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# Investigation of Statistical Relationships among Morphological Characteristics of Semi-Arid Watersheds for Using in Hydrological Models (Case Study: Neishabour Bar Watershed)

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**Abstract**

Due to the fact that ecosystems are more fragile and sensitive in arid and semi-arid regions of the world, the phenomenon of floods and the resulting damage and loss will be more severe in these areas. The subject of river canals and their morphology is one of the key topics in engineering and river management, which can be used to obtain a useful set of information about the geometric shape, bed shape, longitudinal profile, cross sections, over time. Default geometric relationships in hydrological models such as Kineros2 are based on field measurements in US watersheds and cause uncertainty in model results. Therefore, the purpose of this study is to determine the regional statistical relationships between the width and depth of the canal with the area of the upstream watersheds for employing in hydrological models such as Kineros2, and the width and depth of the canal with other basin characteristics. The data in this research are mainly topographic maps of Neishabour Bar watershed. Thus, according to topographic maps, preliminary studies were carried out to identify sub-basins. In this study, the basin is divided into 34 sub-basins that involve Lar Formation (in 16 sub-basins), and marl (in 18 sub-basins), where, 27 sub-basins in upstream are non-orchard lands. The linear and nonlinear regressions and equations were studied and evaluated using the software such as Excel, SPSS, Curve Expert, and XLSTAT. The results of correlation of physical parameters with canal width and depth, nonlinear regression analysis and analysis of variance in the relationships between canal depth/width with upstream area in the whole basin ($R^2$=0.58 for canal depth and $R^2$=0.14 for canal width), in upstream Lar formation, in downstream and non-orchard lands, showed a greater impact of the upstream acreage on the canal depth relative to the width (due to the higher coefficient of determination and less error). Furthermore, the separation of sub-basins in terms of geological formation and the presence of orchards had a significant effect on improving equations and reducing errors. The greater impact of the canal depth than the width from the upstream area is mostly related to successive droughts and the absence of flash floods in the area to change the canal depth, while the width of the canals has been mainly a function of human manipulations on the river bed. Stepwise linear regression analysis also showed a higher correlation between canal depth than the canal width with the physical parameters of the basin ($R^2$=0.85 and $R^2$=0.77, respectively).

**Keywords:** Canal width and depth, Regression analysis, River morphology, Semi-arid region, Statistical equations, Regional equations, Watershed.

## 1. Introduction

Considering that a large part of Iran has arid and semi-arid climate, studying the behavior of rivers in arid and semi-arid watersheds is one of the main and important study in the country (Javan and Falsoleyman, 2006). The behavior of rivers in arid and semi-arid regions is strongly influenced by the climate of the region and its rainfall regimes. Therefore, studying the behavior of rivers in arid and semi-arid regions in Iran is essential for sustainable management of watersheds (Poormohammadi and Dastorani, 2015). Extent and diversity of the country's watersheds in terms of climatic conditions, vegetation, soil and geology and the impossibility of equipping all of them with flow measurement stations, propose some solutions for hydrological estimates in ungauged basins with the help of watershed statistical relationships (Ghiasi et al., 2004). Knowledge of the physical and morphometric characteristics of a watershed and having information about the climatic conditions of the region can give a relatively accurate perception of the quantitative and qualitative functioning of the dynamic hydrological system of a watershed (Ministry of Energy, 1987). In addition, in order to obtain information and determine local and regional relationships in arid and semi-arid regions, statistical relationships between morphological features and field measurements in these areas should be determined, including the depth and width of canals. Statistical relationships include simple, multiple linear regression, and analysis of variance and correlation, which assist us to establish a relationship between these characteristics and stream variables (width, depth, and cross-sectional area). Determination of geomorphological and watershed characteristics by field surveying is done simultaneously with GIS applications and preparation of geographical maps from aerial photographs.

In fact, the cross sectional area of streams is compared to the characteristics and variables of the watershed (Scott et al., 1996). Various models have been proposed so far for hydrological estimates in the watershed. One of the most famous of these models is the Kineros2 (Kinematic Runoff and Erosion) or K2 physical model. This model has been implemented in Neishabour Bar watershed using default relationships between the area of the upstream watershed with the width and depth of the canal (Sobhani, 2016).

### 1.1. Kineros2 Model

K2 is a physical model which is employed to study the rate of soil erosion and the routing of surface runoff. This model is useful in surface hydrology in order to predict and estimate surface runoff and sediment load due to erosion within watersheds. In the Kineros model, the watershed is subdivided into sub-basins, each of them is simulated at similar surface flow levels and canal components. K2 is an updated version of the Kineros model (Woolhiser et al., 1990) under a graphical user interface, i.e. Agwa (Automated Geospatial Watershed Assessment) and run in the ArcGIS software. Osterkamp et al. (1983) examined the morphology of canals based on the continuity equation, the Manning formula, and the equation for shear stress distribution. In this study, the width-to-depth ratio was used as a substitute for canal sedimentary properties and shear stress distribution. The equations were calibrated using canal data and the calibrated equations were tested using relatively stable canal data. Calibration results and tests led to organization in relation to canal dynamics. Ebisemiju (1989), in examining the morphology, geometric and hydraulic relationships of the downstream alluvial flow canals in the a river basin, southwestern Nigeria, examined the cross-sectional area of 423 canals along the main river and its 28 tributaries and found that the relationship between watershed area and canal capacity ($m^2$ cross section) is exponential and there is a relatively strong positive relationship between these two parameters (R = 0.6556) which is significant at the level of 0.001. Scott et al. (1996) conducted a study in southeastern Arizona on the extraction of canal morphological features and their prediction in GIS. More than 200 canal sections were surveyed in the basin. Regression analysis showed very significant relationships between canal characteristics (mean width, depth and cross sectional area) and basin variables. In fact, there are statistical relationships between stream variables that were measured in the field, such as width, depth, and cross-sectional area of the stream and a set of watershed parameters such as stream level, basin area, shape, drainage characteristics, and altitudinal characteristics determined using GIS. The models with high coefficient of determination ($R^2$ = 0.84) were obtained, as well. In the field of hydrological modeling, Nam Avar (2011) evaluated the efficiency of Kineros2 model in predicting runoff in Kameh watershed using Agwa - GIS software. Comparing the simulated results and observations, it was concluded that the K2 model simulated the shape of the hydrograph and the peak flow relatively well. While due to the lack of sediment statistics, the mode calibration for sediment load simulation was not possible. In a study Mollaifar (2013) evaluated the efficiency of Kineros2 in simulating flood hydrographs of Ziarat watershed. The results showed that the K2 model estimates the hydrological components with acceptable accuracy. Memarian et al. (2013) used the Kineros2 model to analyze the effects of land cover changes and land use in the Langat Basin, Malaysia. Calibration results showed a very good relationship between observational data and simulation results for runoff and sediment estimation. Validation results proved that K2 is valid for runoff modeling. In K2, the basis for calculating the width and depth of the canal is the usage of statistical relationships between these two parameters with the upstream area. In this regard, there are default models or relationships in the K2 model, which are mostly based on field measurements in US watersheds. But as it is clear, the use of non-native relations causes uncertainty in the results of the model and reduces the validity of the model. Thus, since no specific study has been done so far to extract the regional equations used in the K2 model for Iran in semi-arid regions, the most important goal is to find a relationship between the canal width/depth with the area of the upstream watershed. In the meantime, the relationships between canal width and depth with other basin characteristics such as length, area, pyramid, compaction coefficient, average slope, and time of concentration are also examined.

