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Statistical Modeling to Predict the Hydrological Characteristics of the Sub- Basins of the Northern Jordan Rift Valley(*)

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Abstract

Morphometric parameters are an applicable method to understand the hydrological system of water drainage basins. To determine the capabilities of sub-basins, morphometric analysis was adopted, using the linear, areal, drainage network, formality, and relief variables of the drainage basin. Moreover, remote sensing and GIS have been proven to be efficient tools for identifying morphological parameters. This study might help to take water conservation measures and undertake repairs of drainage basin management structures for better decision-making in the future. The data used in the assessment cover the long-term from (1970-2020) and constitute the monthly and daily rates of rainfall and temperature for four climatic stations. Furthermore, the morphological parameters were calculated from the digital elevation model (DEM) file with a 30 m resolution obtained from U.S. Geological Survey (USGS). Also, using algorithms formulas, represented by the SCS method for runoff estimation, equations for morphometric variables, and equations for hydrological variables estimation. A correlation matrix (Pearson's correlation coefficient) was set up between the hydrological and morphometric variables to determine that the morphometric variables had a statistically significant relationship with the hydrological variables. This would enable us to predict the hydrological variables of the sub-basins of the study area. Based on linear regression analysis using SPSS, the results of the correlation analysis that were applied to

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all morphometric and hydrological variables (39 variables) showed that there are significant positive and negative statistical relationships between them. The variables that were used in the regression analysis were also adopted on the basis of the results obtained from the correlation analysis. These were variables that had a high degree of correlation and that had a linear relationship with it. Moreover, the regression analysis prepared statistical models for the hydrological variables in the form of mathematical equations through which we could estimate and predict the hydrological variables with the least possible error.

Keywords Jordan Rift Valley. hydrological variable, morphometric variable. Regression coefficient, Pearson's correlation, statistical models.

مستخلص:

يعد تحليل المتغيرات المورفومترية طريقة قابلة للتطبيق لفهم النظام الهيدرولوجي في احواض التصريف المائي. حيث يتم الاعتماد على التحليل المورفومتري لتحديد إمكانيات الأحواض المائية الفرعية من خلال تحديد المتغيرات الخطية ، الشكلية ، خصائص الشبكة المائية ، والمتغيرات التضاريسية لاحواض التصريف المائي. علاوة على ذلك ، تعتبر تقنيات الاستشعار عن بعد و نظم المعلومات الجغرافية أدوات فعالة في تحديد المتغيرات المورفومترية، من خلال الاعتماد على نموذج الارتفاع الرقمي (DEM)، والتي تم الحصول عليها هيئة المسح الجيولوجي الأمريكية (USGS) . كما تم استخدام المعادلات الرياضية لتقدير الجريان المائي، وحساب المتغيرات المورفومترية، و حساب الخصائص الهيدرولوجية. أيضا استخدم معامل ارتباط بيرسون لاستخراج العلاقة ما بين المتغيرات المورفومترية والخصائص الهيدرولوجية في الأحواض المائية في منطقة الدراسة. كما اعتمدت الدراسة على التحليل باستخدم معادلة الانحدار الخطي بغية إنشاء نماذج إحصائية تمكننا من التنبؤ بالمتغيرات الهيدرولوجية المتمثلة بالجريان السطحي، زمن التأخير، زمن التركيز، زمن التصريف، سرعة الجريان السطحي ، ومعامل الفيضان بالاعتماد على المتغيرات المورفومترية و البالغ عددها ٣١ متغيرا. ويتضح ذلك من خلال المعادلات والرسوم البيانية ذات الصلة وإمكانية تطبيقها على أحواض التصريف المائي في مناطق أخرى من العالم. بناء على ما تقدم يمكن ان تساهم نتائج الدراسة في اتخاذ التدابير للحفاظ على الموارد المائية، و إدارة أحواض التصريف المائي لاتخاذ قرارات أفضل في المستقبل.

كلمات مفتاحية: وادي الأردن الصدعي، متغير هيدرولوجي ، متغير مورفومتري. معامل الانحدار، معامل ارتباط بيرسون ، النماذج الإحصائية.

1 Introduction

Hydro-geomorphology is a science that represents the relationship between several hydrologic and geomorphic processes, (Higgins and Coates 1990). The drainage basin Morphometric variables, and hydrological units should be taken into consideration for planning the management, development, and administration of natural resources at any scale. (Salunkea and Wayalb 2021., Sindhu et al. 2015., Strahler 1964., Strahler 1957., Demoulin 2010., Prakash et al. 2019., Pande et al. 2018., Al-Sababhah 2019). As such, relationships can be extracted by conducting a correlation study of their drainage basin morphological and hydrological characteristics, (Miller 1953). Also, the use of (GIS) results in the proper understanding of drainage basin management if combined with satellite data, (Singh et al. 2014., Altaf and Romshoo 2013., Al-sababhah 2023). The results of various studies showed that morphometric analysis reveals basic information about hydrogeology, and characteristics of overlapping watersheds from ground and surface water potential, (Harinath and Raghu 2013., Al-sababhah and Alomari 2019). Therefore, invaluable natural resources within river basins, such as vegetation, water resources, soil, etc., need protection and conservation before they are exposed to degradation, (Morgan 2005). In order to evaluate the statistical relations between morphometric variables of drainage basins, we can rely on quantitative analysis to understand their topographic characteristics for the proper basin management, and it can determine the correlation coefficients between different parameters with the aim to understanding their underlying connection and their role in the basin hydro geomorphology, (Rai et al. 2018). This is based on the morphometric ranking method integrating hydrological models with GIS to determine the hydrogeomorphological relationships. The present study first extracts the values of morphometric and hydrological variables for sub-basins in the studied area, then estimates the Pearson correlation coefficient between hydrological and morphometric variables, and later defines the strong correlations between variables. In the end, the production of statistical models helps to predict the hydrological variables for these basins through relationships between variables.

2 Methods and Materials

2.2 Study area

The study area, the northern Jordan rift valley basin, is located in the northwestern district of Jordan and geographically lies between longitude 35°32' E and 35°52' E and latitude32°15' N and 32°40'N covering an area of 1079 km² from the total area of Jordan, which is around 92,000km2 The northern Jordan rift valley basin can be subdivided into five drainage basins including al-Arab, Ziqlab, al-Rayan, al-Taibeh, and Kufranja. These valleys were analyzed in the present study. Figure (1a). From a topographical point of view, the study area watershed is characterized by its complex relief. Indeed, all the rivers have their source in the elevations of the east bank of the northern Jordan valley, some of which reach 1226 m above sea level. They end up below sea level in the Jordan River at elevation (- 453m). Figure (1b). In the northern Jordan Valley sub-catchment, there are six slope classes identified and calculated in degrees. The slopes vary from 0° to 58.2°. Figure (1c). Climatologically, the long-term analysis observed a regional rainfall average of 447 mm per year (i.e., from approximately 243 mm minimum to 570 mm maximum). Figure (1d). Also, the long-term analysis of temperature showed that the area's average temperature was approximately 19.6°C, with a mean annual minimum and maximum temperature between 14.6 °C and 23 °C, respectively. Figure (1e). Finally, the study area can be subdivided into three climate regions, including semi-arid, semi-humid, and humid regions. Figure (1f).

