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Research Paper

SWPT: An automated GIS-based tool for prioritization of sub-watersheds based on morphometric and topo-hydrological factors

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ABSTRACT

The sub-watershed prioritization is the ranking of different areas of a river basin according to their need to proper planning and management of soil and water resources. Decision makers should optimally allocate the investments to critical sub-watersheds in an economically effective and technically efficient manner. Hence, this study aimed at developing a user-friendly geographic information system (GIS) tool, Sub-Watershed Prioritization Tool (SWPT), using the Python programming language to decrease any possible uncertainty. It used geospatial–statistical techniques for analyzing morphometric and topo-hydrological factors and automatically identifying critical and priority sub-watersheds. In order to assess the capability and reliability of the SWPT tool, it was successfully applied in a watershed in the Golestan Province, Northern Iran. Historical records of flood and landslide events indicated that the SWPT correctly recognized critical sub-watersheds. It provided a cost-effective approach for prioritization of sub-watersheds. Therefore, the SWPT is practically applicable and replicable to other regions where gauge data is not available for each sub-watershed.

1. Introduction

The process of making a decision for planning and management of watersheds is often very difficult in many developing countries where human resource and financial budget are limited and performing these activities are expensive and time consuming (Fan and Shibata, 2014; Kim and Chung, 2014; Rahmati et al., 2016). Most scientists have acknowledged that watershed is the most appropriate unit of landscape analysis, particularly for land and water resources planning and management issues. Unfortunately, since last decades, watersheds are being degraded or have a potential to be impaired due to the anthropogenic activities and human induced climate change (Yadav et al., 2018). One of the most important principals for integrated and efficient watershed management is sub-watersheds prioritization. It can help to control soil erosion, floods, and sediment loads identification of critically endangered sub-watersheds to achieve sustainable development

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(Chowdary et al., 2013; Altaf et al., 2014; Fan and Shibata, 2014). It will be possible if the process of ranking sub-watersheds is considered by runoff/peak discharge and erosion risk assessment (Jain and Das, 2010).

Several attempts have been made to analyze and prioritize sub-watersheds in different scales by Multi Criteria Decision Analysis (MCDA) (Sinha et al., 2008; Meyer et al., 2009; Fernández and Lutz, 2010; Wang et al., 2011; Kang et al., 2013; Stefanidis and Stathis, 2013; Zou et al., 2013; Rahaman et al., 2015; Rahmati et al., 2016; Toosi and Samani, 2017; Vulević and Dragović, 2017; Arabameri et al., 2018), Weighted Sum Analysis (WSA) (Aher et al., 2014), sediment yield index (Samal et al., 2015; Ayele et al., 2017), Principle Component Analysis (PCA) (Meshram and Sharma, 2017), Water Erosion Prediction Project (WEPP) (Pandey et al., 2009), Simulator for Water Resources in Rural Basins (SWRRB) (Williams et al., 1985), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998; Tyagi et al., 2014), Area Weighted Vegetation (AWV) (Katiyar et al., 2006), Water and Energy Transfer between Soil, Plants and Atmosphere (WetSpa) (Zeinivand and De Smedt, 2009), and soil erosion modelling (Farhan and Anaba, 2016; Ahmed et al., 2017; Gashaw et al., 2018).

However, in the aforementioned studies, the Weighted Sum Analysis (WSA) proposed by Aher et al. (2014) is one of the most efficient methods to prioritize sub-watersheds in data-scarce and/or un-gauged regions. They considered morphometric parameters—in the relief, areal, and linear aspect—for analyzing prioritization of sub-watershed using only digital elevation model (DEM). The morphometric analysis is an important part of sustainable land and water resource conservation, particularly in developing countries where detailed quantitative information and the budget allocated to integrated watershed management are scarce (Avinasha et al., 2011; Thomas et al., 2011; Prasannakumar et al., 2013; Sujatha et al., 2014; da Silva et al., 2017). According to Adhami and Sadeghi (2016), topo-hydrological and geomorphometric factors have the direct impact on the site selection and execution of land and water conservation measures in sub-watersheds. These factors make provision for the insight into catchment evolution and its role in development of drainage morphometry (Bali et al., 2012; Patel et al., 2013; Sujatha et al., 2014). So far, however, there has been little discussion about considering topo-hydrological parameters such as topographic wetness index (TWI), stream power index (SPI), and sediment power index (STI) in prioritization of sub-watersheds. It is worth mentioning that no previous studies have considered the above-mentioned parameters together for such purposes. In addition, there is no tool to compute these parameters, which are time consuming and labor intensive, because they should be separately calculated using geo-spatial techniques. Therefore, this study focused on developing an effective tool which was written in Python language, running as an extension of ArcGIS 10.2 software to decrease uncertainties associated with morphometric and topo-hydrological variables (Aher et al., 2014). Thus, the main objective of this study is to develop a user-friendly geospatial–statistical tool which allows efficient prioritization of sub-watersheds.