## 2. Material and Methods

### 2.1. Study area

The study basin is located 100 km northwest of Khorasan Razavi province and 54 km northwest of Neishabour city. This basin is located in the geographical range of 36° 27' 34" to 36° 36' 27" north latitude and 58° 40' 45" to 58° 49' 34" east longitude. From north and northwest it is bounded by the Baqie River watershed, on the south by the Taghan River watershed, on the east and northeast by the Akhlamd River watershed, and on the southwest by the Kal Karizi River watershed. The output of this watershed is located on Ariyeh hydrometric station. The study area is mountainous with flood-prone surfaces. The average altitude of the basin is 2245 meters, its average slope is 32 %, the mean annual rainfall is 459 mm, and the average monthly temperature is 7.5 degrees Celsius. The total area of the Bar watershed is about 115.85 square kilometers.

The relationship between canal width and depth with morphological characteristics and physical properties of the sub-basin were investigated. The Bar basin geologically has two completely separate structures including Lar formation (limestone and gray dolomite) and downstream land formation (light gray marl Bamyan ,calcareous layer, lime and delichai marl, shale structure and phyllite sandstone and alluvial lands). Furthermore, in the downstream, agricultural lands in the form of orchards by residents invaded the riverbed and caused changes in the width and depth of the stream. Thus, in order to improve statistical relationships, the basin was subdivided by considering the type of geological formation and the absence of non-orchard lands. In this study, an attempt was made to establish logical and regional relationships between the width and depth of the canal and the area of the upstream catchment. For this purpose, the basin was divided into 34 sub-basins (Figure 2). In each sub-basin, the relationship between canal width and depth with the upstream area of the sub-basin, and after preparing the digital elevation model and investigating the satellite images of the study area, field visits were completed and 34 stream sections were selected to evaluate the morphology of the upstream watershed.

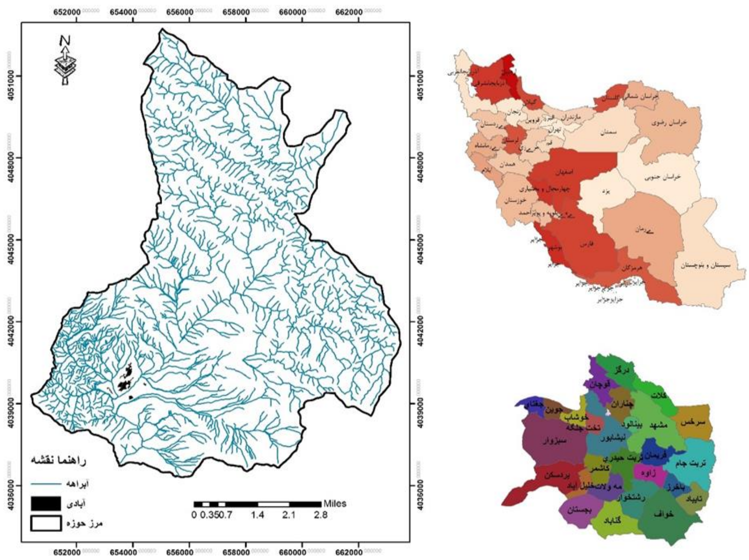


**Fig. 1.** Geographic location of Bar watershed in Neishabour city and Khorasan Razavi province, Iran

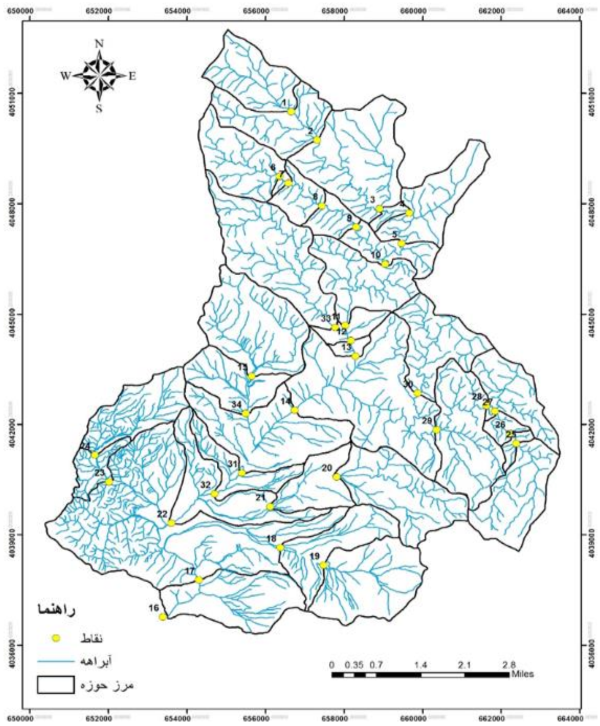


**Fig. 2.** Outlet points with upstream watersheds

Attempts were made to select sampling sites with different soil types and different hydrological conditions from all over the catchment. The locations of the points were captured using GPS, and photographs were taken at each point after the metering to match with Google Earth images. Physical features, geometric and geomorphological properties were determined using Geographic Information System (GIS) and statistical relationships were analyzed.