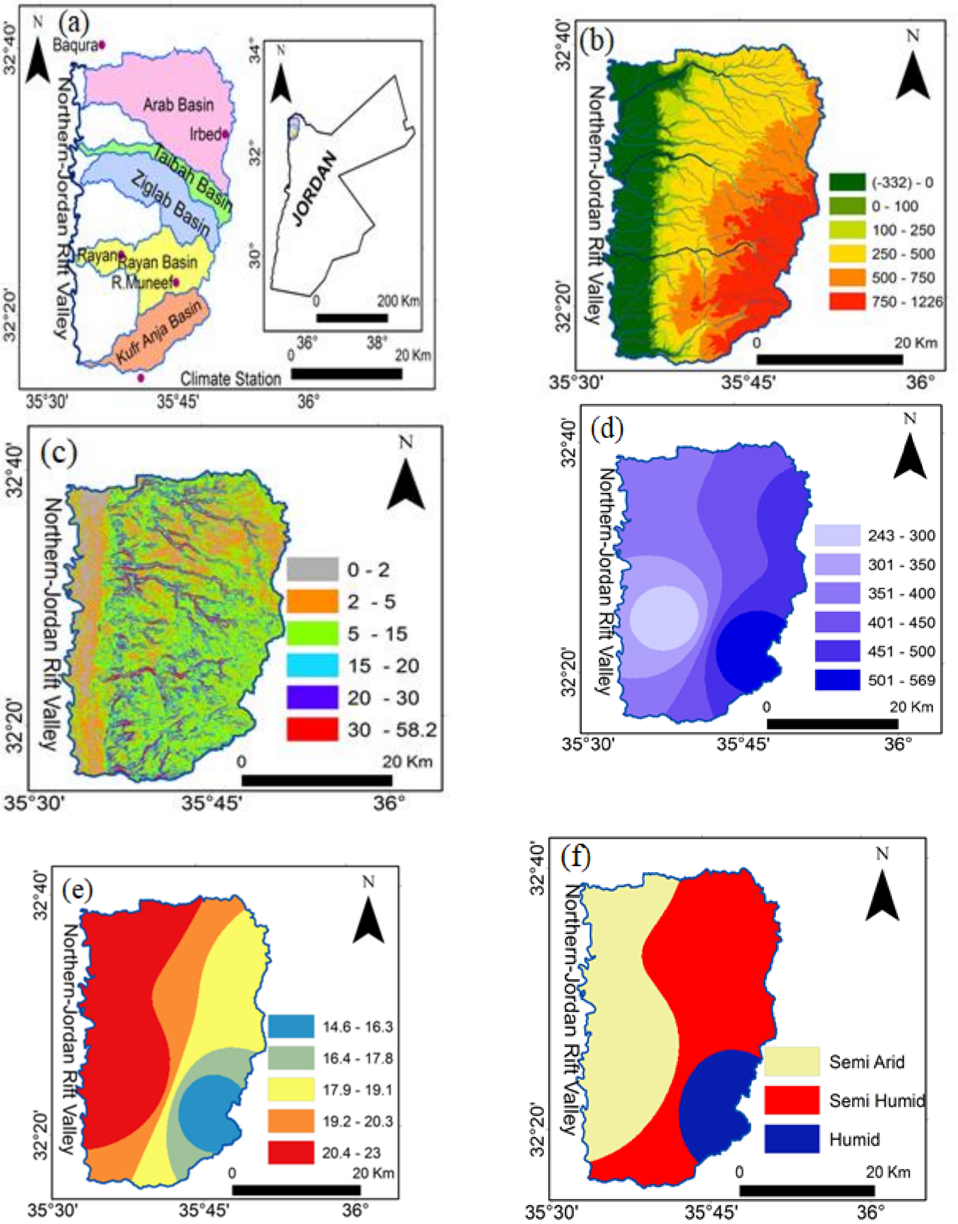

Figure 1 a Study Area, b Elevation (m), c Slope (Degree) d Rainfall (mm), e Temperature (C°) f Climate Regions

Data 2.2

The data used in the assessment cover the long-term from (1970-2020) and constitute the monthly and daily rates of rainfall and temperature for four climatic stations. Figure (1a). They are also used to determine the climatic characteristics and for runoff estimation. The morphological parameters were calculated from the Digital Elevation Model (DEM) file with 30 m resolution obtained from U.S. Geological Survey (USGS). The set of data was calculated by exporting shape files by ARC-GIS, and using algorithms and formulas.

2.3 Hydro-Morphometric Analysis

2.3.1 Morphometric Analysis

In this study, a morphometric analysis of the thirty-three parameters of all the five sub-watersheds has been carried out using standard mathematical formulae. They are given in Table 1.

Table I: Morphometric Parameters

Morphometric parameters	Method, Reference	Morphometric parameters	Method, Reference
Area (A)	DEM	Geometry Number (Gn)	Gn= Bn× Dd / D, (Strahler 1964) (6)
Perimeter (P)	DEM	Elongation Ratio (Re)	$Re=(2/Lb) \times (A/3.14)^{0.5}$,(Schum 1956) (7)
Length (Lb)	DEM	Circularity Ratio (Rc)	$Rc=4*3.14(A/p^{2})$, (Miller 1953) (8)
Mean Width (Wb)	Wb=A/Lu ,(Horton 1932) (1)	Shape Factor (Sf)	$Fr=A/Lb^{2,}$ (Horton 1932) (9)
Max. Elevation (H)	DEM	Drainage Density (Dd)	Dd=Lu/A, (Horton 1932) (10)
Min. Elevation (h)	DEM	Stream Frequency (Fs)	Fs=Nu/A, (Horton 1932) (11)
Stream Order (U)	DEM	Length of Overland Flow(Lo)	Lg=A/2*Lu, (Horton 1945) (12)
Mean Slope (Sm)	DEM	Compactness Coefficient (Cc)	$C=0.2821*p/A^{0.5}$, (Singh&Dubey 1994)

			(13)
Mean Elevation (Em)	DEM	Drainage Texture (T)	T=Nu/p, (Horton 1945) (14)
Actual Main Stream length (La)	DEM	Drainage Intensity (Dint)	Di=Fs/Dd, (Faniran 1968) (15)
Typical of the main stream (Lt)	DEM	Basin Slope Degree (D)	D =Bh/(Lb*60), (Strahler 1957) (16)
Total Stream Number (Nu)	DEM	Dissection Index (Dind)	(H-h)/H, (Singh&Dubey,1994) (17)
Total Stream Length (Lu)	DEM	Mean Stream Length(Lsm)	Lsm=Lu/Nu, (Horton 1945) (18)
Mean of Bifurcation ratio (Rbm)	R = N / N+1 (Strahler 1957) (2)	Detour Coefficient (Dc)	Dc=La/Lt, (Horton 1932) (19)
Basin Relief (Br)	Br=H-h, (Strahler 1957) (3)	Texture Ratio (Tr)	Rt=Cp /p, (Schumm 1956) (20)
Relief Ratio (Rr)	Rh= H /Lb. (Schumm 1956) (4)	Ruggedness Value (Rn)	Rn=Br*Dd, (Strahler 1957) (21)
Hypsometric Integral (Hi)	Hi=(H - Em)/(H−h), (Wilson 2009) (5)		

All these morphometric parameters were calculated and analyzed for the sub watersheds of the Northern Jordan Rift Valley Basin, Table 2.

Table 2: The values of morphometric parameters of the sub watersheds

Morphometric parameters	Basins				
	Arab	Ziglab	Taibah	Rayan	Kufr Anja
Area (A)	272.9	142.6	60.3	147	112.2
Perimeter (P)	114	94.6	95	98	82.7
Length (Lb)	27.2	25.5	29	25.1	24.6
Mean Width (Wb)	10.0	5.6	2.0	5.8	4.6
Max. Elevation (H)	856	1090	1025	1187	1236

Min. Elevation (h)	-285	-304	-291	-302	-334
Stream Order (U)	5	4	3	4	4
Mean Slope (Sm)	8.7	11.4	11.7	12.3	12.5
Mean Elevation(Em)	338	475	498	586	682
Actual Main Stream length (La)	16	13.3	30	13	16
Typical of the main stream (Lt)	11.5	12.2	28.2	11.2	12.7
Total Stream Number (Nu)	319	114	53	131	131
Total Stream Length (Lu)	331	123	65	140	116
Mean of Bifurcation ratio (Rbm)	1.96	1.87	1.58	1.65	1.8
Basin Relief (Br)	1141	1394	1316	1489	334
Relief Ratio (Rr)	41.95	54.67	45.38	59.32	13.58
Hypsometric Integral (Hi)	0.55	0.56	0.60	0.60	0.65
Geometry Number (Gn)	1.98	1.32	1.88	1.43	1.53
Elongation Ratio (Re)	0.69	0.53	0.30	0.54	0.49
Circularity Ratio (Rc)	0.26	0.20	0.08	0.19	0.21
Shape Factor (Sf)	0.37	0.22	0.07	0.23	0.19
Drainage Density (Dd)	1.21	0.86	1.08	0.95	1.03
Stream Frequency (Fs)	1.17	0.80	0.88	0.89	1.17
Length of Overland Flow (Lo)	0.61	0.43	0.54	0.48	0.52
Compactness Coefficient (Cc)	0.41	0.58	0.46	0.53	0.48
Drainage Texture (T)	2.80	1.21	0.56	1.34	1.58
Drainage Intensity (Dint)	0.96	0.93	0.82	0.94	1.13
Basin Slope Degree (D)	0.70	0.91	0.76	0.99	0.23
Dissection Index (Dind)	1.33	1.28	1.28	1.25	1.27
Mean Stream Length (Lsm)	0.96	0.93	0.82	0.94	1.13
Detour Coefficient (Dc)	1.39	1.09	1.06	1.16	1.26
Texture Ratio (Tr)	2.70	5.40	6.80	5.60	8.00
Ruggedness Value (Rn)	1.38	1.20	1.42	1.42	0.35

2.3.2 Hydrological Analysis

The hydrological characteristics were studied by adopting mathematical models. One of the most important aspects of this study is the fact that the basin area is one of the promising areas suitable for the investment of surface water and groundwater in economic quantities that can contribute to the revitalization of various sectors, particularly agricultural ones. These characteristics are:

Lag Time

Lag is the delay between the time runoff from a rainfall event over a watershed begins until runoff reaches its maximum peak. Lag Time may be represented. By the following relationship:

$$TL = (0.4XA)^{0.3} / (Sm/Dd) \quad (22)$$

Where TL is Lag Time (hr), A area, Sm mean slope, and Dd drainage density, (Berkeley, 1991).

