

Prioritization of sub-basins by morphometric analysis of the drainage basin for adopting protective measures in Galikesh Watershed

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Article history: Received: 5 Jan. 2015

Revised: 8 Feb. 2015

Accepted: 25 Apr. 2015

Abstract

Watershed is regarded as a very complex system of natural, social, economic and ecological dimensions and like any similar systems, exploitation of its resources requires a comprehensive and coordinated planning and management. Given the importance of watershed management projects for the development and management of natural resources, the enhancement of the efficiency of these activities is essential in order to avoid wasting capitals. Prioritization of sub-basins is one of the most comprehensive tools in natural resource management and sustainable development. The purpose of this study was to prioritize the sub-basins of Galikesh watershed in Golestan province by morphometric analysis and GIS. Morphometric analysis; as a low-cost and quick method; has attracted much attention in recent years. In this study, analysis of morphometric parameters included overland flow length, bifurcation ratio, drainage density, drainage network, watershed form factor, roundness factor, coefficient of elongation, and compression ratio. These parameters are divided as either linear (correlated with erosion) or form (inversely correlated with erosion) coefficients. The priority of each sub-basin was determined according to the average of morphometric parameters. The results of morphometric parameters showed that the highest number of sub-basins fall in the middle to high classes (44.44%) with 6A, 4A and 9A facing critical situation, and 3A and 1A with a more favorable situation than the other sub-basins. Field studies properly corroborate the results, as watersheds 6A and 4A have the highest erosion and poorest soils (hydrologic group C). Therefore, this type of research can be used as a low-cost and quick method of watershed prioritization in order to carry out protective measures.

Keywords: Prioritization of sub-basins, morphometric analysis, Galikesh watershed

1. Introduction

Watershed is an ideal unit for managing natural resources, the adjustment of the impacts of natural disasters, and to achieve sustainable development (Khan et al., 2001). The first condition to control erosion and improve the critical situation in a watershed is to identify and prioritize areas and sub-areas with critical condition. In case of control measures, the areas with higher priorities should be given more attention. Ranking

watersheds is necessary and inevitable in order to perform any kind of treatment. Ranking sub-watersheds is a classification on the basis of the current condition of resources, and erosion status; that eventually facilitates undertaking conservation and management practices in critical areas (Suresh et al., 2005). Dividing and then ranking basins into large watersheds and then numerous catchments, reduce the time and cost of the

implementation of watershed management operations, and simultaneously enhance the efficiency of the projects. Prioritization is based on important factors, such as design and development of a watershed, and is carried out with respect to physiographic features, drainage, geomorphology, soil, land use, land cover and water resources (Paul et al., 2012). Many studies have been conducted on watersheds prioritization that is briefed as follows: Ahar and colleagues (2013) used FAHP to rank watersheds in Pim Palagon in India by using nine morphometric parameters. The results suggested that 60.85% of the area fell in the middle to very high classes and were in need of conservational measures. Mishra et al. (2007) ranked sub-basins with morphometric parameters via the Soil and Water Assessment Tool (SWAT) in a semi-humid tropical ecosystem in India. Takar and Dyman (2007), using morphometric analysis, remote sensing and GIS techniques, prioritized eight watersheds in Mohr, India. Jawd and Khandai (2009), in Kamera watershed in India, categorized the region on the basis of morphometric properties and land use. Peacock et al. (2012) sorted sub-basins in

order to manage non-point polluting sources from four perspectives of regional economy, society, culture and environment. Zehtabian and colleagues (2009) examined the potential of flooding in the Marmeh watershed and determined the priority areas for flooding.

Mohammad and Ahmad (2011) provided a prioritized sub-basin plan for management programs in Marouf watershed. Jamalia et al. (2011) applied a spatial multi-criteria analysis (SMCE) and decision-making techniques for the prioritization of sub-basins in order to construct gabion check dams. In the mentioned studies, watersheds priority has been merely examined for water supply in the area, and changes in land use and vegetation have been the main parameters in determining the situation. Here, prioritization has been carried out on the basis of trend and direction of the changes in these parameters. The purpose of this study was to determine critical sub-basins in the Galikesh watershed, Golestan province with morphometric analysis, in order to control erosion, facilitate and reduce cost of watershed management projects.

