (L_u), stream order (U), bifurcation ratio (R_b), stream length ratio (R_L) and length of overland flow (L_g). Table 1 described the drainage network parameters for the sub-watersheds (e.g drainage basin area, perimeter, basin length and length of main channel).

As shown in Figure 3 and 2, the drainage network of the analyzed watersheds indicates that it is a fourth order watershed formed by streams of various orders. According to Strahler's (1952) stream ordering system, stream order classification is important for indexing the size and scale of the basin.The number of streams of given order (N_u) represents the total number of streams in the watershed, counted as stream segments with the order 'u'. SWD-1 and SWD-4 have the highest stream order 4 in the study work, while SWD-2 and SWD-5 have the highest stream order 3 (see Figure 2). The variation in stream order found in these sub-watersheds is primarily due to topographic conditions in the watershed region. These stream orders were used to calculate the watershed's morphometric characteristics.

The sub-basin area ranges from 10.89 km^2 (SWD-3) to 67.30 km^2 (SWD-2), while the perimeter ranges from 22.13 km (SWD-3) to 64.54 km (SWD-2) (SWD-2). The total length of all streams in the watershed ranges from 15 km (SWD-5) to 72.7 km (SWD-2), for a total length of 203.2 km.

Stream lengths in the sub-basins range from 1.12 km (SWD-1) to 5.59 km (SWD-3). The length of the watershed ranges from 5.093 km (SWD-3) to 14.33 km (SWD-2), with a total length of 52.8 km. Table 3 shows the bifurcation ratio values for all sub-watersheds, indicating that the bifurcation ratio ranges from 2.5 in SWD-4 to 5 in SWD-2. The greater the bifurcation ratio, the greater the soil erosion (Aher et al., 2014; Malik et al., 2019).

4.2. Areal parameters

The drainage density values for the five sub-basins shown in (Table 3) range from 0.382 km/km^2 (SWD-5) to 2.568 km/km2 (SWD-3). The low drainage density value for SWD-5 indicates a highly permeable subsurface under vegetation cover with low relief, whereas the high drainage density value for SWD-3 indicates a well-developed efficient drainage network with impervious subsurface materials, less vegetation cover, and high relief.

The stream frequency values range from 0.229 km^{-2} (SWD-5) to 0.837 km^{-2} (SWD-1). A low stream frequency value indicates low runoff in the region, while a higher value indicates higher runoff. The texture ratio of the five sub-watersheds (Table 3) ranges from 0.210 km^{-1} (SWD-5) to 0.987 km^{-1} (SWD-1). According to the classification, all of the sub-basins are classified as having coarse drainage texture. In the basin, the mean surface flow length of all sub-watersheds ranges from 0.195 to 1.308 km.

4.3. Shape parameters

The value forming factors for all sub-watersheds are shown in Table 3, indicating that the form factor ranges from (0.328) to (0.420). The circularity ratio ranges from 0.203 to 0.457 for all sub-watersheds. Sub-watersheds SWD-1, SWD-3 are circular in shape, but sub-watersheds SWD-2, SWD-4, and SWD-5 are elongated.

The calculated compactness coefficient values for all sub-watersheds in Table 3 range between 1.479 and 2.219. A high compactness coefficient value (> 1) indicates more compact sub-catchments. The elongation coefficient values for all sub-watersheds in Table 3 range from 0.646 to 0.731, indicating that the terrain is high relief and steep.