Concentration Time

Time of concentration (Tc) is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. The hydraulically most distant point is the point with the longest travel time to the watershed outlet, and not necessarily the point with the longest flow distance to the outlet. Time of concentration is generally applied only to surface runoff and may be computed, using many methods, by the following equation:

$$Tc = (LaX1000)^{1.15} / (7700XBr)^{0.38} \quad (23)$$

Where Tc is Concentration Time (min), La the actual main stream length, and Br basin relief, (Heath 1980).

Drainage Time

Drainage time is the time it takes water to travel from one location to another. Travel time between the two points is determined using the following relationship:

$$Td = (0.00013)X(LaX1000)X(Br)^{0.38} \quad (24)$$

Where Td is Drainage time (hour), La the actual main stream length, and Br basin relief, (Merkel 2001).

Velocity of Runoff

The velocity method assumes that time of concentration is the sum of travel times for segments along the hydraulically most distant flow path; it is computed by the following equation:

$$V = Tc/Lb \quad (25)$$

Where **V** is velocity of Runoff (m/sec), Tc Concentration Time (min), and Lb basin Length, (Maidment 1993).

Flood Factor

The flood factor is referred to as the time interval between precipitation and the flood event, and both response time and runoff velocity are the most important determinants of the basin's hydrological characteristics. The morphometric characteristics of the basins clearly affect their hydrological characteristics, by either increasing the speed of the water movement in the streams, then the arrival of the flood to the end of the basin, or any location along the main course of this basin; it is calculated by the following equation:

$$Rc = Dd\ X(Fs.1stord) \quad (26)$$

Where Rc is flood factor, Dd drainage density, and Fs.1stord Stream Frequency of first stream order, (Chow et al. 1988).

The hydrological variables were treated to understand the nature of the runoff in the basin area and to estimate their values under the morphometric variables. Table 3.

Table 3: The values of hydrological variables

variables Hydrological	Basins				
	Arab	Ziglab	Taibah	Rayan	Kufr Anja
Lag Time (hr) (TL)	0.57	0.25	0.24	0.26	0.26
Concentration Time (min) (TC)	157.07	117.69	306.55	111.81	250.52
Drainage time (hour) (Td)	30.19	27.08	59.76	27.14	18.93
Velocity of Runoff (m/sec) (V)	0.17	0.22	0.09	0.22	0.10
Flood Factor (Rc)	1.1	0.7	1.2	0.8	1.3

2.4 SCS-CN Method, (USDA 2004)

The method selected for our study is the SCS-CN. In hydrological modeling, runoff estimation is the most important aspect, and there are number of empirical methods for its estimation. The most commonly and widely used empirical method is the Soil

Conservation Service-Curve Number Method (SCS) developed by United States Department of Agriculture and Soil Conservation Service (USDA-SCS). This method is very popular due to its simplicity, flexibility, and requirement of a single parameter called Curve Number (CN) for computation of runoff. Hydrologic soil group number, land use type, and vegetation cover are the basic catchment characteristics used for curve number calculations. The equation for surface runoff is given by:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad (27)$$

Where, Q is Accumulated runoff or rainfall excess in mm, P Rainfall depth in mm, Ia Initial abstraction in mm, and S Potential maximum retention in mm. The US Soil Conservation Service has found by experience that,

$$Ia = 0.2S \qquad (28)$$

The term S is given by,

$$S = \frac{25400}{CN} - 254 \qquad (29)$$

Where, CN is Curve Number. For the study area conditions some modifications were done and now Ia = 0.3S. Equation for discharge can now be written as:

$$Q = \frac{(P - 0.3S)^2}{(P - 0.7S)} \qquad (30)$$

The curve numbers were adjusted; therefore, the total simulated runoff matched with the observed runoff data of the watersheds throughout the calibration process. The SCS-CNs were optimized according to the general condition of the land cover and land form within the study area. Table 4 indicates the Runoff values (m^3/sec) based on the SCS-CN Method.

Table 4: The values of Runoff (m^3/sec)

Basins	Arab	Ziglab	Taibah	Rayan	Kufr Anja
Runoff (m^3/sec)	0.41	0.47	0.48	0.37	0.45

2.5 Statistical Analysis

2.5.1 Pearson's Correlation Coefficient

A correlation matrix is used to show all possible correlation coefficients between all variables. The matrix is useful to show how strongly each independent variable is related to the dependent variable at different lag times. Pearson's Correlation Coefficient,was set up between the hydrological and morphometric variables to determine thatthe morphometric variables have a statistically significant relationship with the hydrological variables, and to enable us to predict the hydrological changes of the sub-basins of the study area, by the following equation:

(31) $$r_p = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{(n\sum x^2 - (\sum x)^2)(n\sum y^2 - (\sum y)^2)}}$$

The value of the correlation coefficient ranges between (-1,1), where X represents the independent variable (morphometric variables), and Y is the dependent variable (hydrological variables) as well, according to required relationships, and n number of years.

2.5.2 Regression analysis

Regression analysis is widely used for prediction, where its use has substantial overlap with the field of geomorphological and hydrological studies. The regression equations obtained from these parameters show that there are curved lines describing the correlation between the hydrological and morphometric variables, according to the following equation:

$Y = \mathrm{a} + \mathrm{b1x1} + \mathrm{b2x2} + \ldots\ldots + \mathrm{bnxn}$ (32)

Where y is the predicted values (hydrological variables), a is the amount of change in the studied phenomenon, and b is the value of Y in terms of X, which is indicated on the independent variables (morphometric variables), (Humaidan et al. 2006). The statistical significance of the change in the curvature of the general trend of the phenomenon with respect to the zero value that assumes that there is no change, and the importance of changing the averages of its values statistically during time, were obtained by testing the statistical significance of the regression equations of hydrological and morphometric variables, depending on Linear regression analysis using SPSS.

3. Results and discussion

3.1 The correlation between the hydrological and morphometric variables

There is a correlation between the variables and the factors that make up any of the natural systems, as determining the correlation coefficient between these variables and factors helps to measure the size of the relationship between them (Anton et al. 2002, Chapman and Monroe 1993, Naiman et al. 1983). The current study relied on the Pearson correlation coefficient to determine the relationship between morphometric and hydrological variables. Pearson's Correlation coefficients analysis between morphometric and hydrological variables for study area indicates the presence of a negative correlation between runoff volume and sub-basin area, and a positive relationship with basin length with statistical significance at the level of 5%. There is also a positive correlation between Lag Time, Area, Perimeter, Mean Width, Stream Order, Total Stream Number, Total Stream Length, and Mean of Bifurcation ratio. The Elongation Ratio, Length of Overland Flow and Detour Coefficient have statistical significance at the level of 1% and 5%. The negative correlation between Time and Maximum Elevation, Mean Elevation and Texture Ratio show statistical significance at the level of 1%. There is also a negative correlation between Concentration Time and Area in addition to Circularity Ratio, Elongation Ratio and Form Factor with statistical significance at the level of 5%. A positive correlation with basin length and Main Stream length is statistically significant at 5%. A positive relationship between Runoff Time, Basin Length, and Main Stream length and a negative relationship with Circularity Ratio, Elongation Ratio and Drainage Intensity are statistically significant at 5%. Also, a positive relationship between Velocity of Runoff, Basin Relief, Relief Ratio, and Basin Slope Degree, and a negative relationship with The Main Stream length with statistical significance are observed at the 5% level. Finally, a positive relationship between Flood Factor, Geometry Number, Stream Frequency, and Length of Overland Flow, and a negative one with Basin Relief, Relief Ratio, Basin Slope Degree and Compactness Coefficient are found at the levels of 1% and 5% respectively. The relationship between these variables does not always determine the strength of effectiveness in prediction. We may find a strong relationship between the morphometric variable and a hydrological variable, but the possibility of prediction is limited, although this variable is weak, and vice versa. Thus, the process of increasing the effectiveness of forecasting must combine more than one variable in order to give a high predictability. See Table 5.

