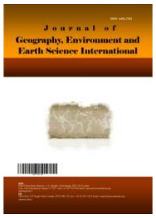

Journal of Geography, Environment and Earth Science International

25(6): 1-11, 2021; Article no.JGEESI.70795
ISSN: 2454-7352

Prioritization of Flash Flood-Prone Areas in Small Coastal Basins around the Mediterranean Using Geomorphological Variables

V. A. Kotinas[1*]

[1]Department of Geology and Geoenvironment, Section of Geography and Climatology, National & Kapodistrian University of Athens, Panepistimiopolis, Zografou, 15784, Greece.

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JGEESI/2021/v25i630289
Editor(s):
(1) Anthony R. Lupo, University of Missouri, USA.
Reviewers:
(1) Rahul Kumar Jaiswal, India.
(2) Najiba Chkir Ben Jemâa , University of Sfax, Tunisia.
Complete Peer review History: https://www.sdiarticle4.com/review-history/70795

Original Research Article

Received 02 May 2021
Accepted 08 July 2021
Published 10 July 2021

ABSTRACT

The present study aims to model flash flood risk in small coastal watersheds in areas that are characterized by Mediterranean climate through extensive morphometric analysis which can prove invaluable for the investigation of flood risk, in ungauged watersheds, where flash floods are frequent. The available topographic data (EU-DEM) are analyzed through Geographic Information Systems (GIS) to produce all the secondary variables that are necessary for this morphometric analysis. Watershed prioritization techniques that are applied on geomorphological variables have proven to be an effective way of estimating the relative flash flood risk in a sub-watershed level. A series of morphometric parameters are used (bifurcation ratio, drainage frequency, drainage density, drainage texture, length of overland flow, circularity ratio, form factor, elongation ratio) which have an effect on flood risk. In small watersheds, with intermittent runoff, this effect can be different than in larger watersheds, so our methodology differs significantly from the methodology other researchers use. The compound factor is calculated by aggregating the assigned ranks of these morphometric indices and the sub-watersheds are prioritized according to their flash flood risk. The study area is located in the island of Samos, in Eastern Greece, where flood events are usual and pose a risk to villages and infrastructure around the island. The selected watershed (Imvrasos river) is divided into several sub-watersheds (W-1 to W-8) and a series of morphometric

**Corresponding author: E-mail: vkotinas@geol.uoa.gr;*

indices are calculated and evaluated through statistical procedures and by applying prioritization techniques, in order to locate the sub-basins that have the highest risk to flash floods. Sub-watersheds W-2 and W-3 (on the southern part of Imvrasos area) show the highest prioritization values, and should be prioritized for better watershed management planning.

Keywords: Geomorphology; G.I.S; hydrology; flood risk; flash floods; morphometric analysis.

1. INTRODUCTION

River flooding is a natural process of the hydrologic cycle affecting large areas on our planet. Flash floods are common in small mountainous watersheds which are very common in southern Europe and other places around the world. The increase of the population and infrastructure near rivers, in combination with more frequent extreme rainfall events, caused by climate change, increases the flash flood hazard in these areas, making flash floods more intense and recurrent [1].

The drainage pattern and the geometry of a river system are controlled mainly by climate, lithology and topography [2], but rainfall intensity is a key factor especially in areas that are characterized by temperate climate [3]. Geomorphology and climate play a key role in areas surrounding the Mediterranean Sea: in these areas small watersheds are prevalent and runoff is seasonal [4,5], usually occurring only during storm events.

Drainage morphometric analysis of ungauged catchments can provide a dynamic tool for estimating the conditions and developing regional hydrological models at catchment or sub-catchment level in the absence of data availability and can be used to resolve different hydrological problems in river watersheds [6,7]. Through this analysis the river catchment's hydrological conditions can be identified, and the sub-watersheds can be rated based on their flood susceptibility.

The aim of this study is to understand the hydrologic behavior of flash flood prone drainage basins in small coastal watersheds in areas characterized by a temperate climate through G.I.S. analysis of the morphometric characteristics of these watersheds. By utilizing digital elevation models and GIS tools we prioritize the sub-watersheds to identify the flood susceptible area in the main watersheds of Samos Island, Greece.