## 2.2. Characteristics of selected watersheds

### 2.2.1. Area and perimeter of the sub-basins

The surface of the basin includes the ridges where all the precipitation at this level tends to a point called the watershed outlet. The perimeter and length of the watershed are also used to determine the parameters related to the shape of the watershed (Mahdavi, 2007; Alizadeh, 2014). In this study, the area, perimeter and length of each sub-basin in GIS environment were calculated.

### 2.2.2. The length of the main stream

The length of the main stream is one of the main factors in determining the time of concentration of the basin and includes the stream that has the longest length in the sub-basin (Mahdavi, 2007; Alizadeh, 2014).

### 2.2.3. Compaction ratio

The compaction coefficient, also known as the Gravilius coefficient, is obtained from the ratio of the perimeter of the basin to the perimeter of a circle whose area is equal to the area of the basin. The calculation formula is as follows:

$$\mathrm{Cc} = \frac{\mathrm{p}}{\mathrm{p}'} = \frac{\mathrm{p}}{2\sqrt{\pi \mathrm{a}}} = 0.282\frac{\mathrm{P}}{\sqrt{\mathrm{A}}} \quad (1)$$

where P is the perimeter of the basin in kilometers and A is the area of the basin in square kilometers. This coefficient is dimensionless and is close to one for almost round basins and about 1.5 to 2.5 for elongated basins, which indicates its deviation from the circle (Mahdavi, 2007; Alizadeh, 2014).

### 2.2.4. Watershed average slope

Slope as a very important factor in hydrology can be expressed as changes in the amount of altitude between two points. However, from the point of view of digital elevation models, it is better to be known as the angle of the tangent surface at each point of the digital elevation model with the horizontal surface. Most GIS software uses a 3x3 kernel with eight adjacent cells to map the slope of each cell. Assuming the coding of Figure (3), the slope of cell i will be equal to:

$$\mathrm{Si} = \sqrt{\left[\left(\frac{(h_4+2h_5+h_6)-(h_2+2h_1+h_8)}{8*R}\right)^2 + \left(\frac{(h_4+2h_3+h_2)-(h_6+2h_7+h_8)}{8*R}\right)^2\right]} \quad (2)$$

where h1 to h8 is the altitude of adjacent cells and R is the cellular resolution (Abdollahi, 2002).

### 2.2.5. Time of concentration

The maximum time it takes for water to travel its hydrological path from the farthest point of the basin to the outlet is called the time of concentration.

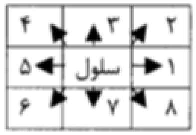


**Fig. 3.** Coding of flow directions

The time of concentration (tc) is the time interval between the end of excess precipitation and the turning point of the descending branch of the hydrograph. To calculate the time of concentration, the empirical method of Kirpich (Mahdavi, 2007) was used as follows:

$$\mathrm{Tc} = 0.949\left(\frac{L3}{H}\right)^{0.385} \quad (3)$$

where Tc is the time of concentration (hours), L is the length of the largest hydrologic path in the basin in kilometers, H is the difference in height between the lowest and highest points of the basin in meters (Mahdavi, 2007; Alizadeh, 2014).

### 2.2.6. Drainage density

Drainage density indicates the length of streams per unit area. If the sum of the length of all the streams of the basin is measured and divided by its area, the density of the hydrographical network of the basin is obtained. As the drainage density increases, the flood magnitude also increases. The amount of drainage density in a basin can indicate the severity and weakness of runoff and erosion magnitude in different parts of the basin (Alizadeh, 2014). Drainage density is obtained from Eq (4), as follows:

$$\mathrm{Dd} = \frac{\sum \mathrm{Li}}{\mathrm{A}} \quad (4)$$

where, Dd is the density of the river network ($Km/Km^2$), Li is the length the streams of each sub-basin (km) and A is the area of the sub-basin ($km^2$).

### 2.2.7. The slope of the main stream

The gross and net slope methods have been used to study the slope condition of the main canals of the sub-basins. The following empirical relationships have been used to estimate the gross and net slope.

Gross slope:

$$\mathrm{tg}\alpha = \frac{\mathrm{h}}{\mathrm{l}}100 \quad (5)$$

where h is the difference between the maximum and minimum altitude of the main river (m), L is the length of the horizontal image of the stream in the longitudinal profile (m). Net slop:

$$tg\alpha = \frac{2s}{l^2}100 \quad (6)$$

where S is the area under the longitudinal profile curve ($m^2$), L is the length of the horizontal image of the main stream (m).

## 2.3. Statistical relationships and regression analysis

### 2.3.1. Correlation coefficient

Pearson correlation coefficient for a statistical sample ($X_i$, $Y_i$) with n pair data is defined as below:

$$r = \frac{\sum_{j=1}^{n} Yi(Xi - \bar{X})}{\sqrt{\sum_{j=1}^{n}(Xi - \bar{X})\sum_{j=1}^{n}\left(Yi - \bar{Y}\right)^2}} \quad (7)$$

### 2.3.2. Simple linear regression

A linear regression model that has only one independent variable is called simple. In simple linear regression, if (Y) is considered as dependent variable and (x) is considered as independent variable, the regression line equation can be obtained as follows:

$$Y = b_0 + b_1 x \quad (8)$$

where Y is the estimated value, $b_1$ is regression line slope or regression coefficient and $b_0$ is the intercept or regression constant (Rezaei and Soltani, 1998).