2. Material and methods

2.1. Study area

The study area is a watershed located in Golestan Province, Iran (Fig. 1). The watershed lies between 55°38′E to 55°40′E longitudes and 37°37′N to 37°39′N latitudes and has a drainage area of about 23,071 ha. Its elevation varies significantly from 189 m to 2527 m above sea level. Slope degree ranges from 0 to 78°, with an average value of 11.2°. The study area is mountainous in the south and is flat in the north. Based on Köppen-Geiger climatic classification system, it has a humid climate with the mean annual precipitation of 766 mm. The mountainous springs of the study area supply freshwater, the average spring discharge approximately stands at 10 lit/s according to Iranian Department of Water Resources Management (IDWRM), to highly populated area. Additionally, the probability analysis proved that Golestan Province as a large basin with lots of sub-watersheds, is adversely affected by devastating flash floods, lack of water and soil conservation, and environmental degradation (Omidvar and Khodaei, 2008; Bhowmik et al., 2015; Haghizadeh et al., 2017; Rahmati et al., 2018). The lithology of the study area is characterized by different units including gypsiferous marl, limestone, sand dunes, sandstone, shale, swamp and valley terrace deposits. The soil of the study area classified as Inceptisols, Entisols Mollisols, Alfisols. From a vegetation viewpoint, study area is a part of the Hyrcanian vegetation zone which is a green belt stretching over the northern slopes of the Alborz Mountains chain. The main tree species in the study area are Quercus castaneafolia (chestnut-leaved oak), Carpinus betulus (hornbeam), Acer cappadocicum (coliseum maple), Acer velutinum (velvet maple), Alnus subcordata (Caucasian alder), and Cerasus avium (mazzard cherry). However, during the last decade, the watershed is facing several environmental issues and anthropogenic disturbances such as overgrazing driving rapid erosion and transfer of sediment into rivers, land-use changes, urbanization and industrialization. Forests are increasingly fragmented and converted to other forms of land use (Mohammadi and Shataee, 2010). These impacts caused a reduction of forest ecological diversity and altered the ecological and environmental processes. Hence, these challenging issues resulted in changing hydrological behavior as well as inappropriate location and irregular data collection of existing hydrometric stations.

2.2. Methodology

2.2.1. Theoretical background of the prioritization tool

This section explains the rationale behind the sub-watershed prioritization tool (SWPT) which is developed to represent the prioritization of sub-watersheds in data-scarce and/or un-gauged regions. In order to assess the runoff/peak discharge and erosion risk, the morphometric and topo-hydrological factors are considered for prioritization of micro-watersheds even without considering important factors such as soil map (Abdulkareem et al., 2018a, b). To analyze morphometric characteristics, measurement of the gradient of channel network, linear features, and contributing ground slopes of the drainage area are needed (Thakkar and Dhiman, 2007). Hence, in this study, morphometric and topo-hydrological parameters were used to prioritize sub-watersheds including: (1) areal aspects (drainage density (D), stream frequency (F_s), drainage texture (R_t), form factor (R_f), circularity ratio (R_c), constant of channel maintenance (C), elongation ratio (R_e), and compactness coefficient (C_c)); (2) linear aspects (bifurcation ratio (R_b)); and (3) topo-hydrological factors (topographic wetness index (TWI), stream power index (SPI), and sediment transport index (STI)) (Table 1).

For appropriate ranking of the hydrological units, the present study follows Weighted Sum Analysis (WSA) approach introduced by Aher et al. (2014). The WSA, as a rigorous statistical method, is coupled with geo-spatial technologies to specify which parameter should be considered in the final combination for analysis. To avoid the individual biasness of several morphometric and topo-hydrological factors associated with weights, the WSA method estimates relative significance of each parameter via the statistical