Table 3: Linear, Areal and Shape Parameters of All Eastern Jeddah Sub-Watersheds

Sub- watershed name	Linear	Areal				Shape			
	R_b	D_d	F_s	R_t	L_{om}	F_f	R_c	C_c	R_e
SWD-1	2.9	0.940	0.837	0.987	0.532	0.354	0.457	1.479	0.671
SWD-2	5	1.080	0.431	0.449	0.463	0.328	0.203	2.219	0.646
SWD-3	4	0.714	0.459	0.226	0.700	0.420	0.280	1.892	0.731
SWD-4	2.9	0.979	0.550	0.598	0.511	0.339	0.282	1.885	0.657
SWD-5	4.2	0.886	0.509	0.466	0.564	0.353	0.268	1.932	0.670

Table 4: Preliminary Priority Ranking of Linear, Areal and Shape Parameters of All Eastern Jeddah Sub-Watersheds

Sub-watershed name	Linear	Areal				Shape			
	R_b	D_d	Fs	R_t	L_{om}	F_f	R_c	C_c	R_e
SWD-1	4	3	1	1	3	4	5	1	4
SWD-2	1	1	5	4	5	1	1	5	1
SWD-3	3	5	4	5	1	5	3	3	5
SWD-4	5	2	2	2	4	2	4	2	2
SWD-5	2	4	3	3	2	3	2	4	3

4.4. Compound factor from the weighted sum approach (WSA)

A cross-correlation analysis between the linear, area, and shape parameters must be performed at a 5% level of significance in order to signal the sub-basins. At a 5% significance level, Table 5 shows that the combination of the following parameters: D_d, L_{om}, R_t , R_e, F_f ,and R_e has a significant positive correlation, while both R_c and Cc have a significant negative correlation.

The priority ranks of the sub-basins were determined using Equation 1 and the compound factor shown in Table 6. The weights assigned to morphometric parameters were calculated by dividing the total correlation coefficient of each parameter by the grand total of correlations shown in Table 5. A model was developed to evaluate the final priority ranking by assigning weights to the various parameters. In Equation (2), the compound factor for watershed prioritization was calculated as follows:

$$\text{Compound factor (CF)} = (-0.095 \times \text{PPR of } R_b) + (0.52\times \text{PPR of } D_d) + (-0.021 \times \text{PPR of } F_s) + (-0.173 \times \text{PPR of } R_t) + (0.047 \times \text{PPR of } L_{om}) + (0.074 \times \text{PPR of } F_f) + (0.358 \times \text{PPR of } R_c) + (0.215 \times \text{PPR of } C_c) + (0.075 \times \text{PPR of } R_e) \quad (2)$$

Sub-watershed SWD-2 received the highest priority ranking, number one, followed by sub-watersheds SWD-4, SWD-5, SWD-1, and SWD-3 in that order (Table 6). Figure 3 depicts the final priority-ranking map for all sub-watersheds. The final priority ranking was carried out in such a way that the compound factor with the lowest value received priority rank 1, the compound factor with the next lowest value received priority rank 2, and so on for all Jeddah sub-watersheds (Aher at al., 2014; Malik at al., 2019).

Table 5: Cross-Correlation Matrix between Linear, Areal, and Shape Parameters

Morphometric Parameter	R_b	F_s	D_d	R_t	L_{om}	F_f	R_c	C_c	R_e
R_b	1	-0.74	0.135	-0.647	-0.054	-0.038	-0.756	0.825	-0.049
F_s	-0.74	1	0.078	0.932	-0.157	-0.13	0.97	-0.923	-0.121
D_d	0.135	0.078	1	0.428	-0.991	-0.96	-0.161	0.296	-0.963
R_t	-0.647	0.932	0.428	1	-0.504	-0.479	0.816	-0.734	-0.47
L_{om}	-0.054	-0.157	-0.991	-0.504	1	0.985	0.086	-0.211	0.986
F_f	-0.038	-0.13	-0.96	-0.479	0.985	1	0.114	-0.216	1
R_c	-0.756	0.97	-0.161	0.816	0.086	0.114	1	-0.98	0.124
C_c	0.825	-0.923	0.296	-0.734	-0.211	-0.216	-0.98	1	-0.227
R_e	-0.049	-0.121	-0.963	-0.47	0.986	1	0.124	-0.227	1
Sum of correlation	-0.324	-0.071	1.777	-0.59	0.159	0.251	1.223	0.733	0.257
Grand total	3.416	3.416	3.416	3.416	3.416	3.416	3.416	3.416	3.416
Weight	-0.095	-0.021	0.52	-0.173	0.047	0.074	0.358	0.215	0.075