1.1 Study Area

The Mediterranean Sea and the Black Sea are components of the same marine system, communicating through the Sea of Marmara [8]. On the southwest of Marmara Sea is the Aegean Sea where a complex of islands is located (most of them belonging to Greece). Samos Island is located on the Eastern part of the Aegean Sea, in close proximity to Turkey and is one of the largest Greek islands. It is located between longitudes 26° 33' 36" E and 27° 3' 36" E and latitudes 37° 48' 36"N and 37° 38' 24"N. The island is characterized by its elongated shape and its mountainous relief. The central part is characterized by two geomorphological depressions where the main river network of the island is formed. Climate is mild and wet in winter and dry in summer, with an average precipitation of 676.5 mm/year (during the period 1979-2019; [9]) and an average temperature of 18.98^{o} C for the same period of time. The streams are ephemeral, and during summer they are completely dry in most of their drainage length. In the island elevation ranges from 1234 meters to sea level (on the coast) and average elevation is ~312 meters. Average slope for the whole island is 37.2% but the central part of the island where the large watersheds are formed is characterized by relatively flat topography. Tidal range in this particular location of the world is very low (about +-5 cm; [10]) and doesn't play any significant role in coastal processes.

"Imvrasos" river (Fig. 1) flows through the largest neogene basin of the island and drains the second largest watershed of Samos (having an area of ~44km^2). It is located in the SE part of the island and its river outlet is located near the "Iraio (Heraion) of Samos", an area that is characterized as an "UNESCO world heritage site because of the significant Greek ancient monuments that were found there. This area is also a touristic attraction during summer and very sensitive infrastructure is located nearby (e.g. the international airport of Samos). The watershed can be divided to 8 sub-watersheds of 4th or higher order [11] and flood events very frequent and intense (e.g. during the years 2001, 2013, 2019) affecting the flood plain between Iraio and Pythagoreio. As a result, this study can prove invaluable to mitigate problems caused by flash floods in this area.