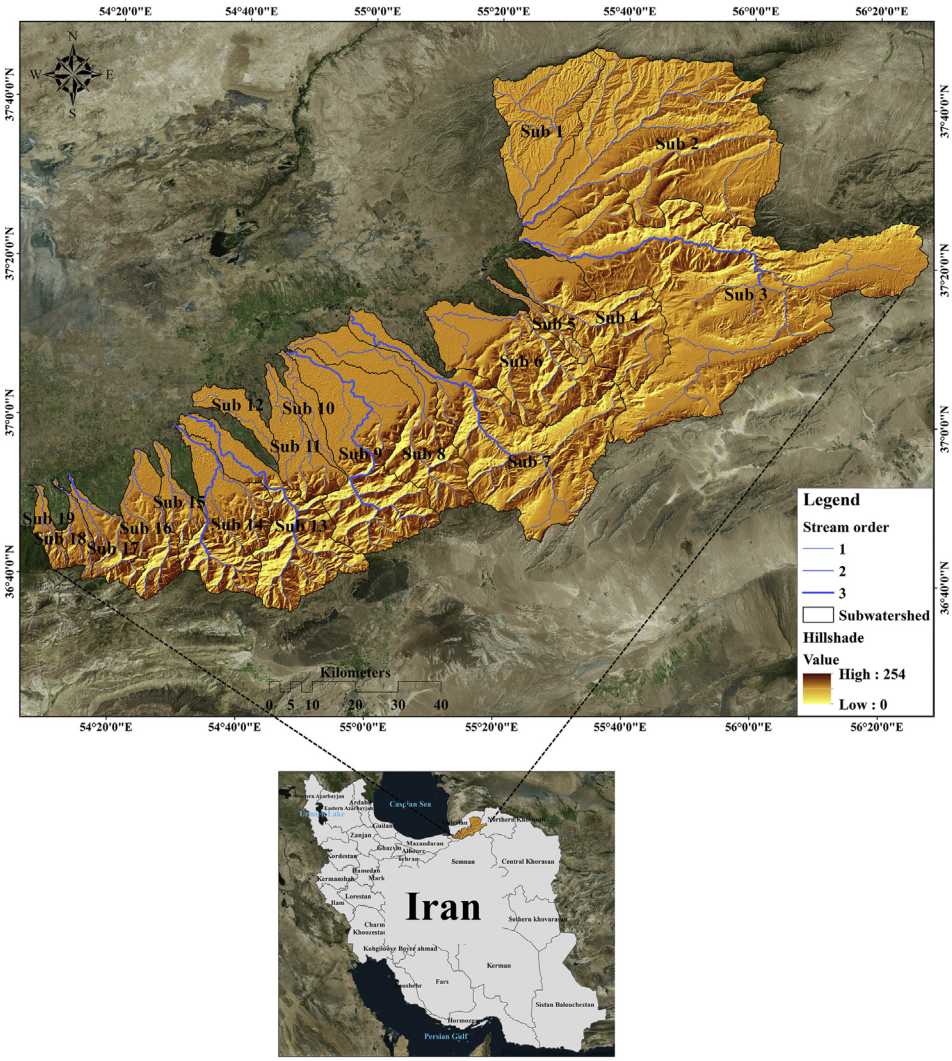


Figure 1. Location of the Golestan Watershed, Golestan Province, Iran (there are 19 sub-watersheds).

correlation, and also assigns the weight to each parameter with respect to its due importance (Eq. (1)) (Aher et al., 2014):

$$\text{Prioritization} = \sum_{i=1}^{n} W_i \times X_i \tag{1}$$

where W_i is the weight of each morphometric parameter calculated by the WSA approach; and X_i is the value of morphometric parameters. The mentioned approach is able to recognizing the efficiency of factors to consider the individual impacts, separately.

Although the above mentioned approaches are effective, there are some limitations on the effective use of the method. Dataset analysis of morphometric and topographic parameters are time consuming and labor intensive because they should be separately calculated using geo-spatial techniques. In addition, in order to estimate the correlation and weight of parameters, users should employ statistical software such as SPSS, which is not accessible for most of experts. To deal with mentioned constraints, we developed an effective framework which was written in Python (Fig. 2), a modern high-level programming language (Rahmati et al., 2018). There are several advantages of using Python language including: (1) freely available and quite popular in programming community; (2) users do not have to be specialist in computer programing; and (3) in a productive environment, it allows users to develop their ideas by the assemblage and connection of existing software components. Therefore, sub-watershed prioritization tool (SWPT) was introduced in the ArcToolbox and runs as an extension of ArcGIS 10.2 software (Marowka, 2018). The conceptual architecture of the SWPT is shown in Fig. 3.

2.3. Hydro-geomorphometric analyses

Hydro-geomorphometic analysis is the foundation of the current study in which the SWPT tool is built upon. This analysis is divided into two sets of factors including morphometric factors and topo-hydrological factors. Morphometric factors encompass drainage density (D), stream frequency (F_s), drainage texture (R_t), form factor (R_f), circularity ratio (R_c), constant of channel maintenance (C), elongation ratio (R_e), compactness coefficient (C_c), and bifurcation ratio (R_b); while topo-hydrological parameters embrace topographic wetness index (TWI), stream power index (SPI), and sediment transport index (STI). These two sets of factors were utilized for designing SWPT in order for prioritization of a watershed for treatment purposes. A digital elevation model of the study area with a pixel size of 10 m was prepared, from which the

Table 1
Methodology adopted for computating morphologic and topo-hydrological parameters.

Parameters	Definition/formula	References
Stream frequency (F_s)	$F_s = N_u/A$ where N_u is total number of stream segments of order ‘u’ and A is area enclosed within the boundary of watershed divide (Basin area)	Horton (1932)
Compactness constant (C_c)	$C_c = 0.2821P/A^{0.5}$ where P is length of watershed divide which surrounds the basin (Basin perimeter)	Horton (1945)
Constant of channel maintenance (C)	$C = 1/D$ where D is drainage density	Schumm (1956)
Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$ where N_{u+1} is number of segments of the next higher order	Schumm (1956)
Drainage density (D)	$D = L_u/A$ where L_u is total stream length of order ‘u’	Horton (1932)
Elongation ratio (R_e)	$R_e = \sqrt{4 \times A/P_i}/L_b$ where L_b is distance between outlet and farthest point on the basin boundary (Basin length)	Schumm (1956)
Circularity ratio (R_c)	$R_c = 4 \times P_i \times A/P^2$ where P is length of watershed divide which surrounds the basin (Basin perimeter)	Miller (1953)
Form factor (R_f)	$R_f = A/{L_b}^2$ where L_b is distance between outlet and farthest point on the basin boundary (Basin length).	Horton (1932)
Drainage texture ratio (R_t)	$R_t = N_u/P$	Horton (1945)
Topographic wetness index (TWI)	$\mathrm{TWI} = \ln(A_s/\tan\beta)$ where A_s is the local upslope area draining through a certain point per unit contour length and $\tan\beta$ is the local slope	Beven and Kirkby (1979)
Stream power index (SPI)	$A_s \times \tan\beta$	Whipple and Tucker (1999)
Stream transport index (STI)	$\mathrm{STI} = (m+1) \times A_s/22.13^m \times \sin\beta/0.0896^n$ where β is the local slope gradient in degrees, m is the contributing area exponent, and n is the slope exponent	Moore and Burch (1986)