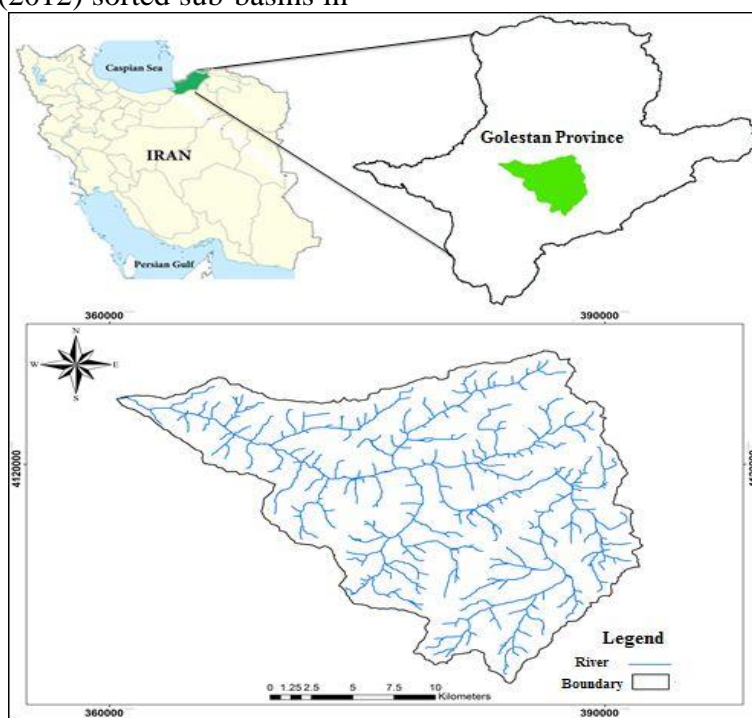


Fig. 1: Location of Galikesh watershed in Golestan province of Iran

2. Materials and Methods

In this study, morphometric analysis was used to prioritize the watersheds. First morphometric parameters were calculated in each watershed. Then, by comparing the results of these indicators, these watersheds were prioritized in terms of the need to perform watershed management practices and their erosion status. Morphometric analysis is one of the effective ways to prioritize the areas and could be indicative of the drainage network. The analysis of the morphometric parameters indicates the status of the basin in terms of different factors such as erosion (Vittala et al., 2004). These include a large number of parameters. However, in the study only those parameters with a greater impact on erosion were selected and calculated. Eight parameters used for this research are as follows.

Drainage density ratio: is the length of all streams in the watershed. The drainage network density is calculated by the following formula:

$$D_d = \sum L / A \quad (1)$$

Where D_d is the density of drainage channels in km. km^{-2} , L is the length of each of the streams in the basin in km , N is the number of channels in the basin, and A is the area of the basin in km^2 .

Drainage texture: is obtained as the ratio of the number of channels in the basin.

$$R_{tc} = \frac{N_B}{P_b} \quad (2)$$

Where N_B denotes the number of channels and P_b is the watershed perimeter in km . **Overland flow length:** is calculated using the following formula in which D_d is the drainage density of the basin. Half of drainage density is expressed as the overland flow length.

$$L_o^- = \frac{1}{2D_d} \quad (3)$$

Bifurcation ratio: is used to determine the effect of drainage on flood hydrograph in the watershed. This coefficient is the ratio of the number of streams in a lower level to the next larger level. To determine the bifurcation ratio in the basin, the following formula is used:

$$B_R = (n_1/n_2 + n_2/n_3 + \dots + n_{i-1}/n_i) * 1/i-1 \quad (4)$$

Where B_R is the bifurcation ratio, n_1 the number of branches in the first level, n_2 the number of branches in the second level, n_i is the number of branches in the i^{th} level, and finally i is the number of branches of the final level in the basin.