Table 5 Pearson's Correlation Coefficients between the hydrological and morphometric variables

Var	A	P	Lb	Wb	H	h	U	Sm	Em	La	Lt
Q	-0.54*	-0.43	0.37	-0.57	-0.04	-0.14	-0.54	0.14	0.01	0.56	0.60*
TL	0.92*	0.84*	0.23	0.87*	-0.80*	0.50	0.82*	-0.94*	-0.74*	-0.18	-0.33
Tc	-0.59*	-0.40	0.54*	-0.64	0.03	-0.17	-0.61	0.23	0.26	0.85*	0.80*
TD	-0.44	0.15	0.93*	-0.53	-0.40	0.59	-0.66	-0.05	-0.31	0.93*	0.94*
V	0.46	0.38	-0.44	0.51	-0.02	0.25	0.45	-0.16	-0.27	-0.75	-0.66*
Rc	-0.17	-0.21	0.32	-0.21	-0.07	-0.25	-0.14	-0.03	0.20	0.55	0.42
Var	Nu	Lu	Rbm	Br	Rr	HI	Gn	Re	Rc	Sf	Dd
Q	-0.49	-0.49	-0.05	-0.21	-0.29	0.09	0.06	-0.61*	-0.50	-0.59	-0.12
Tl	0.96**	0.97**	0.69*	-0.02	-0.05	-0.57	0.65	0.75*	0.65	0.83**	0.76*
Tc	-0.40	-0.43	-0.45	-0.46	-0.58	0.55	0.50	-0.74*	-0.64*	-0.68*	0.40
TD	-0.39	-0.32	-0.60	0.43	0.28	-0.14	0.56	-0.70*	-0.84*	-0.60	0.28
V	0.25	0.29	0.31	0.62*	0.73*	-0.59	-0.53	0.59	0.47	0.53	-0.50
Ff	0.06	0.005	-0.10	-0.73*	-0.82*	0.56	0.63*	-0.29	-0.17	-0.23	0.70
Var	Fs	Lo	Cc	T	Dint	D	Dind	Lsm	Dc	Tr	Rn
Q	-0.21	-0.15	0.09	-0.49	-0.17	-0.29	-0.16	-0.17	-0.46	0.43	-0.26
TL	0.62	0.77**	-0.69	0.91*	0.07	-0.05	0.26	0.07	0.85*	-0.84**	0.25
Tc	0.23	0.39	-0.49	-0.40	-0.06	-0.58	-0.40	-0.06	-0.17	0.58	-0.31
TD	-0.39	0.25	-0.29	-0.53	-0.83*	0.28	0.48	-0.83*	-0.50	0.06	0.55
V	-0.42	-0.49	0.59	0.23	-0.12	0.73*	0.52	-0.12	-0.03	-0.54	0.44
Rc	0.70**	0.69**	-0.77*	0.10	0.32	-0.82*	-0.58	0.32	0.36	0.35	-0.49

)Correlation is significant at the 0.01 level (2-tailed. **

) Correlation is significant at the 0.05 level (2-tailed. *

The study also determined the mean and standard deviation of the morphometric and hydrological variables based on the results of the statistical analysis. Table 6.

Table 6 The mean and standard deviation of the morphometric and hydrological variables

Parameter	Average	STDEV	Parameter	Average	STDEV	Parameter	Average	STDEV
A	147	78.43	Rbm	1.8	0.16	Dint	0.96	0.11
P	97	11.23	Br	1135	465.5	D	0.72	0.30
Lb	26.3	1.81	Rr	43	17.9	Dind	1.03	0.58
Wb	5.6	2.89	HI	1	0.04	Lsm	0.96	0.11
Z	1078.8	149.2	Gn	1.6	0.29	Dc	1.19	0.13
z	-303	18.91	Re	0.51	0.14	Tr	5.70	1.97
U	4	0.71	Rc	0.19	0.07	Rn	1.15	0.46
Sm	11.3	1.53	Sf	0.22	0.11	Q	0.44	0.05
Em	516	128.6	Dd	1.03	0.13	TL	0.32	0.14
La	17.7	7.04	Fs	0.98	0.18	Tc	188.7	86.1
Lt	15.2	7.31	Lo	0.52	0.07	TD	32.6	15.7
Nu	150	100	Cc	0.5	0.07	V	0.16	0.06
Lu	155	102.3	T	1.50	0.82	Rc	1.02	0.26

3.2 Prediction of hydrological characteristics

A regression equation is a formula by which a dependent variable is predicted from an independent variable. Accordingly, we can formulate a mathematical model through the multiple regression equation to predict the hydrological characteristics depending on the independent variables represented by the related morphometric variables. It is also effective in the forecasting process. The large number of morphometric variables included in the regression equation to predict the hydrological variables aimed to enhance prediction accuracy and provide more statistically significant results. The independent variables used to establish the functional forms of model parameters were selected based on the results of the Pearson's correlation coefficients. However, the strong correlation coefficient does not always provide appropriate results in prediction when applying the multiple regression equation, due to the lack of statistical significance of the independent variable alone at the 5% level. Thus, we had to resort to the introduction of two or more independent variables in the regression equation to obtain the appropriate statistical significance and a confidence level greater than 95%.

3.2.1 Prediction of Runoff

The best-performing parameter functions in the statistical models are listed by the regression equations that provide high accuracy for the prediction of Runoff as demonstrated below (33-38): Statistical prediction of Runoff based on the mean elevation (Em), given as model:

$$Q = 0.435 + (2.207 \times x10^{-6} \times Em) \quad (33)$$

Statistical prediction of Runoff based on Area (A), Length (Lab), and Perimeter (P), given as model:

$$Q = 0.225 + (0.001 \times A) + (0.031 \times Lb) + (-0.007 \times P) \quad (34)$$

Statistical prediction of Runoff based on Hypsometric Integral (HI), Elongation Ratio (Re), Basin Slope Degree (D), Compactness Coefficient (Cc) and Ruggedness Value (Rn) given as model:

$$Q = 1.904 + (-1.772 \times HI) + (-0.432 \times Re) + (-0.09 \times Cc) + (-0.133 \times Rn) \quad (35)$$

Statistical prediction of Runoff based on Circularity Ratio (Rc), Stream Frequency (Fs), Basin Slope Degree (D), and Texture Ratio (Tr), given as model:

$$Q = 1.695 + (-0.365 \times Rc) + (-0.647 \times Fs) + (-0.473 \times D) + (-0.0.038 \times Tr) \quad (36)$$

Statistical prediction of Runoff based on Drainage Density (Dd), Drainage Intensity (Dint) Basin Slope Degree (D), and Texture Ratio (Tr), given as model:

$$Q = 2.307 + (-0.554 \times Dd) + (-0.877 \times Dint) + (-0.458 \times D) + (-0.024 \times Tr) \quad (37)$$

Statistical prediction of Runoff based on Length of Overland Flow (Lo), Basin Slope Degree (D), Length (Lb), Mean Width (Wb), given as model:

$$Q = -0.012 + (-1.316 \times Lo) + (-0.223 \times D) + (0.047 \times lB)(0.012 \times Wb$$

(38)

The direction of change of the study area in the total average of the predicted runoff values can be determined using the above-mentioned six statistical models and the estimated value in Figure (2a), while the direction of change in the predicted estimated values of runoff for sub-basins is shown in Figure (2b).

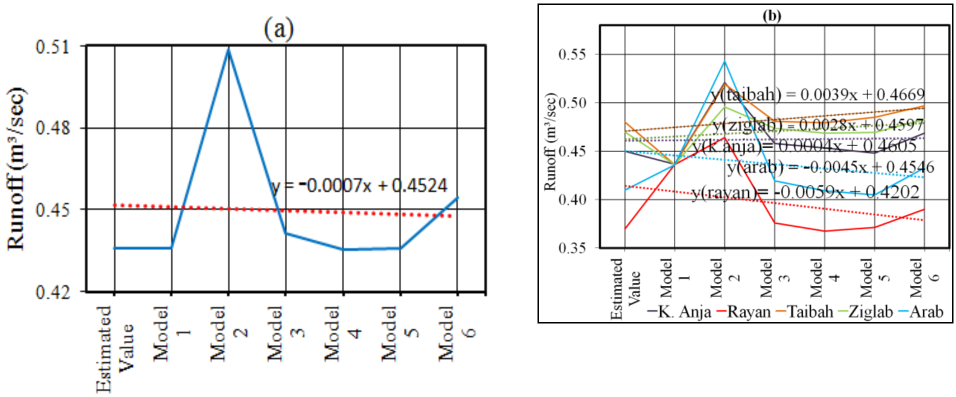

Figure 2 (a) The total average of the predicted runoff values; (b) Estimated and predicted runoff values for sub-basins

As for the differences between the predicted values through the aforementioned six statistical models and the estimated value for the study area, the lowest Runoff differences were between the predicted values and the estimated values in the first (0.0001 m³/sec) and the fourth models (0.0004 m³/sec), Table 7.