morphometric and topo-hydrological factors were extracted for each sub-watershed. The computation of these factors was automatically conducted by the SWPT extension tool (Fig. 4).

2.4. Prioritization of sub-watersheds

In order to prioritize sub-watersheds of the study area, the SWPT tool was used to automatically compute the correlation coefficients between each two morphometric and topo-hydrological factors and prepare a correlation matrix based which one can decide which factors can affect the prioritization and which not. In this study, we decided to use those factors that had a correlation coefficient more than 0.6. Using the selected factors, the SWPT tool also calculates WSA index through which sub-watersheds will be prioritized. The tool can sort sub-watersheds based on the above information in a descending manner such that the most susceptible sub-watershed to runoff generation and soil erosion is ranked as number 1 and the least susceptible one is positioned at bottom of the list.

3. Results

3.1. Geomorphometric characteristics

The results of geomorphometry parameters using an automated GIS-based tool for prioritization of sub-watersheds (SWPT) is

```
strordstrah_Dissolve2 = workspace + "\\str_diss.shp"
arcpy.Dissolve_management(strorder, strordstrah_Dissolve2, "GRID_CODE", "", "MULTI_PART", "DISSOLVE_LINES")

all_orders = field2list(strordstrah_Dissolve2, "GRID_CODE")
for orders in all_orders:
        arcpy.AddMessage("#"*33)
        arcpy.AddMessage(orders)
        ppath = workspace + "\\ord_%s.shp"%orders
        arcpy.Select_analysis(strorder, ppath, "\"GRID_CODE\" =%s"%orders)
        out_spliterpoints = workspace + "\\spliterpoint%s.shp"%orders
        line(ppath,workspace,out_spliterpoints)
        order_diss = workspace + "\\ord_%s_diss.shp"%orders
        arcpy.Dissolve_management(ppath, order_diss, "GRID_CODE", "", "MULTI_PART", "DISSOLVE_LINES")
        mystrahler = workspace + "\\ord_spl_%s.shp"%orders
        arcpy.SplitLineAtPoint_management(order_diss, out_spliterpoints, mystrahler, "20 Meters")


order_info = {}
for orders in all_orders:
        mystrahler = workspace + "\\ord_spl_%s.shp"%orders
        sss(mystrahler, "length","!shape.length@METERS!")
        x = field2list(mystrahler, "length")
        length = 0
        for segment in x:
                length += float(segment)
        count = len(x)
        order_info[orders] = [count,length]

arcpy.AddMessage(order_info)
```

Figure 2. Code selection of prioritization process.