Gravelius method (compression ratio): This parameter is defined as the ratio of the circumference of the basin to the perimeter of a hypothetical circle of the same size. This is calculated as given by formula (5):

$$C_c = 0.28 \times \left(\frac{P}{\sqrt{A}} \right) \quad (5)$$

Where P is the basin's circumference in km , A is the basin's area in square kilometers, and CC is the Gravelius Compression Ratio.

In fact, this factor represents the basin deviation from the circular shape in which larger numbers than the unit value represent elongated basins while on the contrary, the values closer to the unit value will denote a circular form of the basin.

Miller method (roundness coefficient or circularity coefficient): This coefficient is calculated by formula (6):

$$R_c = 12.56 \times \left(\frac{A}{P^2} \right) \quad (6)$$

Where P is basin's circumference in km , A is the basin's area in square kilometers, and R_c is the Miller roundness index. R_c value of one indicates a circular shape.

Horton index (watershed form factor): This coefficient (form factor) is calculated as follows:

$$R_c = \frac{A}{L^2} \quad (7)$$

Where R_c is basin form coefficient, L is the length in kilometer, and A is the area of the

basin in square kilometers. The above equation indicates that shorter watersheds are wider. If the form factor exceeds the unit value, the probability of flooding will increase, and values lower than one indicate less change of overflowing and thus flooding in the watershed. An R_C of one indicate a square watershed shape

Schumm method (basin elongation ratio) is calculated using formula (8):

$$R_e = \frac{2(\sqrt{\frac{A}{\Pi}})}{L} \tag{8}$$

Where A is the area of the watershed in square kilometers, and L is the basin’s length in kilometers. The value of this factor is always lower than one.

2.1. Prioritization of watersheds

To be able draw a comparison between different watersheds, a number of factors or indices were used. After the calculation of morphometric parameters, these factors are sorted with respect to their relationship with erosion and area assigned a rank.

Morphometric parameters are divided into two categories of linear and form.

Linear parameters: These parameters are directly linked to erosion, and a lower rank is given to the larger values. This category includes drainage density, bifurcation ratio, overflow length and texture of the surface drainage.

Form parameters: These parameters are inversely proportional to erosion and unlike the linear parameters; the maximum rank is given to the highest value. This category also includes elongation factor, (8)form factor, roundness factor, and compression ratio.

After calculating the parameters and determining the weight of each sub-basin, the average of weights in each sub-basin is calculated as follows:

(Linear parameters total weight) + (form parameters total weight) / (total number of parameters)

By calculating the average of ratings assigned to each class of morphometric parameters in each sub-basin, they can be placed into seven categories according to table 1. As table 1 indicates, lower averages are given higher priorities.

Table 1: Determination of the class of morphometric parameters according to their averages

Class	Priority	Average value
A	Critical	>2.4
B	Very high to Critical	2.5 – 3.5
C	High to very high	3.6 – 4.6
D	Medium to high	4.7 – 5.7
E	Low to medium	5.8 – 6.8
F	Very low to low	6.9 – 7.9
G	Very low	8>

3. Results and Discussion

The values calculated for morphometric parameters in each sub-basin, and sub-basins’ ranking are presented in Table 2. The presence of the morphometric parameters lower than the average, suggests a facilitated condition for erosion agents to function. Morphometric parameters could be compared on the basis of their ranking. The rankings are ordered from 1 to 9, with 1 indicating the highest priority for undertaking protective measures

Averages of linear and form parameters according to formula 11 are presented in Table 3. Finally, using the obtained averages, sub-basins were prioritized. As specified in Table 3 the total averages of sub-basin 5A and 8A are equal; and thus the priority of each of these sub-basins is determined by the severity of erosion in that area. Larger amounts of erosion, indicates the delicacy of the situation in the region. The sub-basin 5A to 8A has higher priorities and worse situations. Figure 2 shows priority of each sub-basin based on

morphometric analysis given in Table 3. As it stands, the highest number of sub-basins falls in the middle to high classes (four sub-basins). Generally, 2 sub-basins (3A and 1A)

correspond to the highest averages and 3 sub-basins (6A, 4A and 9A) are given the first priority for undertaking protective measures.