Table 7 Difference between estimated and predicted runoff values (m³/sec)

Basins	Arab	Ziglab	Taibah	Rayan	K. Anja	Difference
Estimated	0.4100	0.4700	0.4800	0.3700	0.4500	0.4360
Model 1	0.4357	0.4360	0.4361	0.4363	0.4365	0.4361
Difference	0.0257	0.0340	0.0439	0.0663	0.0135	0.0001
Model 2	0.5431	0.4959	0.5193	0.4641	0.5209	0.5087
Difference	0.1331	0.0259	0.0393	0.0941	0.0709	0.0727
Model 3	0.4193	0.4735	0.4807	0.3760	0.4580	0.4415
Difference	0.0093	0.0035	0.0007	0.0060	0.0080	0.0055
Model 4	0.4092	0.4685	0.4795	0.3677	0.4533	0.4356
Difference	0.0008	0.0015	0.0005	0.0023	0.0033	0.0004
Model 5	0.4049	0.4694	0.4851	0.3715	0.4482	0.4358
Difference	0.0051	0.0006	0.0051	0.0015	0.0018	0.0002
Model 6	0.4329	0.4830	0.4971	0.3902	0.4687	0.4544
Difference	0.0229	0.0130	0.0171	0.0202	0.0187	0.0184

3.2.2 Prediction of Lag Time

The best performing parameter functions in the statistical models are listed by the regression equations that provide high accuracy for prediction of Lag Time as shown below (39-44):

Statistical prediction of Lag Time based on Area (A), given as model:

$$Tl = 0.072 + (0.002 \times A) \quad (39)$$

Statistical prediction of Lag Time based on Mean Slope (Sm), given as model:

$$Tl = 1.308 + (-0.088 \times Sm) \quad (40)$$

Statistical prediction of Lag Time based on Area (A), Mean Slope (Sm), and Drainage Density (Dd), given as model:

$$Tl = 0.058 + (0.001 \times A) + (-0.024 \times Sm) + (0.37 \times Dd) \quad (41)$$

Statistical prediction of Lag Time based on Area (A), Mean Slope (Sm), Drainage Density (Dd), and the Actual Main Stream length (La), given as model:

$$Tl = 0.255 + (0.001 \times A) + (-0.037 \times Sm) + (0.448 \times Dd) + (-0.0.003 \times La) \quad (42)$$

Statistical prediction of Lag Time based on Mean Slope (Sm), the Actual Main Stream length (La), Ruggedness Value (Rn), and Stream Frequency (Fs), given as model:

$$Tl = 0.449 + (-0.065 \times Sm) + (-0.003 \times La) + (0.094 \times Rn) + (0.341 \times Fs) \quad (43)$$

Statistical prediction of Lag Time based on Elongation Ratio (Re), Basin Slope Degree (D), Ruggedness Value (Rn), given as model:

$$Tl = -0.127 + (0.789 \times Re) + (-0.632 \times D) + (0.428 \times Rn) \quad (44)$$

The direction of change of the study area in the predicted lag time values can be determined using the above-mentioned six statistical models and the estimated value in Figure (3a), while the direction of change in the predicted and estimated values of lag time for sub-basins is found in Figure (3b).

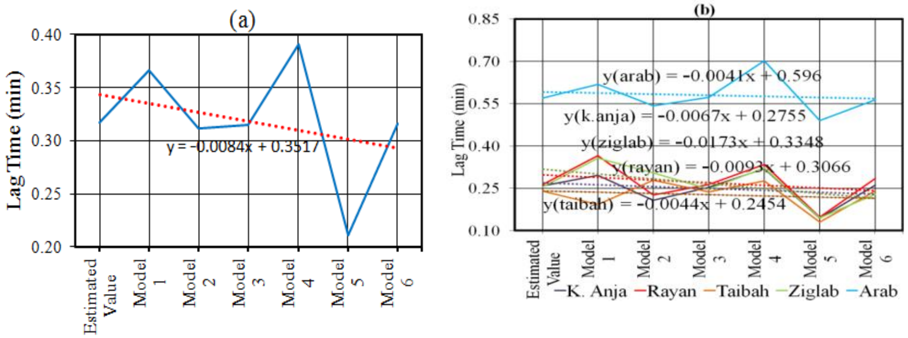

Figure 3(a) The total average of the predicted of Lag time (min) values; (b) Estimated and predicted Lag time (min) values for sub-basins

As for the differences between the predicted values through the aforementioned six statistical models and the estimated value for the study area, the lowest Lag time differences were between the predicted values and the estimated values in the second (0.0053 min) and the six models (0.0013 min), Table 8.

Table 8 Difference between estimated and predicted Lag time (min)

Basins	Arab	Ziglab	Taibah	Rayan	K. Anja	Difference
Estimated	0.5697	0.2545	0.2394	0.2629	0.2589	0.3171
Model 1	0.6179	0.3572	0.1926	0.3660	0.2964	0.3660
Difference	0.0481	0.1027	0.0468	0.1031	0.0375	0.0489
Model 2	0.5424	0.3048	0.2784	0.2256	0.2080	0.3118
Difference	0.0273	0.0503	0.0390	0.0373	0.0509	0.0053
Model 3	0.5721	0.2470	0.2374	0.2631	0.2538	0.3147
Difference	0.0023	0.0075	0.0020	0.0003	0.0052	0.0024
Model 4	0.7013	0.3223	0.2753	0.3346	0.3199	0.3907
Difference	0.1316	0.0678	0.0359	0.0717	0.0609	0.0736
Model 5	0.4893	0.1457	0.1307	0.1479	0.1442	0.2115
Difference	0.0804	0.1088	0.1087	0.1150	0.1147	0.1055
Model 6	0.5639	0.2286	0.2405	0.2850	0.2610	0.3158
Difference	0.0058	0.0259	0.0011	0.0221	0.0021	0.0013

3.2.3 Prediction of Concentration Time

Concentration Time is the time taken by water droplets to travel from the farthest point in the watershed to the outlet (McCuen, 2005). This is a theoretically based definition that depends on watershed characteristics; many empirical and kinematic wave models have been developed based on this definition (Ganti,2018).

The best performing parameter functions in the statistical models are listed by the regression equations that provide high accuracy for prediction of concentration time as shown below (45-50):

Statistical prediction of Concentration Time based on the Actual Main Stream length (La), given as model:

$$Tc = 4.393 + (10.438 \times La) \qquad (45)$$

Statistical prediction of Concentration Time based on the Actual Main Stream length (La), and Basin Relief (Br), given as model:

$$Tc = 105.669 + (10.809 \times La) + (-0.095 \times Br) \quad (46)$$

Statistical prediction of Concentration Time based on the Actual Main Stream length (La), Basin Relief (Br), and Mean Slope (Sm), given as model:

$$Tc = 45.086 + (10.740 \times La) + (-0.092 \times Br) + (5.141 \times Sm)$$
(47)

Statistical prediction of Concentration Time based on Basin Relief (Br), Mean Slope (Sm), Length (Lb), given as model:

$$Tc = -1253.75 + (-0.136 \times Br) + (28.78 \times Sm) + (48.38 \times Lb)$$
(48)

Statistical prediction of Concentration Time based on the Actual Main Stream length (La), Mean Slope (Sm), and Dissection Index (Dind), given as model:

$$Tc = 128.870 + (11.416 \times La) + (-4.881 \times Sm) + (-84.143 \times Dind)$$
(49)

Statistical prediction of Concentration Time based on Shape Factor (Sf), and Drainage Texture (T), given as model:

$$Tc = 321.206 + (-2215.98 \times Sf) + (231.996 \times T)$$ (50)

The direction of change of the study area in the total average of the predicted concentration time values can be determined using the above-mentioned six statistical models and the estimated value, Figure (4a), while the direction of change in the estimated and predicted concentration time values for sub-basins is shown in Figure (4b).