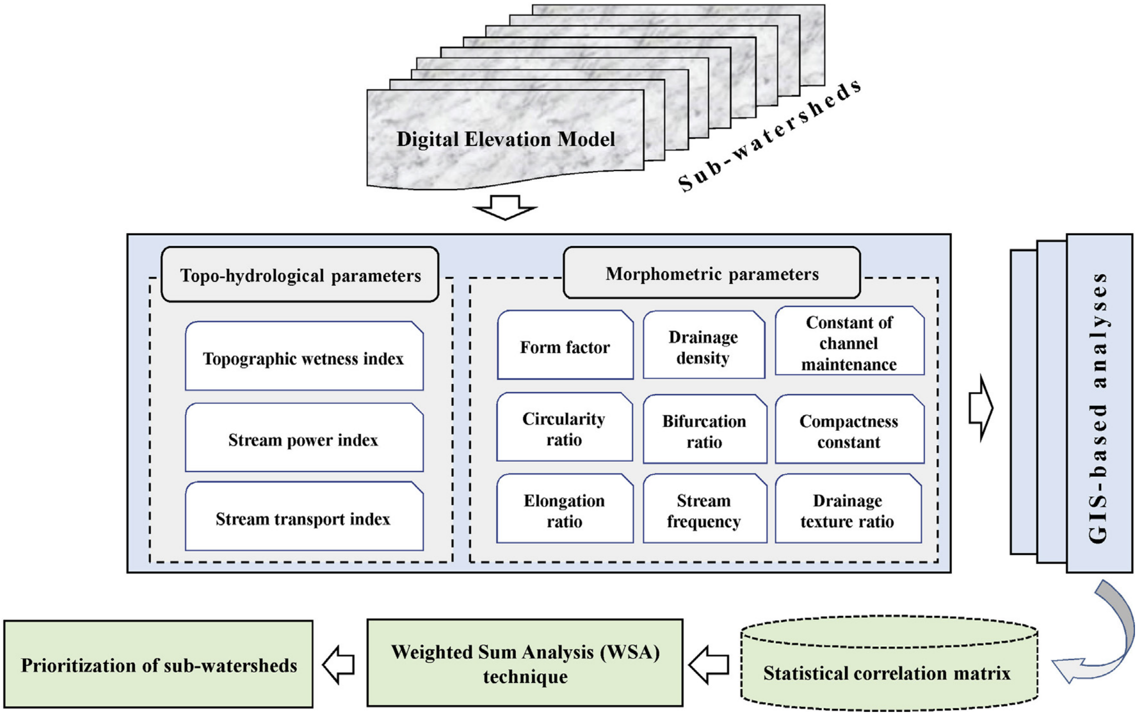
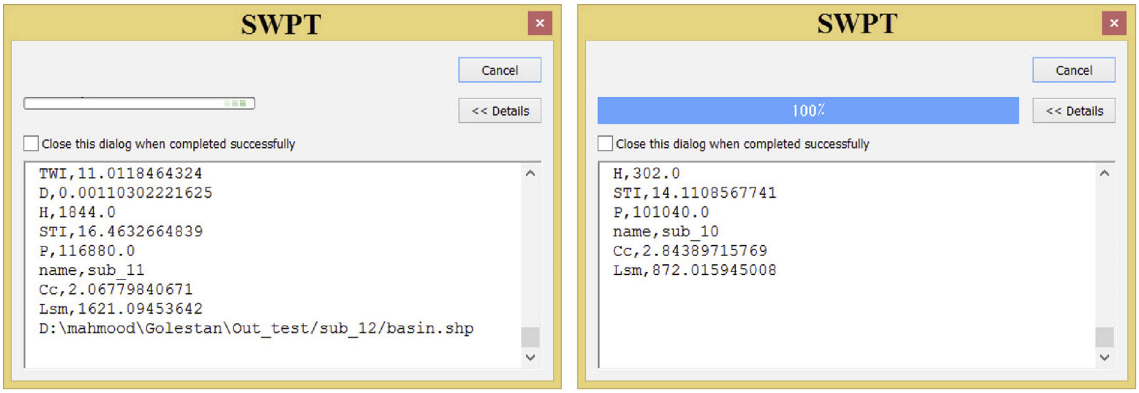


Figure 3. A conceptual architecture (processing steps) for prioritizing sub-watersheds.

shown in Table 2. It can be observed that the frequency of streams (F_s) ranges between 0.00000188 (sub-watershed 13) and 0.0000000329 (sub-watershed 03). According to the results of bifurcation ratio (R_b), the highest value is obtained by sub-watershed 13 (2.916), while sub-watershed 04 acquired the lowest one (1.594). In terms of R_f, results of SWPT showed that sub-watershed 19 and sub-watershed 05 have the most (0.615) and lowest (0.140) values, respectively. The prioritization of the results of elongation ratio (R_e) is the same as the R_f index. Basically, sub-watershed 19 had the highest value of R_e, followed by sub-watersheds 14, 06, 04, 07, 15, 02, 09, 12, 13, 18, 01, 11, 10, 03, 08, 16, 17 and 05. Sub-watershed 01 based on the circularity ratio (R_c) factor, obtained the highest value (0.237) and the sub-watershed 13 had the lowest one (0.080). According to the results of drainage density (D) and drainage texture (R_t), sub-watershed 13 and sub-watershed 03 positioned at the first and the last rank. The highest and the lowest values of the compactness coefficient (C_c) factor belonged to sub-watersheds 09 (3.523) and 01 (2.049), respectively. The values of the constant of channel maintenance (C) factor depict that sub-watershed 03 (4405.87) and sub-watershed 13 (578.91) rank at the first and the last position, respectively. According to TWI, SPI and STI, the results of prioritization conclude that sub-watersheds 08, 17, and 07 gain the highest values and sub-watersheds 17, 08, and 13 receive the lowest values, respectively (Table 2).

3.2. Automated prioritization of sub-watersheds

The correlation matrix obtained by the weighted sum analysis (WSA) approach of morphometric properties for the sub-watersheds is shown in Table 3. The reported results are for the correlation coefficient (r) more than 0.6. F_s has a significant correlation, positive value of correlation coefficient, with R_b ($r = 0.63$), D ($r = 0.93$), R_t ($r = 0.85$), and TWI ($r = 0.64$), and a negative value of correlation coefficient with C_{cm} ($r = -0.68$), SPI ($r = -0.72$), and STI ($r = -0.8$). R_b, except for F_s, does not have any correlation with the other morphometric parameters of the watershed. While R_f has a high and positive correlation ($r = 0.99$) with R_e and R_c, it only shows



```
TWI,11.0118464324
D,0.00110302221625
H,1844.0
STI,16.4632664839
P,116880.0
name,sub_11
Cc,2.06779840671
Lsm,1621.09453642
D:\mahmood\Golestan\Out_test/sub_12/basin.shp
```

```
H,302.0
STI,14.1108567741
P,101040.0
name,sub_10
Cc,2.84389715769
Lsm,872.015945008
```

Figure 4. A view of process window of SWPT calculations for the study area.