### 2.3.3. Multiple linear regression

In multiple regression, the variables are assumed to be linear, and accordingly, the mathematical model of multiple linear regression with n independent variables is as follows (Rezaei and Soltani, 1998):

$$Y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n X_n \quad (9)$$

### 2.3.4. Stepwise regression

In stepwise regression, a number of independent variables are entered into the equation and the order in which they are entered is determined by a statistical criterion obtained via the stepwise method (Rezaei and Soltani, 1998).

### 2.3.5. Nonlinear regression

In many scientific studies, there are nonlinear relationships such as exponential, logarithmic and polynomial between variables. The nonlinear regression relationship can be written as follows (Rezaei Pajand and Bozorgnia, 2002):

$$y_n = f\left(x_n, \theta\right) + z_n \quad (10)$$

where $x_n$ is a vector containing the regression or independent variables for the $n^{th}$ state, and ɵ represents the nonlinear parameters of the selected model.

## 3. Results and discussion

In this study, statistical relationships between the width and depth of the stream with its upstream area from different aspects (total basin, sub-basins based on the existence of Lar Formation, the absence of Lar Formation, and sub-basins based on the absence of orchards and stepwise linear regression for the whole basin) and the width and depth of the stream with the physical characteristics of the watershed were performed and examined using software such as EXCEL, SPSS, CURVE EXPERT, and XLSTAT. The physical properties estimated in this work by empirical equations and GIS software are the area, perimeter, length of main stream, time of concentration, compaction ratio, average slope, basin length and longitudinal profile of main stream (net and gross slope). The results of the calculations are given in Table (1).

### 3.1. Equations derived from statistical analysis

The relationship between the width and depth of the stream (meters) with the area of the upstream watershed is obtained as follows and the correlation coefficient and RMS error of each section is observed according to Table (4).

### 3.2. Nonlinear regression

In the whole basin (34 sub-basins):

- Relationships between width/depth of the stream and the upstream area.

One-way analysis of variance (ANOVA) was performed and the significance value was less than 0.05, which indicates the significance of regression at 95% level.

$$D = 2.384084A^{0.368329} \quad (11)$$

$$W = 0.278008A^{0.218895} \quad (12)$$

- Relationships between the depth/width of the stream and watershed physical parameters