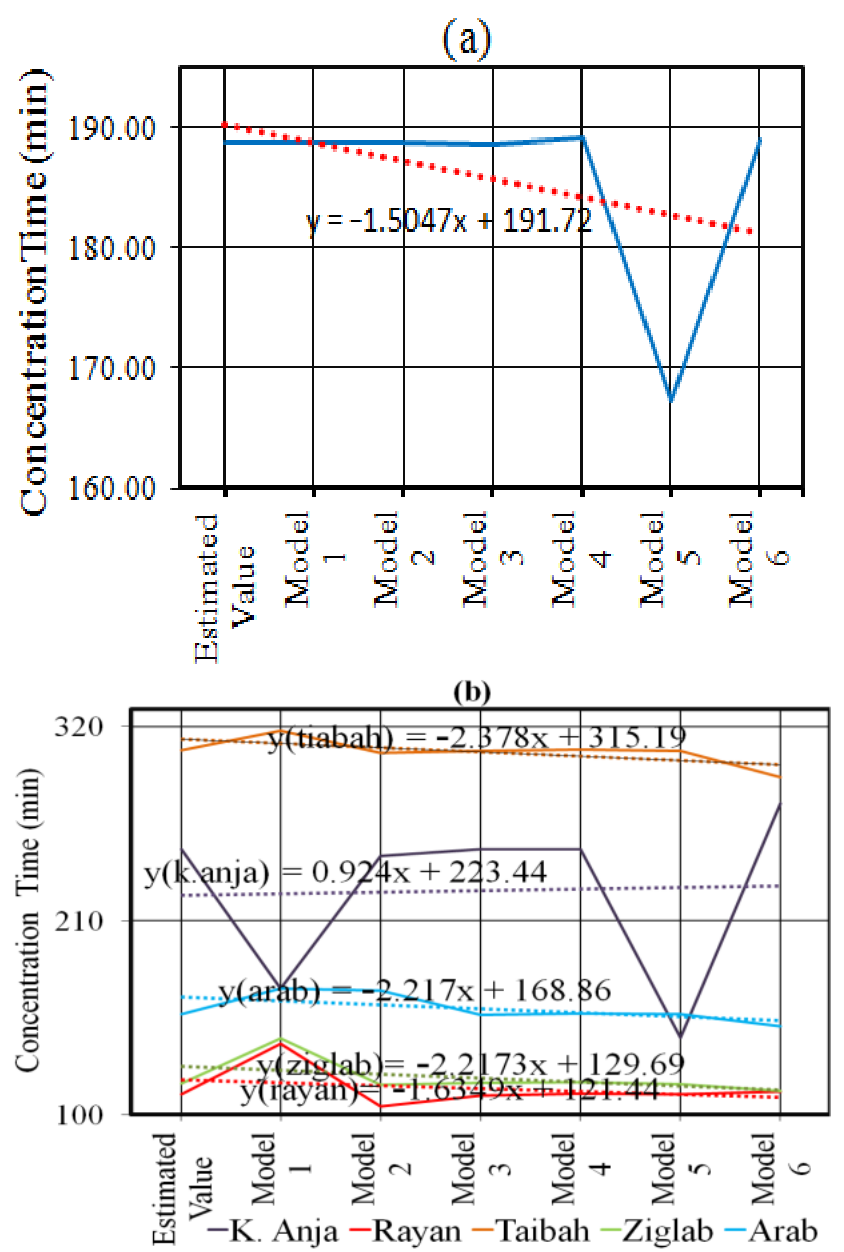

Figure 4(a) The total average of the predicted concentration time (min) values; (b) Estimated and predicted concentration time (min) values for sub-basins

As for the differences between the predicted values through the aforementioned six statistical models and the estimated value for the study area, the lowest concentration time differences were between the predicted values and the estimated values in the first (0.001 min) and the second models (0.02 min), Table 9.

Table 9 Difference between estimated and predicted concentration time (min)

Basins	Arab	Ziglab	Taibah	Rayan	K. Anja	Total Average
Estimated	157.1	117.7	306.6	111.8	250.5	188.7
Model 1	171.4	143.2	317.5	140.1	171.4	188.7
Difference	14.3	25.5	11	28.3	79.1	0.001
Model 2	170.2	117.0	304.9	104.7	246.9	188.7
Difference	13.1	0.7	1.6	7.1	3.6	0.02
Model 3	156.7	118.3	306.4	111.0	250.5	188.5
Difference	0.39	0.6	0.19	0.85	0.06	0.18
Model 4	157.3	118.3	306.9	112	250.6	189.0
Difference	0.2	0.6	0.34	0.16	0.09	0.29
Model 5	156.9	117.4	306.2	111.7	143.6	167.2
Difference	0.2	0.2	0.34	0.12	106.9	21.6
Model 6	150.4	113.7	291.2	113.1	276.4	189.0
Difference	6.7	4	15.3	1.3	25.9	0.23

3.2.4 Prediction of drainage time

The best-performing parameter functions in the statistical models are listed by the regression equations that provide high accuracy for the prediction of drainage time as demonstrated below (51-56):

Statistical prediction of drainage time based on Length (Lb), given as model:

$$TD = -179.285 + (8.063 \times Lb) \qquad (51)$$

Statistical prediction of drainage time based on Length (Lb), and Shape Factor (Sf), given as model:

$$TD = -143.220 + (7.126 \times Lb) + (-52.932 \times Sf) \; (52)$$

Statistical prediction of drainage time based on Length (Lb) and Mean Slope (Sm), given as model:

$$TD = -262.896 + (9.490 \times Lb) + (4.07 \times Sm) \quad (53)$$

Statistical prediction of drainage time based on Length (Lb) and Mean Slope (Sm) and Basin Relief (Br), given as model:

$$TD = -258.593 + (9.132 \times Lb) + (4.123 \times Sm) + (0.004 \times Br) \quad (54)$$

Statistical prediction of drainage time based on Length (Lb) and Mean Slope (Sm), and Mean Stream Length (Lsm), given as model:

$$TD = -201.604 + (8.198 \times Lb) + (3.777 \times Sm) + (-25.081 \times Lsm) \quad (55)$$

Statistical prediction of drainage time based on Length (Lb), Mean Slope (Sm), Mean Stream Length (Lsm), and the Actual Main Stream length (La) given as model:

$$TD = -252.229 + (9.740 \times Lb) + (4.5 \times Sm) + (-17.849 \times Lsm) + (-0.283 \times La) \quad (56)$$

The direction of change of the study area in the total average of the predicted drainage time values can be determined using the above-mentioned six statistical models and the estimated value in Figure (5a), while the direction of change in the predicted values and the estimated values of drainage time for sub-basins is shown in Figure (5b).