Table 2
Morphometric and topo-hydrological parameters of the sub-watersheds.

Sub-watershed code	Parameters											
	F_s	R_b	R_f	R_e	R_c	D	R_t	C_c	C	TWI	SPI	STI
Sub_16	0.000000431	2.142	0.231	0.542	0.163	0.0009	0.0006	2.473	1052.048	10.471	6.067	17.611
Sub_17	0.000000601	2.108	0.218	0.527	0.087	0.0008	0.0005	3.385	1133.281	9.636	7.103	19.16
Sub_18	0.000000354	1.744	0.291	0.608	0.103	0.0008	0.0006	3.102	1249.661	10.859	5.676	16.183
Sub_15	0.000000616	1.697	0.370	0.686	0.200	0.00112	0.00123	2.23	892.698	10.823	5.582	16.442
Sub_14	0.000000258	2.137	0.513	0.808	0.146	0.00073	0.00075	2.608	1363.964	10.387	6.221	17.714
Sub_04	0.000000180	1.594	0.467	0.771	0.183	0.00053	0.00051	2.333	1881.752	10.304	6.444	18.77
Sub_05	0.000000645	2.643	0.140	0.423	0.115	0.0011	0.0008	2.937	891	11.165	5.364	16.074
Sub_06	0.000000127	2.000	0.470	0.773	0.189	0.0004	0.000403	2.294	2248.331	10.275	6.562	19.464
Sub_07	0.0000000876	1.953	0.446	0.753	0.130	0.0003	0.00027	2.764	2915.141	10.086	6.724	20.057
Sub_08	0.000000900	2.274	0.236	0.548	0.124	0.001	0.0009	2.83	900.334	11.876	4.589	14.752
Sub_09	0.000000863	2.088	0.325	0.643	0.080	0.001	0.0012	3.523	869.974	11.454	5.052	15.257
Sub_13	0.00000188	2.916	0.294	0.612	0.080	0.0017	0.00146	3.513	578.905	11.262	4.896	14.062
Sub_03	0.0000000329	1.987	0.243	0.556	0.123	0.00022	0.00015	2.849	4405.869	10.399	6.324	20.018
Sub_12	0.000000133	2.263	0.295	0.613	0.128	0.0004	0.00036	2.784	2257.339	10.01	6.747	19.181
Sub_02	0.0000000425	2.125	0.359	0.676	0.203	0.000257	0.000218	2.214	3880.206	10.273	6.345	18.684
Sub_11	0.000000140	2.193	0.254	0.569	0.116	0.000482	0.000305	2.935	2074.617	10	6.797	20.05
Sub_01	0.000000155	1.953	0.269	0.586	0.237	0.000494	0.000491	2.049	2023.93	10.365	5.954	17.094
Sub_10	0.000000191	1.838	0.245	0.558	0.176	0.000547	0.000627	2.377	1828.011	10.72	6.043	17.7685
Sub_19	0.000000494	1.866	0.615	0.885	0.226	0.00102	0.00108	2.102	971.351	10.415	6.159	17.855

a high and negative correlation ($r = -0.97$) with C_c. The results of correlation between D and R_t with other factors indicated that they have positive relationships with TWI and negative relationships with C, SPI and STI. TWI has a high and negative correlation with SPI ($r = -0.98$), and STI ($r = -0.88$). The SPI in spite of having a high and negative relationship with the F_s, D, R_t and TWI, it had a high and positive relationship with the STI ($r = 0.94$) factor as well.

The final prioritization of sub-watersheds is carried out based on the compound parameter values (CPV). A sub-watershed with the lowest CPV value is determined as the first priority and other sub-watersheds will be ranked accordingly (Aher et al., 2014). The CPV is estimated using the weights of each morphometric parameter. The results of sub-watershed prioritization are shown in Table 4. Sub-watershed 03 received the highest priority ranking with compound parameter value (CPV = −460.528), followed by sub-watersheds 02 (CPV = −405.578), 07 (CPV = −305.118), 12 (CPV = −236.493), 06 (CPV = −235.536), 11 (CPV = −217.557), 01 (CPV = −211.954), 04 (CPV = −197.292), 10 (CPV = −191.590), 14 (CPV = −143.087), 18 (CPV = −131.055), 17 (CPV = −119.399), 16 (CPV = −110.671), 19 (CPV = −102.192), 8 (CPV = −94.311), 15 (CPV = −93.886), 05 (CPV = −93.581), 09 (CPV = −91.210), and 13 (CPV = −60.661) (Table 3).

3.3. *Performance assessment*

In order to compare the real condition of sub-watersheds in terms of geohazards (e.g. flash floods and landslides), flash flood and landslide inventories of the study area were obtained from Iranian Department of Water Resources Management (IDWRM). The number of flash flood (n_F) and landslide (n_L) events during 2005–2018 have been recorded for each sub-watershed. According to Fig. 5, sub-watersheds 3 ($n_F = 28$, $n_L = 22$), 2 ($n_F = 15$, $n_L = 14$), 7 ($n_F = 13$, $n_L = 14$), and 12 ($n_F = 10$, $n_L = 11$) are the most critical zones based on historical records of flash flood and landslide events. Therefore, these important available records clearly confirm the results of SWPT tool.