**Table 1.** Physiographic information of the sub-basins of Bar watershed

| Sub-Basin | Perimeter (Km) | Area (Km$^2$) | Compaction ratio | Drainage density (km/km$^2$) | Main stream Gross slope (%) | Main stream Net Slope (%) | Time of concentration (hr) | Mean Slop (%) | Altitude range (m) | Basin length (km) | Main stream length (km) | Stream width (w) (m) | Stream depth (D) (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 7.57 | 3.06 | 1.23 | 9.22 | 3.39 | 1.92 | 0.51 | 13.51 | 116 | 2.45 | 2.86 | 1.81 | 0.2 |
| B2 | 9.54 | 6.23 | 1.21 | 9.21 | 2.76 | 1.57 | 0.67 | 14.62 | 153 | 3.77 | 3.96 | 5 | 0.5 |
| B3 | 10.89 | 12.35 | 1.43 | 8.11 | 1.57 | 1.20 | 1.44 | 13.05 | 193 | 6.23 | 8.27 | 6.8 | 1 |
| B4 | 3 | 12.67 | 1.45 | 8.15 | 1.78 | 1.13 | 1.61 | 13.07 | 200 | 6.79 | 9.26 | 10 | 1 |
| B5 | 10 | 16.04 | 1.73 | 7.92 | 1.50 | 0.79 | 1.90 | 12.42 | 210 | 7.28 | 10.86 | 6.3 | 1 |
| B6 | 8 | 3.26 | 1.25 | 8.21 | 3.25 | 3.21 | 0.55 | 19.48 | 208 | 2.60 | 3.71 | 3.7 | 0.6 |
| B7 | 2 | 3.40 | 1.23 | 8.14 | 3.26 | 3.19 | 0.60 | 19.62 | 215 | 2.87 | 4.02 | 3.8 | 0.65 |
| B8 | 5.21 | 4.68 | 1.34 | 8.26 | 2.85 | 2.61 | 0.81 | 19.40 | 242 | 3.96 | 5.44 | 4.15 | 0.3 |
| B9 | 4.52 | 5.68 | 1.44 | 8.40 | 2.69 | 2.40 | 1.04 | 19.71 | 269 | 5.02 | 6.98 | 3.54 | 0.3 |
| B10 | 1 | 23.39 | 1.57 | 8.19 | 1.44 | 0.83 | 1.92 | 14.65 | 300 | 7.43 | 12.34 | 7.2 | 1 |
| B11 | 10 | 27.10 | 1.61 | 8.25 | 2.94 | 4 | 2.04 | 17.61 | 569 | 8.53 | 16.07 | 17 | 2 |
| B12 | 6 | 34.29 | 1.42 | 8.25 | 3.28 | 4.60 | 1.94 | 21.04 | 705 | 9.12 | 16.52 | 21 | 3 |
| B13 | 3 | 34.65 | 1.44 | 8.18 | 3.81 | 5.42 | 1.94 | 21.73 | 759 | 9.39 | 16.79 | 23.5 | 2.5 |
| B14 | 8.27 | 59.23 | 1.68 | 8.01 | 4.21 | 5.80 | 1.98 | 26.81 | 1109 | 10.51 | 19.55 | 16.7 | 2 |
| B15 | 1.66 | 5.44 | 1.18 | 4.43 | 18.42 | 23.89 | 0.32 | 48.34 | 823 | 3.17 | 3.63 | 12.7 | 0.5 |
| B16 | 7 | 115.58 | 2.20 | 6.67 | 3.35 | 3.66 | 2.86 | 32.03 | 13.7 | 16.05 | 28.42 | 13.5 | 2 |
| B17 | 11.45 | 106.84 | 2.29 | 6.85 | 3.55 | 4.02 | 2.68 | 31.46 | 102 | 14.94 | 26.80 | 13.4 | 1.5 |
| B18 | 9.37 | 8.03 | 1.30 | 3.78 | 23.75 | 15.18 | 0.34 | 47.93 | 1053 | 3.74 | 4.16 | 33 | 0.5 |
| B19 | 9.2 | 4.89 | 1.17 | 3.30 | 29.34 | 20.58 | 0.24 | 51.51 | 929 | 2.53 | 2.95 | 21.5 | 0.5 |
| B20 | 10.31 | 4.75 | 1.33 | 4.49 | 15.09 | 22.51 | 0.39 | 30.63 | 738 | 3.54 | 4.19 | 7.9 | 1 |
| B21 | 7.5 | 7.01 | 1.91 | 3.78 | 14.90 | 18.20 | 0.54 | 35.32 | 1037 | 5.05 | 6.17 | 22.7 | 1 |
| B22 | 8.4 | 85.29 | 2.13 | 6.56 | 3.71 | 4.45 | 2.49 | 30.42 | 1323 | 13.43 | 24.72 | 20 | 2 |
| B23 | 6 | 4.28 | 1.55 | 8.09 | 16.94 | 10.13 | 0.42 | 33.08 | 772 | 3.65 | 4.53 | 8 | 0.5 |
| B24 | 8.52 | 3.19 | 1.34 | 7.75 | 20.36 | 13.33 | 0.33 | 33.60 | 749 | 3.19 | 3.66 | 9 | 0.5 |
| B25 | 9 | 3.64 | 1.33 | 7.77 | 8.87 | 4.20 | 0.30 | 28.66 | 447 | 2.09 | 2.80 | 2.75 | 0.3 |
| B26 | 3.46 | 4 | 1.32 | 8.17 | 8.32 | 4.09 | 0.34 | 28.29 | 456 | 3.16 | 3.18 | 2.35 | 0.5 |
| B27 | 3.54 | 4.57 | 1.42 | 8.50 | 7.09 | 3.96 | 0.48 | 27.89 | 492 | 3.82 | 4.38 | 4.1 | 0.7 |
| B28 | 9 | 7.28 | 1.49 | 8.79 | 6.25 | 3.09 | 0.54 | 24.05 | 511 | 4.05 | 4.87 | 3.7 | 0.8 |
| B29 | 10.64 | 12.10 | 1.24 | 8.99 | 5.36 | 3.34 | 0.81 | 29.06 | 584 | 3.90 | 7.29 | 9.3 | 1 |
| B30 | 10 | 3.41 | 1.50 | 4.85 | 2.77 | 1.98 | 0.76 | 19.76 | 208 | 2.30 | 4.88 | 1.95 | 0.25 |
| B31 | 9.55 | 72.63 | 1.83 | 7.51 | 3.87 | 5.01 | 2.22 | 30.34 | 1176 | 12.04 | 22 | 5.5 | 1 |
| B32 | 10 | 74.53 | 1.86 | 7.45 | 3.87 | 4.82 | 2.32 | 30.26 | 1197 | 12.53 | 23.04 | 7.8 | 2 |
| B33 | 13 | 6.25 | 1.47 | 8.32 | 5.95 | 7.46 | 0.87 | 29.41 | 513 | 5.40 | 7.42 | 4 | 1 |
| B34 | 7.52 | 8.04 | 1.20 | 4.7 | 15.89 | 17.80 | 0.41 | 48.16 | 929 | 4.05 | 4.73 | 5.15 | 1 |

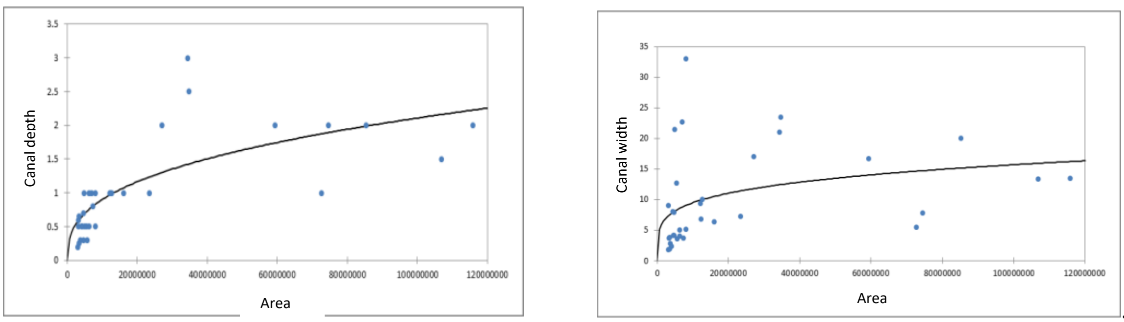


**Fig. 5.** Graphical illustration of the relationships between Canal width/depth and upstream area through the whole basin