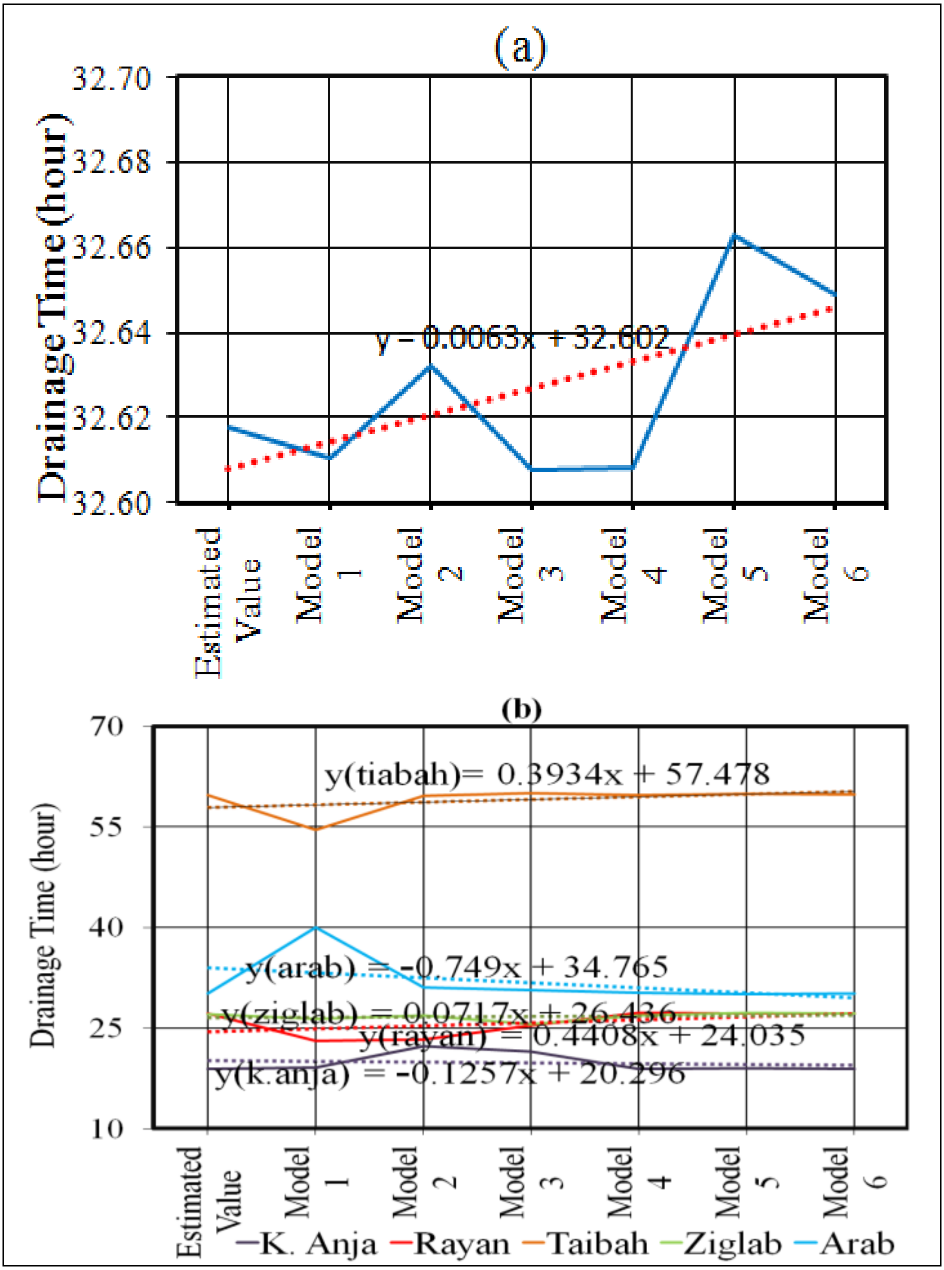

Figure 5(a) The total average of the predicted drainage time (hour) values; (b) Estimated and predicted drainage time (hour) values for sub-basins.

As for the differences between the predicted values through the aforementioned five statistical models and the estimated values for the study area, the lowest drainage time differences were between the predicted values and the estimated values in the first to fourth models, where the difference was the same value (0.001 hours); for the fifth model, the difference was (0.05 hours), Table 10.

Table 10 Difference between estimated and predicted drainage time (hour)

Basins	Arab	Ziglab	Taibah	Rayan	K. Anja	Total Average
Estimated	30.19	27.08	59.76	27.14	18.93	32.62
Model 1	40.03	26.32	54.54	23.10	19.06	32.61
Difference	9.84	0.76	5.21	4.04	0.14	0.01
Model 2	31.08	26.88	59.64	23.29	22.27	32.63
Difference	0.89	0.19	0.12	3.85	3.34	0.01
Model 3	30.67	25.53	59.97	25.40	21.47	32.61
Difference	0.48	1.55	0.21	1.74	2.54	0.01
Model 4	30.23	26.85	59.74	27.29	18.93	32.61
Difference	0.04	0.23	0.02	0.15	0.00	0.01
Model 5	30.07	27.26	59.88	27.15	18.96	32.66
Difference	0.12	0.18	0.12	0.02	0.03	0.05
Model 6	30.12	27.13	59.84	27.21	18.94	32.65
Difference	0.07	0.06	0.08	0.08	0.01	0.03

3.2.5 Prediction of Velocity of Runoff

The best performing parameter functions in the statistical models are listed by the regression equations that provide high accuracy for prediction of Velocity of Runoff as shown below (57-61):

Statistical prediction of Velocity of Runoff based on Relief Ratio (Rr) and the Actual Main Stream length (La), given as model:

$$V = 0.167 + (0.002 \times Rr) + (-0.006 \times La) \qquad (57)$$

Statistical prediction of Velocity of Runoff based on Relief Ratio (Rr), the Actual Main Stream length (La), Drainage Density (Dd) and Stream Frequency (Fs), given as model:

$$V = 0.371 + (2.625 \times 10^{-5} \times Rr) + (-0.011 \times La) + (0.393 \times Dd) + (-0.428 \times Fs)$$

(58)

Statistical prediction of Velocity of Runoff based on the Actual Main Stream length (La), Drainage Density (Dd) and, Stream Frequency (Fs), given as model:

$$V = 0.369 + (-0.011 \times La) + (0.389 \times Dd) + (-0.423 \times Fs)$$ (59)

Statistical prediction of Velocity of Runoff based on Drainage Density (Dd), the Actual Main Stream length (La), Drainage Intensity (Dint), and Basin Slope Degree (D), given as model:

$$V = 0.659 + (-0.021 \times Dd) + (-0.010 \times La) + (-0.347 \times Dint) + (-0.031 \times D)$$

(60)

Statistical prediction of Velocity of Runoff based on Drainage Density (Dd), Stream Frequency (Fs), the Actual Main Stream length (La), and Ruggedness Value (Rn), given as model:

$$V = 0.370 + (0.396 \times Dd) + (-0.429 \times Fs) + (-0.011 \times La) + (-0.001 \times Rn)$$

(61)

The direction of change of the study area in the total average of the predicted velocity of runoff values can be determined using the above-mentioned five statistical models and the estimated value in Figure (6a), while the direction of change in the predicted values and the estimated values of velocity of runoff for sub-basins is found in Figure (6b).

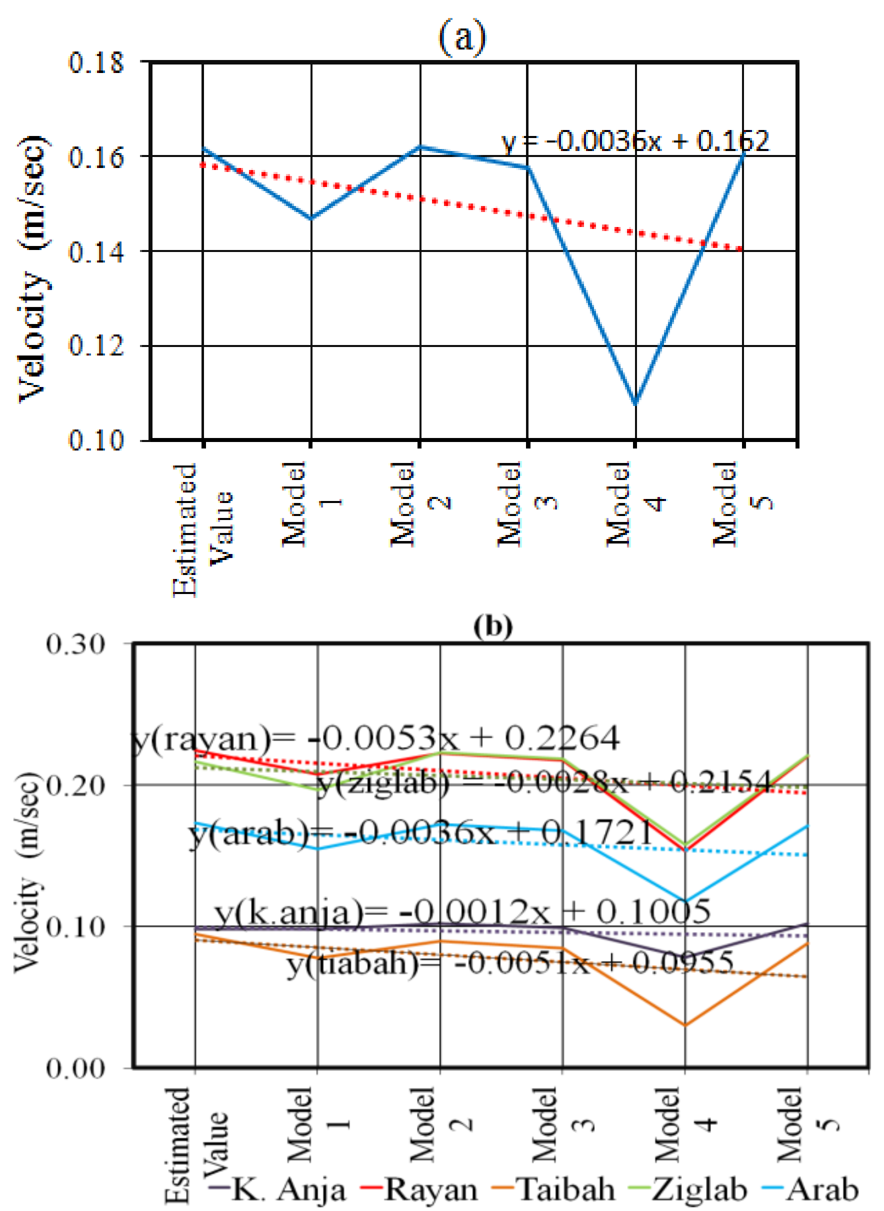

Figure 6(a) The total average of the predicted Velocity of Runoff (m/sec) values; (b) Estimated and predicted velocity of runoff (m/sec) values for sub-basins.