4. Discussion

Since different watersheds have different hydrological behaviors based on their morphometric and topo-hydrological characteristics, identification of critical watershed is a necessary issue in natural resources management, especially in the context of watershed management strategies (Jain and Das, 2010; Javed et al., 2011). There are some methods for prioritization of a watershed such as analyzing soil erosion and/or sediment yield, lithology, land use, environmental degradation factors, morphometric characterization, and multi-criteria decision making (MCDM) (e.g., simple additive weighing (SAW), technique for order preference by similarity to ideal solution (TOPSIS), and compound factor (CF)) which considers expert's knowledge and judgment (Kalin and Hantush, 2009; Besalatpour et al., 2012; Chowdary et al., 2013; Chandniha and Kansal, 2014; Rawat et al., 2014; Rahaman et al., 2015; Kundu et al., 2017; Prasad and Pani, 2017; Ameri et al., 2018; Aouragh

Table 3
Correlation matrix of morphometric properties for the sub-watersheds.

	F_s	R_b	R_f	R_e	R_c	D	R_t	C_c	C	TWI	SPI	STI
F_s	1.0	0.63	−0.19	−0.2	−0.46	0.93	0.85	0.57	−0.68	0.64	−0.72	−0.8
R_b	0.63	1.0	−0.42	−0.44	−0.52	0.5	0.31	0.53	−0.23	0.32	−0.37	−0.4
R_f	−0.19	−0.42	1.0	0.99	0.47	−0.13	0.08	−0.44	0.05	−0.24	0.24	0.23
R_e	−0.2	−0.44	0.99	1.0	0.46	−0.15	0.06	−0.43	0.08	−0.25	0.25	0.23
R_c	−0.46	−0.52	0.47	0.46	1.0	−0.35	−0.16	−0.97	0.21	−0.25	0.21	0.23
D	0.93	0.5	−0.13	−0.15	−0.35	1.0	0.93	0.45	−0.85	0.65	−0.73	−0.84
R_t	0.85	0.31	0.08	0.06	−0.16	0.93	1.0	0.28	−0.81	0.68	−0.75	−0.84
C_c	0.57	0.53	−0.44	−0.43	−0.97	0.45	0.28	1.0	−0.28	0.28	−0.27	−0.32
C	−0.68	−0.23	0.05	0.08	0.21	−0.85	−0.81	−0.28	1.0	−0.48	0.53	0.71
TWI	0.64	0.32	−0.24	−0.25	−0.25	0.65	0.68	0.28	−0.48	1.0	−0.98	−0.88
SPI	−0.72	−0.37	0.24	0.25	0.21	−0.73	−0.75	−0.27	0.53	−0.98	1.0	0.94
STI	−0.8	−0.4	0.23	0.23	0.23	−0.84	−0.84	−0.32	0.71	−0.88	0.94	1.0

Table 4
Prioritization and final ranking of sub-watersheds.

Watershed code	Compound parameter constant	Priority ranking
Sub_03	−460.528	1
Sub_02	−405.578	2
Sub_07	−305.118	3
Sub_12	−236.493	4
Sub_06	−235.536	5
Sub_11	−217.557	6
Sub_01	−211.954	7
Sub_04	−197.292	8
Sub_10	−191.590	9
Sub_14	−143.087	10
Sub_18	−131.055	11
Sub_17	−119.399	12
Sub_16	−110.671	13
Sub_19	−102.192	14
Sub_08	−94.311	15
Sub_15	−93.886	16
Sub_05	−93.581	17
Sub_09	−91.210	18
Sub_13	−60.661	19

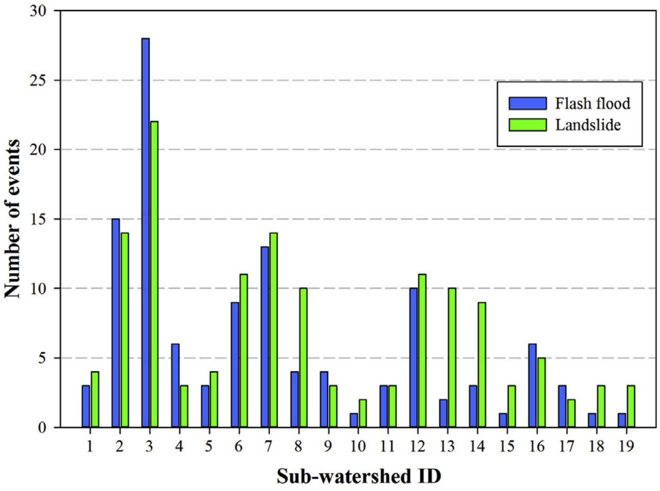


Figure 5. The number of flash flood and landslide events occurred in sub-watersheds during 2005–2018.