Table 2: values of morphometric parameters for Galikesh watershed sub-basins in Golestan province and their corresponding ratings

Sub basin Name	Area (Km ²)	compression ratio	roundness coefficient	Form factor	Elongation ratio	Drainage density	Bifurcation ratio	Drainage texture	Overland flow length
1A	38.07	1.36 (3)	0.53 (7)	0.40 (7)	0.71 (7)	1.07 (4)	2.58 (9)	1.13 (4)	0.46 (6)
2A	23.76	1.62 (8)	0.37 (3)	0.18 (1)	0.47 (1)	0.98 (9)	4.16 (4)	0.7 (9)	0.5 (3)
3A	48.05	1.46 (5)	0.45 (5)	0.45 (8)	0.76 (8)	1.02 (6)	2.87 (8)	0.99 (5)	0.48 (5)
4A	44.84	1.61 (7)	0.37 (2)	0.26 (3)	0.57 (3)	0.99 (8)	5.5 (2)	0.95 (7)	0.5 (2)
5A	48.5	1.33 (2)	0.55 (8)	0.39 (6)	0.71 (6)	0.99 (7)	3.33 (7)	1.29 (3)	0.5 (1)
6A	37.2	1.81 (9)	0.29 (1)	0.19 (2)	0.49 (2)	1.11 (2)	5.58 (1)	0.96 (6)	0.44 (8)
7A	60.94	1.28 (1)	0.59 (9)	0.48 (9)	0.78 (9)	1.03 (5)	3.46 (6)	1.55 (1)	0.48 (4)
8A	25.99	1.37 (4)	0.52 (6)	0.39 (5)	0.7 (5)	1.15 (1)	4.33 (3)	0.84 (8)	0.43 (9)
9A	72.67	1.47 (6)	0.45 (4)	0.31 (4)	0.63 (4)	1.09 (3)	3.52 (5)	1.31 (2)	0.45 (7)

Table 3: average of morphometric parameters and sub-basins prioritizations

Sub basin Name	Average rating	Final Priority	Class
1A	5.87	8	E
2A	4.75	4	D
3A	6.25	9	E
4A	4.25	2	C
5A	5.12	5	D
6A	3.87	1	C
7A	5.5	7	D
8A	5.12	6	D
9A	4.37	3	C