As for the differences between the predicted values through the aforementioned five statistical models and the estimated value for the study area, the lowest velocity of runoff differences was between the predicted values and the estimated values in the first (0.001 m/sec) and the fourth models (0.0005 m/sec), Table 11.

Table 11 Difference between estimated and predicted velocity of runoff (m/sec)

Basins	Arab	Ziglab	Taibah	Rayan	K. Anja	Total Average
Estimated	0.173	0.217	0.095	0.224	0.098	0.161
Model 1	0.155	0.197	0.078	0.208	0.098	0.147
Difference	0.018	0.020	0.017	0.017	0.00004	0.014
Model 2	0.172	0.223	0.090	0.222	0.102	0.162
Difference	0.001	0.006	0.005	0.002	0.004	0.0005
Model 3	0.168	0.218	0.085	0.218	0.099	0.158
Difference	0.005	0.002	0.010	0.007	0.001	0.004
Model 4	0.117	0.158	0.030	0.154	0.078	0.108
Difference	0.056	0.059	0.065	0.071	0.020	0.054
Model 5	0.171	0.221	0.088	0.220	0.102	0.161
Difference	0.002	0.004	0.006	0.004	0.004	0.001

3.2.6 Prediction of Flood Factor

The best performing parameter functions in the statistical models are listed by the regression equations that provide high accuracy for prediction of flood factor as demonstrated below (62-65):

Statistical prediction of Flood factor based on Relief Ratio (Rr) and the Actual Main Stream length (La), given as model:

$$Ff = 1.533 + (-0.012 \times Rr) \qquad (62)$$

Statistical prediction of Flood factor based on Relief Ratio (Rr), the Actual Main Stream length (La), Drainage Density (Dd), and Stream Frequency (Fs), given as model:

$$Ff = 1.535 + (-0.717 \times D) \qquad (63)$$

Statistical prediction of Flood factor based on Relief Ratio (Rr) and Ruggedness Value (Rn), given as model:

$$Ff = 1.424 + (-0.026 \times Rr) + (0.611 \times Rn) \quad (64)$$

Statistical prediction of Flood factor based on Relief Ratio (Rr) and Basin Relief (Br), given as model:

$$Ff = 1.484 + (-0.055 \times Rr) + (0.002 \times Br) \quad (65)$$

The direction of change of the study area in the total average of the predicted flood factor values can be determined using the above-mentioned fourstatistical models and the estimated value in Figure (7a), while the direction of change in the predicted values and the estimated values of flood factor for sub-basins is shown in Figure (7b).

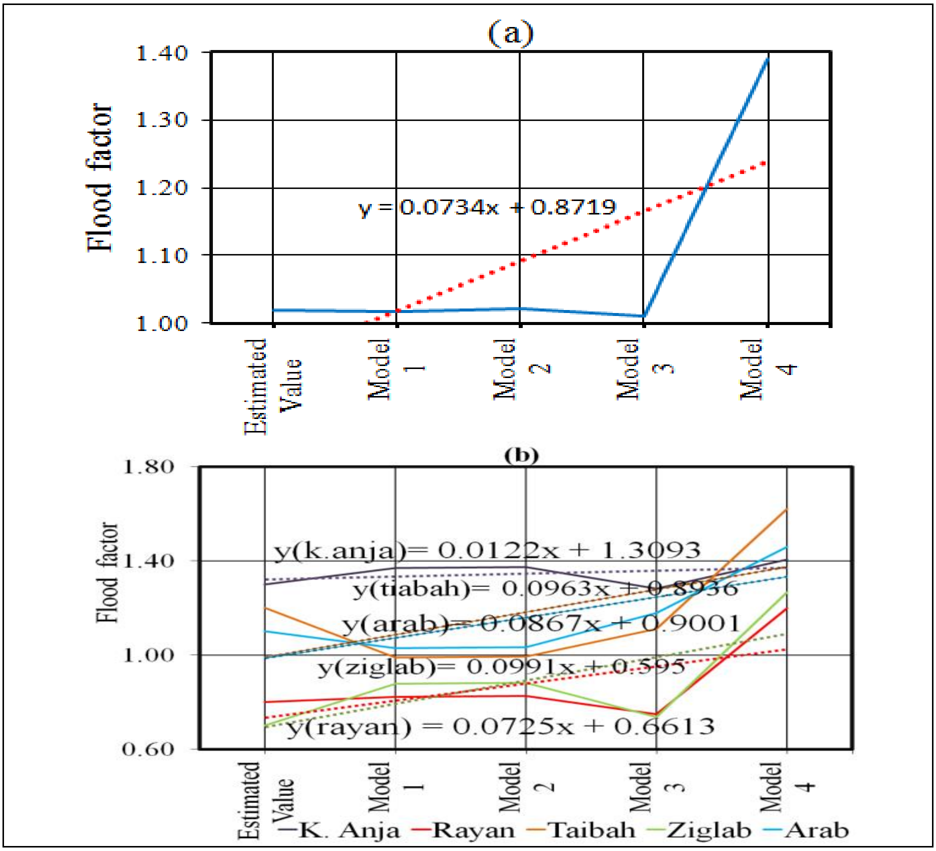

Figure 7 (a) The total average of the predicted flood factor values; (b) Estimated and predicted Velocity of flood factor for sub-basins

As for the differences between the predicted values through the aforementioned six statistical models and the estimated value for the study area, the lowest flood factor differences were between the predicted values and the estimated values in the first (0.003) and the second models (0.001), Table 12.

Table 12 Difference between estimated and predicted flood factor

Basins	Arab	Ziglab	Taibah	Rayan	K. Anja	Total Average
Estimated	1.10	0.70	1.20	0.80	1.30	1.02
Model 1	1.03	0.88	0.99	0.82	1.37	1.02
Difference	0.07	0.18	0.21	0.02	0.07	0.003
Model 2	1.03	0.88	0.99	0.83	1.37	1.02
Difference	0.07	0.18	0.21	0.03	0.07	0.001
Model 3	1.18	0.74	1.11	0.75	1.28	1.01
Difference	0.08	0.04	0.09	0.05	0.02	0.01
Model 4	1.46	1.27	1.62	1.20	1.41	1.39
Difference	0.36	0.57	0.42	0.40	0.11	0.37

Finally, a clear similarity was found between the results of this study and other studies. A study (Al-sababhah and Zeitoun 2019) found a strong positive correlation was found between average slope and Relief ratio, and slope degree, a strong negative correlation was found between average elevation and Dissection Index, also, a negative correlation was found between basin perimeter and both Relief ratio and basin slope degree. Moreover, the catchment area showed the highest correlation with other parameters, where, the overall coherence of the data indicates the participation of the individual hydro-morphological parameters in several influence factors. Multivariate studies yield a better understanding of the physical behavior in arid regions where the records of hydrological events are very scarce or absent. The results were found to be compatible with the fact that most studied basins related to the late period of geomorphology. (Eltahan et al 2020).

4. **Conclusions and Recommendation**

The application of the statistical hydrogeomorphological analysis of the northern Jordan Valley Rift Basin is one of the useful methods to evaluate and accurately predict the hydrological characteristics of this basin based on its morphological characteristics. The results of the correlation analysis that were applied to all morphometric and hydrological variables (39 variables) showed that there are significant positive and negative statistical relationships between them. The variables that were used in the regression analysis were also adopted on the basis of the results obtained from the correlation analysis. These were variables that had a high degree of correlation and that had a linear relationship with it. Moreover, the regression analysis prepared statistical models for the hydrological variables in the form of mathematical equations through which we could estimate and predict the hydrological variables with the least possible error.

The study recommends applying statistical models on drainage basins because of their statistical importance and the possibility of giving valuable results in predictions in different regions of the world, specifically those suffering from lack of or inaccurate hydrological data for their role in making the appropriate spatial decision, and when it comes to environmental risks that are repeated in drainage basins.

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