and Essahlaoui, 2018). However, in most of mentioned methods, prioritization of sub-watersheds was analyzed based on one special factor, one class of data (i.e., hydrological, land use, soil texture, morphometric). On the other hand, according to Mendoza and Martins (2006) and Balasubramanian et al. (2017), the result of MCDM-based methods depends on the expert's opinion, leading to emerge uncertainties resulting in deceasing accuracy. Adhami and Sadeghi (2016) demonstrated that prioritization process of sub-watersheds in the most of mentioned methods is performed based on the experts' experiences, special factor, and one class of data (i.e., hydrological, soil texture, morphometric). However, knowledge-based methods cannot address the uncertainty in the model's output (Janssen et al., 2010; Kruse et al., 2012). In addition, the main limitation in the application of these methods is the need for watershed expert knowledge (Ahmed et al., 2018; Jhariya et al., 2018). This implies an important challenge of MCDA methods for prioritizing sub-watersheds. In the case of sediment yield and erosion (SYE)-based methods, Shivhare et al. (2017) stated that these types of methods need to use data of soil erosion and sediment from hydrometric and sediment gauge stations at the outlet of each sub-watershed within the main watershed which accessibility and availability of these data in most of countries is a big challenge. Unfortunately, sediment transport modeling in data-scarce watersheds has always been difficult (Ayele et al., 2017). Therefore, developing new methods can detect and overcome these problems is one of the critical subjects to better understanding the complex mechanism of sediment yield in watershed management studies (Adhami and Sadeghi, 2016). Aher et al. (2014) reported that among these methods, morphometric characterization of a watershed can be considered as a very effective approach since: (1) it does not need any expert knowledge and gauge stations at the outlet of each sub-watershed, and (2) its required data are often readily available. They presented a new approach for the prioritization of a watershed based on the correlation between morphometric parameters, without any interference of an expert knowledge for decreasing uncertainties and accessing to reliable results. The disadvantages of mentioned methods such as lack of an accurate knowledge of criteria, relationship among the criteria, and complexity of these methods are the reasons for developing a new rational, objective and convenient solution to overcome these challenges (Toosi and Samani, 2017; Wu, 2018). Hence, this study provides a comprehensive approach to identify the most environmentally threatened sub-watersheds within the basin. Although, the proposed tool was designed based on the method of Aher et al. (2014), it considers some additional morphometric and topo-hydrologic parameters for enhancing results and overcome the above-mentioned challenges. The results presented here demonstrate that sub-watersheds 3 and 2 are most stressed, and more attentions should be paid to better manage water, soil and vegetation resources. The results of the current study well indicated that sub-watershed 03 based on the morphometric and topo-hydrologic parameters are selected as the most susceptible sub-watershed to flood. The accuracy of the SWPT was evaluated by comparing it with the results reported by Rahmati et al. (2016) who prioritized this watershed using the AHP method in terms of flood hazard potential. Their results confirmed that sub-watershed 03 was ranked as the first sub-watershed for considering in watershed management plans against floods. In fact, the SWPT tool provides efficient and reliable results for prioritization of watersheds when data availability is a challenge. These results are also similar to the study of Adhami and Sadeghi (2016) who has prioritized all sub-watersheds in this study area using game theory method. Another advantage of the SWPT model could be the availability of its source code for any purpose such as prioritization of other watersheds over the word. This model can be calibrated for other regions in order for better identification and proper management of watersheds for stakeholders, managers and planners. Furthermore, this study proved the potential of the application of The SWPT tool even in data limited and ungauged watersheds.

5. Conclusion

The prioritization of sub-watersheds of a larger basin is a crucial step for making efficient watershed management, adoption and allocation of its natural resources. Also, this task is significantly inevitable in data-scarce and/or ungauged regions because of financial resources, manpower, and time constraints. Different approaches have been used for prioritization of a watershed; however, some are inefficient, some are not applicable for some areas, and some are manually conducted. The present study introduces a new approach to determine the priority of sub-watersheds using an effective and user-friendly tool, written in Python language, running as an extension of ArcGIS 10.2 software. To present an honest approach, without uncertainty and the intervention of expert's opinion, Sub-Watershed Priority Tool (SWPT) was constructed by applying 12 different morphometric indices. The designed tool was successfully tested in a watershed since it prioritized sub-watersheds 3, 2, and 7 as peak-discharged and erosion susceptible zones, respectively, exactly in accordance with observed data. The results showed that the SWPT model is able to accurately rank sub-watersheds in order to recognize the critical sub-watersheds, more efficient than the previous models. Furthermore, according to the results and previous studies conducted in the study area, SWPT not only is able to identify the critical sub-watersheds, but also it requires less time and less cost to perform. This integrated framework and introduced tool can be utilized in other watersheds around the world for implementing management plans and adopting their protection and restoration measures in a much more cost-effective manner.

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Software and data availability

Name of tool: SWPT
Hardware required: General-purpose computer (3 Gb RAM)
Software required: ArcGIS 10.2
Programming languages: Python© 2.7
Program size: 35 KB
Availability and cost: Freely available in GitHub (https://github.com/mahmoodsamadi/SWPT.git)
Year first available: 2018

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