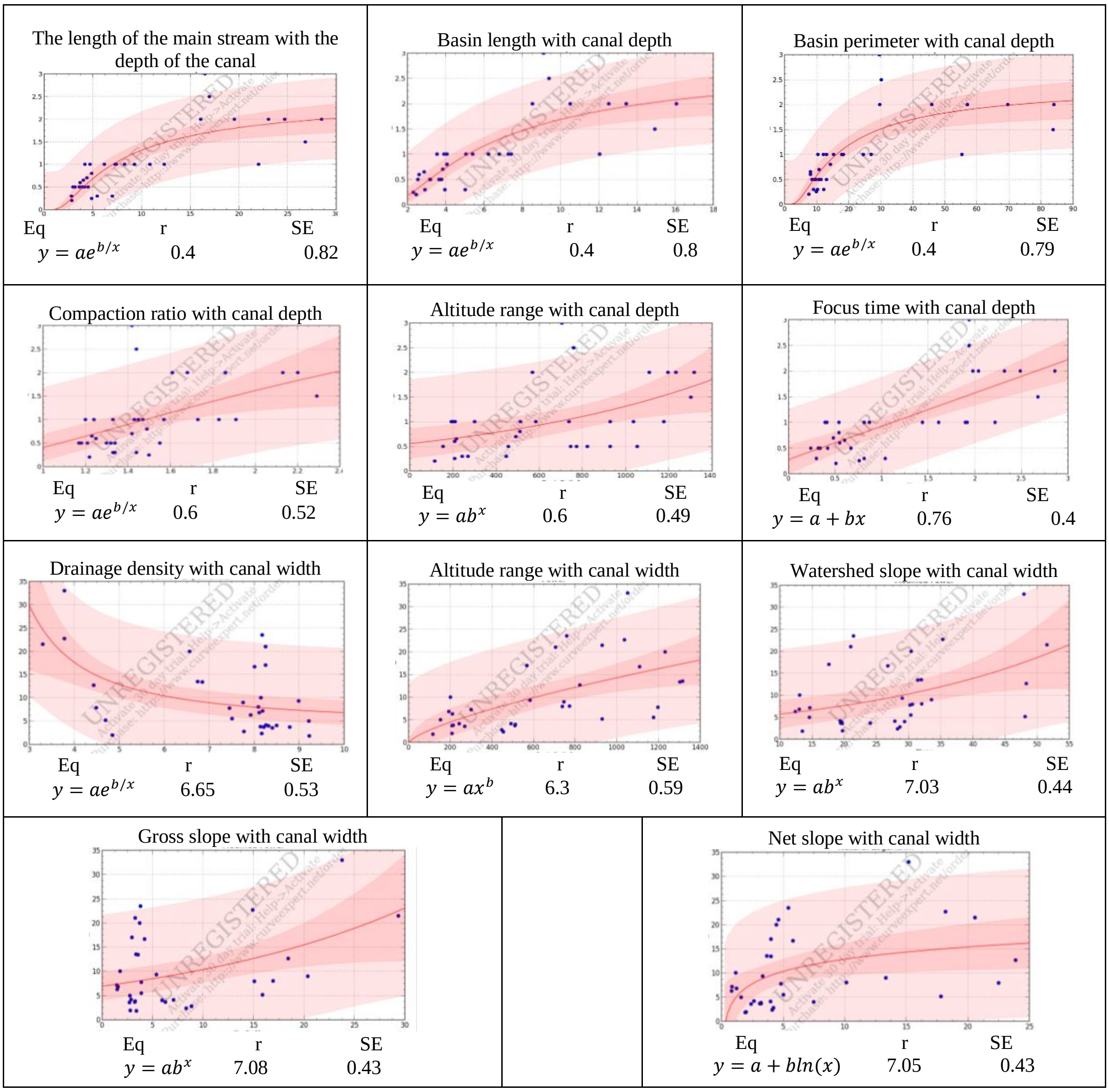


**Fig. 6.** Statistical relationships between canal depth/width and other parameters

Since the watershed is geologically divided into two completely separate formations, one is the Lar Formation (gray and light dolomitic lime and lime) and the second is the downstream formation (including light gray marl with a layer of calcareous, limestone and Delichai marl, shale structure and phyllite sandstone and alluvial lands), separate equations for each (Lar Formation and downstream lands) were obtained to investigate the effect of this factor, i.e. geology on improving equations:

Lar Formation (16 sub-basins):

$$D = 1.339417\ A^{0.536501} \tag{13}$$

$$W = 8.5829\ A^{0.5472} \tag{14}$$

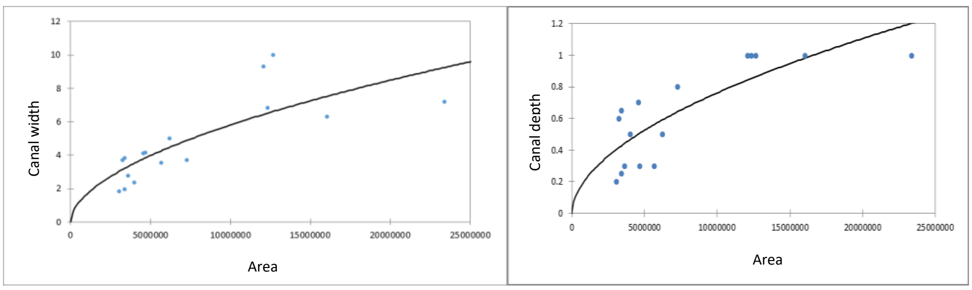


**Fig. 7.** Diagrams of canal width and canal depth with upstream area based on the Lar Formation field

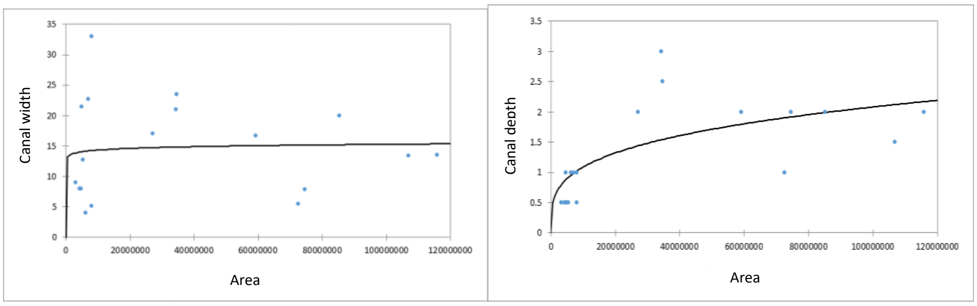


**Fig. 8.** Diagrams of canal width and canal depth with upstream area based on the downstream formation field

Downstream Formation (18 sub-basins):

$$D = 1.1641\ A^{0.2815} \quad (15)$$

$$W = 9.1415\ \ A^{2.7844} \quad (16)$$

Moreover, because in the Bar watershed, orchards and agricultural lands are concentrated at a certain point in the downstream of the basin, and the creation of orchards and encroachment on the bed and river area has caused changes in the width and depth of the stream, the watershed was subdivided to orchards area and non-orchard lands to improve the validity of relationships. Here, only the equations of non-orchard lands were studied and based on them, orchard lands were discussed:

Non-orchard lands (27 sub-basins):

$$D = 1.9099A^{0.8101} \quad (17)$$

$$W = 4.5270A^{0.4803} \quad (18)$$

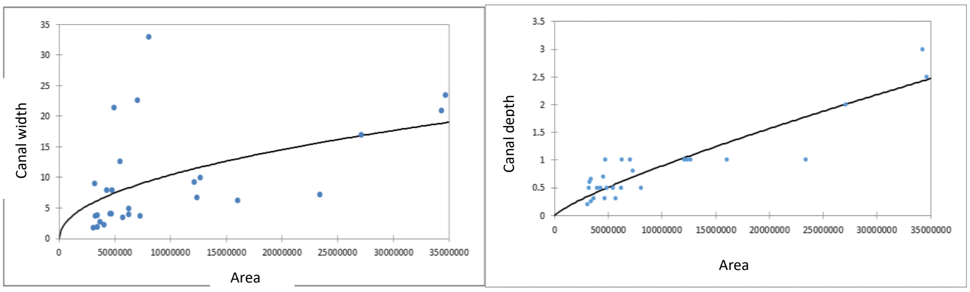


Fig. 9. Diagrams of canal width and canal depth with upstream area based on non-orchard lands

### 3.3. Linear regression

Stepwise regression was evaluated for the whole basin (34 sub-basins) in order to investigate the influence of other parameters on the width and depth of the stream (canal depth as a dependent variable, versus other physical parameters as independent variables). The results are represented in Tables (2) and (3).

$$D = 5.817 - 7.839\text{Area}^{1} + 0.327\text{Stream Length}^{2} - 2.083\text{Compactness factor}^{3} - 3.741\text{Slope}^{4} - 1.785\text{Time of concentration}^{5} \quad (19)$$

$$W = 106.009 - 1.607\ \text{Area} + 2.013\ \text{Perimeter}^{6} - 3.869\ \text{Drainage density}^{7} - 39.440\ \text{Compactness factor} - 0.805\ \text{Slope} + 1.219\ \text{Stream gross slope}^{8} - 0.951\ \text{Stream net slope}^{9} \quad (20)$$

Nonlinear regression analysis between the depth/width of the canal and the physical parameters of the basin and the resulting equations also showed a correlation of over 70% and less standard error for the depth of the canal than the width of the canal. Nonlinear regression analysis and analysis of variance between the width/depth of the canal and the upstream acreage and the resulting equations in the whole basin, Lar Formation, downstream lands, and non-orchard area, showed a greater impact of the upstream catchment on the canal depth (with a higher determination coefficient and lower RMS error) than the width of the canal (Table 4). Furthermore, stepwise linear regression analysis between the depth/width of the canal and other physical parameters of the basin in the resulting equations showed a high correlation coefficient ($R^2$ =0.85 and $R^2$ =0.77, respectively). The results of the research of Scott et al. (1996) in the Walnut Gulch basin in evaluating the morphologic characteristics of the canal (width and depth of the canal), showed a result contrary to the findings of the present study.

**Table 2.** Standardized coefficients for canal width equation in 34 sub-basins

| Source | Value | Standard Error | t | Pr > \|t\| | Lower bound (95%) | Upper bound (95%) |
|---|---|---|---|---|---|---|
| Perimeter (Km) | -6.586 | 1.995 | -3.301 | **0.003** | -10.688 | 2.485 |
| Area ($Km^2$) | 5.678 | 2.176 | 2.609 | **0.015** | 1.205 | 10.151 |
| Basin length (km) | 0.000 | 0.000 | | | | |
| Main stream length (km) | 0.000 | 0.000 | | | | |
| Drainage density ($km/km^2$) | -0.857 | 0.236 | -3.633 | **0.001** | -1.342 | -0.372 |
| Compaction ratio | -.508 | 0.425 | -3.544 | **0.002** | -2.382 | -0.633 |
| Elevation range (m) | 0.000 | 0.000 | | | | |
| Mean Slop (%) | -1.104 | 0.369 | -20.997 | **0.006** | -1.862 | -0.362 |
| Gross slope (%) | 1.141 | 0.364 | 3.136 | **0.004** | 0.393 | 1.889 |
| Net slope (%) | -0.822 | 0.288 | -2.857 | **0.008** | -1.413 | -0.231 |
| Time of concentration (hr) | 0.000 | 0.000 | | | | |

**Table 3.** Standardized coefficients for canal depth equation in 34 sub-basins

| Source | Value | Standard Error | t | Pr > \|t\| | Lower bound (95%) | Upper bound (95%) |
|---|---|---|---|---|---|---|
| Perimeter (Km) | -3.531 | 1.539 | -2.294 | **0.029** | -6.684 | -0.379 |
| Area ($Km^2$) | 0.000 | 0.000 | | | | |
| Basin length (km) | 0.000 | 0.000 | | | | |
| Main stream length (km) | 3.658 | 1.479 | 2.473 | **0.020** | 0.629 | 6.688 |
| Drainage density ($km/km^2$) | 0.000 | 0.000 | | | | |
| Compaction ratio | -0.879 | 0.328 | -2.669 | **0.013** | -1.548 | -0.203 |
| Elevation range (m) | 0.000 | 0.000 | | | | |
| Mean Slop (%) | -0.564 | 0.284 | -1.895 | 0.057 | -1.147 | 0.018 |
| Gross slope (%) | 0.000 | 0.000 | | | | |
| Net slope (%) | 0.000 | 0.000 | | | | |
| Time of concentration (hr) | -2.101 | 1.18 | -1.779 | 0.086 | -4.521 | 0.318 |

In this way, in the logarithmic relationship between the width/depth of the canal and the upstream area of the basin, the width of the canal has a higher coefficient of determination than the depth and is more impacted from the parameters of the catchment. In fact, in the less compacted soils of the Walnut Gulch basin, it was observed that the width of the canal increases relatively more than its depth in response to the increase of flow energy. In fact, different geological, climatic, soil conditions, as well as the amount of manipulation and human encroachment in different basins, can be significantly effective in the same results.