Table 6: Priority Category of All Sub-Watersheds Based on Compound Factor Value

Sub-watershed Name	Compound factor	Prioritized ranks	Priority
SWD-1	3.72	Third	Low
SWD-2	1.44	First	Very High
SWD-3	3.87	Fifth	Very Low
SWD-4	2.52	Second	High
SWD-5	3.42	Fourth	Medium

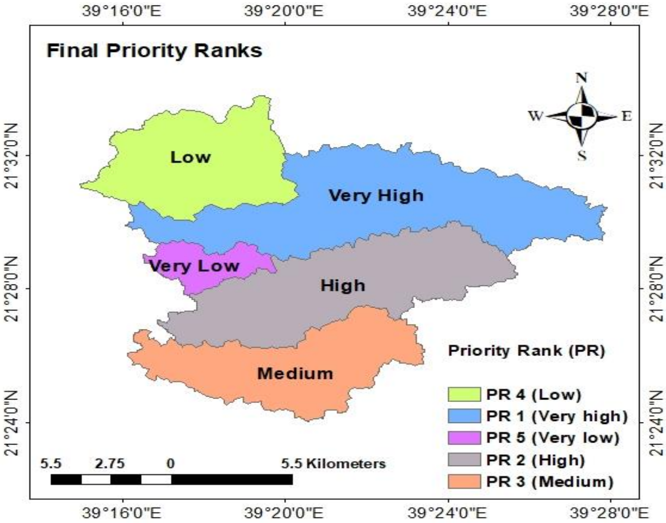

Fig. 3: Final Priority Ranking Map of Sub-Watersheds of Eastern Jeddah.

5. Conclusion

The most important part of making the necessary preparations for the implementation of flood control and early warning system programs is water planners' comprehend of watershed prioritization, which has been enhanced by this work. In other words, the priotrization of watersheds is an important step toward taking precautionary flood risk mitigation measures. A morphometric analysis of all eastern Jeddah sub-watersheds was performed in order to understand the hydrological behavior for effective watershed management. Linear, areal, and shape morphometric parameters were used. The value of the compound factor was used to determine the priority rank of the sub-watersheds (from very low to very high). The WSA method was used to calculate the value of a compound factor. According to the findings, Sub-watershed SWD-2 is the most vulnerable to flooding and soil erosion, followed by SWD-4.

As a result, these two sub-basins will be the starting point for future improvements to avoid potential damage. In other words, these two watersheds should take precedence over the other sub-watersheds. Water resource management and conservation measures must be implemented by the city of Jeddah's responsible authorities. Finally, the WSA demonstrated its effectiveness in watershed management and watershed priotrization for future flood risk mitigation planning. The weighted sum approach is more effective, dynamic, and sustainable than traditional and ordinary watershed prioritization methods that take into account the significance of several characterization parameters. The use of a weighted sum approach in sub-watershed prioritization would result in better decision-making for water resource management and the implementation of flood mitigation measures. Subwatersheds 2 and 4 (SWD-2 and SWD-4) in 2009 were the main contributors to the devastating floods that claimed many lives and destroyed many homes. SWD-2 and SWD-4 are the most susceptible to flooding, according to the WSA. This shows that even though WSA is straightforward, it still has great potential for use in all sub-watersheds that experience flash floods.

References

[1] Kumar A, Darmora A & Sharma S (2012), Comparative assessment of hydrologic behaviour of two mountainous watersheds using morphometric analysis". *Hydrology Journal* 35 (3-4),76-87. https://doi.org/10.5958/j.0975-6914.35.3X.008.

[2] Aher PD, Adinarayana J & Gorantiwar SD (2014), Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a remote sensing and GIS approach. *Journal of Hydrology* 511, 850–860. https://doi.org/10.1016/j.jhydrol.2014.02.028.