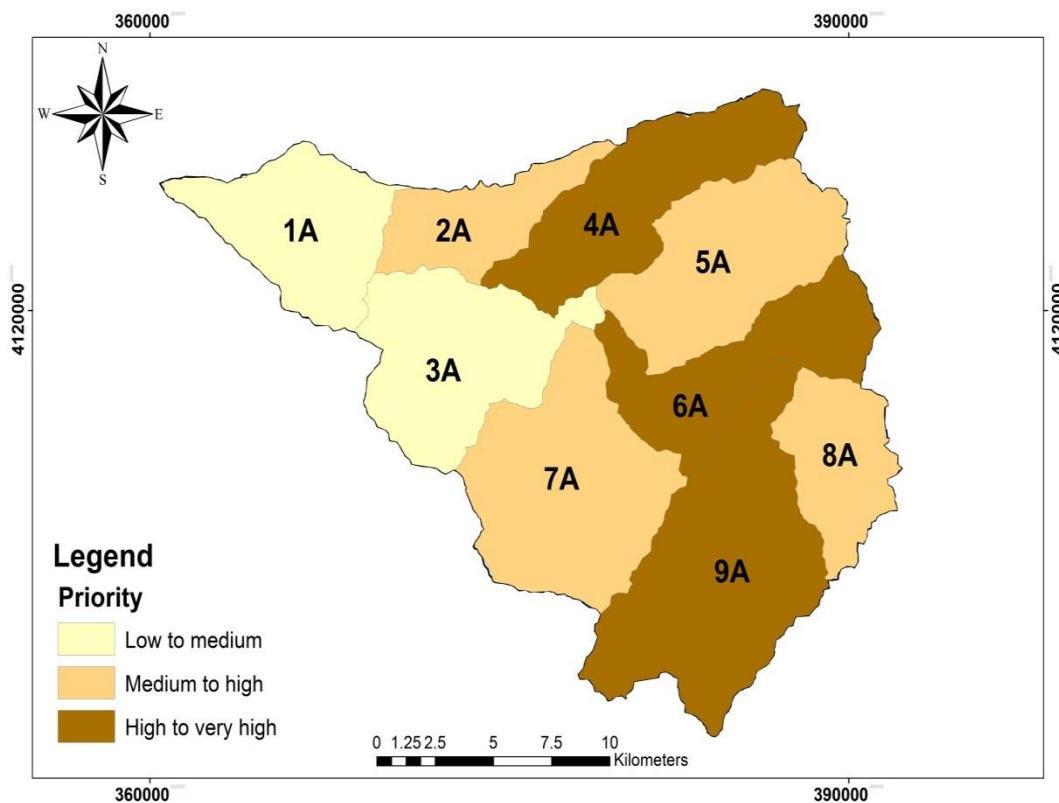


Fig. 2: Prioritization of the Galikesh watershed based on morphometric analysis

4. Conclusion

Integration of morphometric parameters is an efficient way to prioritize sub-basins to implement soil conservation practices (Chandniha et al., 2014 & Gajbhiye et al., 2014). Studies show the ability of GIS in prioritization of watersheds with the morphometric parameters (Pai et al., 2011). The aim of this study was to determine the priority of each sub-basin in Galikesh watershed and to identify critical areas in order to control erosion and implement protective operations in the region. Geological status is the most important factor for erosion and degradation. This basin with sediment deposits and Shemshak and Lar formations is highly sensitive to erosion. In this case, the least sensitivity occurs at sub-basin 3A and the highest at 6A. These sub-basins have uneven surface, gully and river bank erosion, which are important factors for the implementation of protective measures. Due to the large number of rocky outcrops in sub-basin 3A, this sub-basin has been given the least priority for undertaking protective measures. The sub-

basins closer to the outlet of the basin have the least impact on the flood peak and sediment load. The upper parts of the basin have the highest ranks for watershed management activities.

According to studies in the Galikesh watershed and with respect to the information provided in Table 3, sub-basins 6A, 4A and 9A in terms of morphometric parameters, suffer from a more critical situation. Among these sub-basins, 6A and 4A are given higher priorities due to their maximum drainage density, overland flow, roundness, elongation ratio compared to other sub-basins which agree to the findings of Aher et al (2013), Gajbhiye et al (2014) and Thakkar et al (2007).

So it can be said that in Galikesh watershed, because of topographical, morphological parameters, natural erosion and human factors, due attention must be given to sub-basins with more critical conditions (6A, 4A and 9A) to harness water and soil losses and to prevent severe consequences of erosion. In these areas,

according to the criticality of the situation, topographical and climatic conditions, the managerial operation should consist of either biological or mechanical dimensions. Due to the topographical conditions, especial ecology and hydrology of the basin, it is best to use these areas for recreational purposes. In addition, comments and suggestions of experts and the experiences of indigenous peoples should be used for any such propositions in these areas. In this study, an integrated approach of Gis and morphometric analysis was adopted to prioritize sub-basins for planning and conducting operational measures. This method is very effective and convenient in watersheds encountering a lack of data. The methodology adopted in this paper is unique in terms of time and capital. The findings are in good consistency with the results of Aher et al (2010), Javed et al (2009).

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