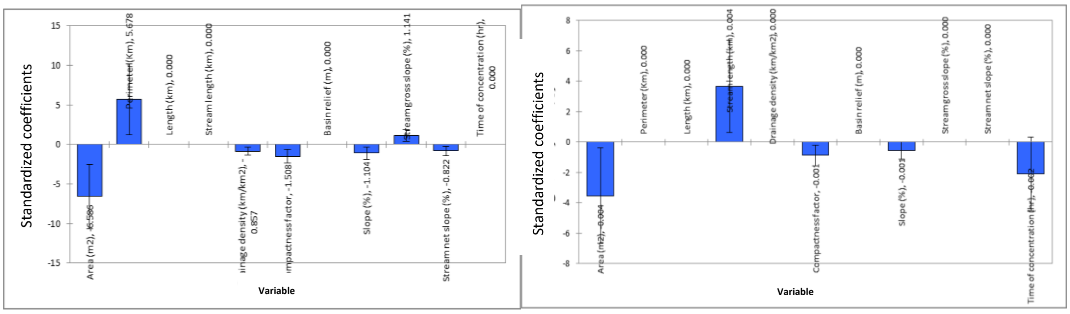


**Fig. 10.** Canal width/depth charts with standardized coefficients at 95% confidence level

Therefore, in the Neishabour Bar watershed due to different climatic conditions (absence of severe and sudden floods to change the depth), and increasing the amount of human intrusion and occupation compared to the Walnut Gulch basin, the width of the waterway, despite the lower coefficient of determination, is more affected and changed than the depth. The results of this study are also confirmed by Ebisemiju (1989), Osterkamp et al. (1983) and the equations obtained in this study can be used in future research.

**Table 4.** Comparison of coefficient of determination and RMS error of the equations obtained from linear and nonlinear regression

| Location | RMSE | $R^2$ | Parameter |
|---|---|---|---|
| Whole basin | 0.4 | 0.58 | **Depth** |
| | 7.25 | 0.14 | **Width** |
| Lar Formation | 0.18 | 0.66 | **Depth** |
| | 1.5 | 0.64 | **Width** |
| Downstream formation | 0.58 | 0.47 | **Depth** |
| | 8.15 | 0.005 | **Width** |
| Non-orchard lands | 0.28 | 0.82 | **Depth** |
| | 7.30 | 0.23 | **Width** |
| Stepwise regression (linear) | 0.29 | 0.85 | **Depth** |
| | 4.1 | 0.77 | **Width** |

## 4. Conclusion

In this study, Neishabour Bar watershed was divided into 34 hydrological sub-basins and local and regional relationships between the depth/width of the stream and the upstream area and the depth/width of the stream with other physical parameters of the basin were investigated. Nonlinear regression analysis between depth and environmental parameters, i.e. area, basin length, main stream length, compaction ratio, and altitude range showed a correlation coefficient above 60% and less standard error. This analysis between the width and drainage density, mean slope, net slope, gross slope, and altitude range showed a correlation coefficient of about 50% and a higher standard error. Nonlinear regression and analysis of variance for 34 sub-basins determined the coefficient of determination of 0.58 for the equation on the depth of canal and 0.14 for the equation on the width of canal. The results of separating the sub-basins based on the geological formation formulate equations with a determination coefficient of 0.66 for depth and 0.64 for the width of the stream under the sub-basins containing the Lar Formation, and equations with a determination coefficient of 0.47 for the canal depth and 0.005 for the canal width in downstream lands. Moreover, less RMS error was obtained for the equations based on the Lar Formation than other lands. This means that by dividing the basin into two parts, the equations obtained for the sub-basins containing Lar Formation are more valid than the other lands. Thus, it can be said that this separation has been effective in improving the equations' validity. The results of subdividing watershed based on non-orchard lands showed the equations with a coefficient of determination of 0.82 for the canal depth and 0.23 for the canal width, which established the effectiveness of gardeners' manipulations on the riverbed. In fact, this encroachment of orchards on the river has affected the natural conditions of the bed, which will also affect the obtained model. It was also found that in all these separations, the improvement of stream depth relationships with upstream area compared to the canal width. In general, it can be said that two very important factors have been influential in this basin: 1) geological structure 2) land use change and human manipulation and encroachment on the stream bed. Stepwise linear regression in the whole basin showed a determination coefficient of 0.85 for the canal depth and a determination coefficient of 0.77 for the width of the stream. In this way, the depth of canal has a significant relationship with the upstream area, compaction ratio, slope, concentration time and length of the main stream. Also channel width has a significant relationship with upstream area, compaction ratio, slope, drainage density, net slope, perimeter, and gross slope. This means that the probability values associated with t in the mentioned parameters are less than the "probability of entry" (0.05) so they were added to the model (Pr> | t |). As it turned out in this study in all equations obtained from linear and nonlinear regression, the depth of the canal was more affected and correlated with the upstream area than the width of the canal. The reason can be attributed to the successive droughts and the absence of flash floods in the region. In fact, since the depth is more affected by geological structures and the floods that occur in the basin are not severe enough to change the depth, thus the width of the canal is mainly affected by human manipulations. In general, in the Neishabour Bar watershed, the depth of the stream is more affected by the parameters of upstream watershed in comparison with the canal width.

## 5. Conflicts of Interest

No potential conflict of interest was reported by the authors

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