[3] Al-Juaidi A.E (2018), A simplified GIS based SCS-CN method for the assessment of land use change on runoff. *Arabian Journal of Geosciences* 11, 269. https://doi.org/10.1007/s12517-018-3621-4.

[4] Al-Juaidi AE, Nassar AM & Al-Juaidi OE (2018), Evaluation of flood susceptibility mapping using logistic regression and GIS conditioning factors. *Arabian Journal of Geosciences* 11, 765. https://doi.org/10.1007/s12517-018-4095-0.

[5] Al-Juaidi AE (2020), The effectiveness of urban water conservation and desalination for water resources management in Jeddah City. *Desalination and Water Treatment* 208, 196–209. https://doi.org/10.5004/dwt.2020.26450.

[6] Al-Juaidi AEM (2023), The interaction of topographic slope with various geo-environmental flood-causing factors on flood prediction and susceptibility mapping. *Environmental Science and Pollution Research* 30, 59327–59348. https://doi.org/10.1007/s11356-023-26616-y.

[7] Al-Shutayri AS & Al-Juaidi AE (2019), Assessment of future urban water resources supply and demand for Jeddah City based on the WEAP model. *Arabian Journal of Geosciences*12, 431. https://doi.org/10.1007/s12517-019-4594-7.

[8] Al-Juaidi AEM & Attia AS (2020), Evaluation of desalination and groundwater supply sources for future water resources management in Riyadh city. *Desalination and Water Treatment,* 175, 11–23. https://doi.org/10.5004/dwt.2020.24892.

[9] Al-Juaidi AEM (2019a), Decision support system with multi-criteria, stability, and uncertainty analyses for resolving the municipal infrastructure conflict in the city of Jeddah. *Journal of King Saud University-Engineering Sciences* 31, 320–326. https://doi.org/10.1016/j.jksues.2017.11.004.

[10] Al-Juaidi (2019b), An integrated framework for municipal demand management and groundwater recovery in a water stressed area, *Arabian Journal of Geosciences* 12,1–10. https://doi.org/10.1007/s12517-019-4503-0.

[11] Al-Juaidi AEM (2019c), A hydrologic-economic-agronomic model with regard to salinity for an over-exploited coastal aquifer, *Arabian Journal of Geosciences* 12, 1–12. https://doi.org/10.1007/s12517-019-4554-2.

[12] Al-Juaidi AE, Kaluarachchi JJ & Kim U (2010), multi-criteria decision analysis of treated wastewater use for agriculture in water deficit regions. *Journal of the American Water Resources Association (JAWRA)* 46, 395–411. https://doi.org/10.1111/j.1752-1688.2009.00409.x.

[13] Al-Juaidi AEM, Rosenberg DE, & Kaluarachchi JJ (2011a), Water management with wastewater treatment and reuse, desalination, and conveyance to counteract future water shortages in the Gaza Strip, *International Journal of Water Resources and Environmental Engineering* 3, 266–282. https://doi.org/10.5897/IJWREE10.030.

[14] Al-Juaidi AE, Kaluarachchi JJ & Mousa AI (2014), Hydrologic-economic model for sustainable water resources management in a coastal aquifer. *Journal of Hydrologic Engineering- ASCE* 19 (2014) 04014020. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000960.

[15] Al-Juaidi AE (2017), Decision support system analysis with the graph model on non-cooperative generic water resource conflicts. *International Journal of Engineering & Technology 6, 145–153.* https://doi.org/10.14419/ijet.v6i4.7566.

[16] Al-Juaidi AE & Hegazy T (2017), Conflict resolution for Sacramento-San-Joaquin Delta with stability and sensitivity analyses usingthe graph model, *British Journal of Mathematics and Computer Science* 20, 1–10. https://doi.org/10.9734/BJMCS/2017/31225.

[17] Al-Juaidi AE, Kim U & Kaluarachchi JJ (2011b), Decision Analysis to Minimize Agricultural Groundwater Demand and Salt Water Intrusion Using Treated Wastewater, Published in Sustainable Water Management Solutions for Large Cities in 2011, GQ10: Groundwater Quality Management in a Rapidly Changing World, Vol. 342, 7th International Groundwater Quality Conference, Eawag, Zurich, Switzerland, 2010.

[18] Kandpal H, Kumar A, Reddy CP & Malik A (2017), Watershed prioritization based on morphometric parameters using remote sensing and geographical information system. *Indian Journal of Ecology* 44(3), 433–437. https://doi.org/10.5958/2455-7145.2018.00035.8.

[19] Khan MA, Gupta VP & Moharana PC (2011), Watersheds prioritization using remote sensing and geographical information system: a case study from Guhiya. *Indian Journal of Arid Environment* 49(3), 465–475. https://doi.org/10.1006/jare.2001.0797.

[20] Meshram SG, & Sharma SK (2015), Prioritization of watershed through morphometric parameters: a PCA-based approach. Applied Water Sciences 7, 1505–1519. https://doi.org/10.1007/s13201-015-0332-9.

[21] Malik A, Kumar A & Kandpal H (2019), Morphometric analysis and prioritization of subwatersheds in a hilly watershed using weighted sum approach. *Arabian Journal of Geosciences* 12, 118. https://doi.org/10.1007/s12517-019-4310-7.

[22] Youssef A, Pradhan B & Sefry S (2016), Flash flood susceptibility assessment in Jeddah city (Kingdom of Saudi Arabia) using bivariate and multivariate statistical models. *Environmental Earth Sciences* 75(1). https://doi.org/10.1007/s12665-015-4830-8.

[23] Dano U (2020), Flash Flood Impact Assessment in Jeddah City: An Analytic Hierarchy Process Approach. *Hydrology* 7(1), p.10. https://doi.org/10.3390/hydrology7010010.

[24] Al Saud MM (2015), Flood Control Management for the City and Surroundings of Jeddah, Saudi Arabia; Springer: New York, NY, USA; London, UK, pp. 1–169. https://doi.org/10.1007/978-94-017-9661-3_1.

[25] Strahler AN (1964), Quantitative geomorphology of drainage basin and channel networks. In: Chow VT (ed) Handbook of applied hydrology. McGraw Hill Book Company, New York section, pp 4–39.

[26] Horton RE (1945) Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Bulletin of Geological Society of America* 56 ,275-370. https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2.

[27] Strahler AN (1952), Hypsometric (area-altitude) analysis of erosional topography. *Bulletin of Geological Society of America* 63, 1117–1142. https://doi.org/10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2.

[28] Rai PK, Mohan K, Mishra S, Ahmad A, Mishra MV (2014), A GIS-based approach in drainage morphometric analysis of Kanhar River basin, India. *Applied Water Sciences* 7(1), 217–232. https://doi.org/10.1007/s13201-014-0238-y.

[29] Horton RE (1932), Drainage basin characteristics. *Transactions American Geophysical Union* 13, 350-361. https://doi.org/10.1029/TR013i001p00350.

[30] Smith KG (1950), Standards for grading textures of erosional topography. *American Journal of Science* 248(9), 655–668.

[31] Miller VC (1953), A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Project NR 389042, Tech. Rept. 3. Columbia University, Department of Geology, ONR, Geography Branch, New York.

[32] Schumn SA (1956), Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Bulletin of Geological Society of America* 67(5), 597–646. https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2.

[33] Nookaratnam K, Srivastava YK, Venkateswarao V, Amminedu E, & Murthy KSR (2005), Check dam positioning by prioritization of micro watersheds using SYI model and morphometric analysis-remote sensing and GIS perspective. *Journal of the Indian Society of Remote Sensing* 33(1), 25–28. https://doi.org/10.1007/BF02989988.