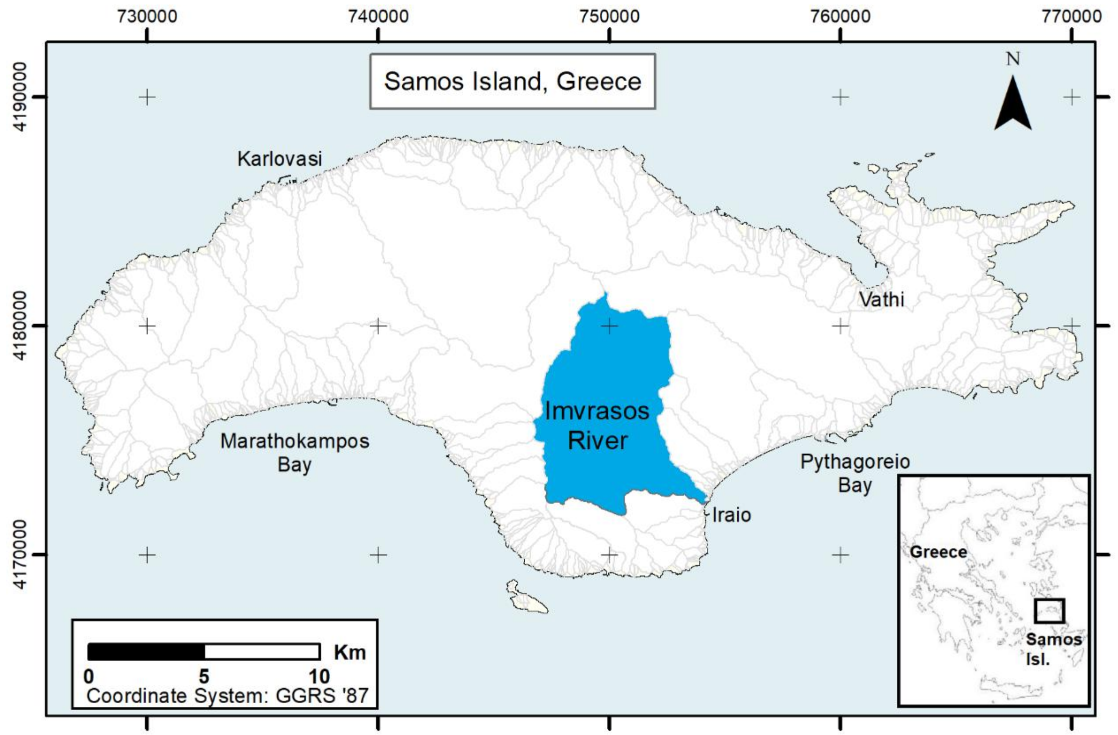

Fig. 1. The island of samos, Greece and the location of one of its largest watersheds which is drained by imvrasos river

This area is characterized by large areas used for cultivation (vineyards, olive trees, fruit bearing trees) and areas covered mainly by sclerophyllous vegetation [9]. In this particular area human interventions to the natural channel of the river are limited, mainly located near the outlet of the river.

2. METHODOLOGY

2.1 Materials

To describe the geomorphological conditions of the study area the Digital Elevation Model over Europe (EU-DEM) was used, having a grid resolution of 25 m × 25 m. Topographic maps of 1:50.000 scale were used mainly for cross-checking and correcting the EU-DEM. The DEM was processed through ARCGIS PRO and SAGA GIS software. The catchment area and the river network of 'Imvrasos' river was calculated automatically after creating a slope map, a flow direction map and flow accumulation map for the study area. The 8 sub-basins were created through a selection of pour points and GIS processing. The main topographic variables (slope, catchment area, perimeter of basin, length of basin, main channel length, max/average altitude) were obtained through G.I.S for each sub-basin of Imvrasos river. The stream order information was assigned to the various parts of the river network, after applying the ordering system developed by Strahler [11].

2.2 Methods

A detailed geo-database was created, as we have seen in the previous chapter, involving all the necessary primary variables and then we further processed the data in order to calculate the secondary morphometric parameters for the study area (e.g. drainage density, elongation ratio).

2.2.1 Basic morphometric parameters

The basic parameters of each sub-watershed were computed through G.I.S. techniques: the area (A), perimeter (P), stream order (u), basin length (L_b), and stream length of order u streams (L_u). The drainage area is considered the most significant hydrological characteristic of a watershed, reflecting the volume of water that is received during precipitation, the infiltration rate and time of concetration [12]. The stream order parameter was introduced by Horton [13] and

Strahler [11] to describe quantitively the properties of a river network. The first order stream has no tributary, and its flow depends totally on surface overland flow. Second-order stream are formed by the intersection of two first-order streams and demonstrate higher surface flow, the third-order streams form when two second-order streams are combined and so on. In the present case study, all sub-basins (Fig. 2) are of fourth-order or higher. The number of streams of various orders (N_u) for each sub-watershed was calculated and their lengths were measured. For each stream order the total length (L_u) was also calculated through G.I.S. According to Patel et al. [6], the length of a basin is crucial while studying the hydrological conditions of a watershed and high values are an indication of high drainage capacity. It has to be noted that L_b is defined as the distance measured along the main flow path from the watershed outlet to the basin divide and its calculation is more complicated than other parameters.

2.2.2 Secondary morphometric parameters

Based on the primary parameters a series of morphometric indices were calculated for each sub-watershed (Table 1). Eight secondary morphometric variables (indices) were calculated:

1) Bifurcation Ratio (R_b) is the ratio of the number of the streams of a given order to the number of streams of the next higher order [13] and is an index of relief and topographic dissection. Bifurcation ratio varies between 2 for flat catchments, and 6 for steep watersheds or watersheds with irregular drainage pattern [14] caused by lithology. Low values of this morphometric index represent higher flood risk, since water tends to gather in a channel.
2) Drainage Density (D_d) is a measure of the total length of streams in a watershed per unit area, and therefore, it is a measure of runoff potential of the catchment. Topography, climate conditions, infiltration rate and resistance of bedrock to erosion play define the drainage density in a sub-watershed. High values of D_d indicate a relatively high density of streams, high runoff, a low infiltration rate, very rapid concetration time and high runoff potential [15].

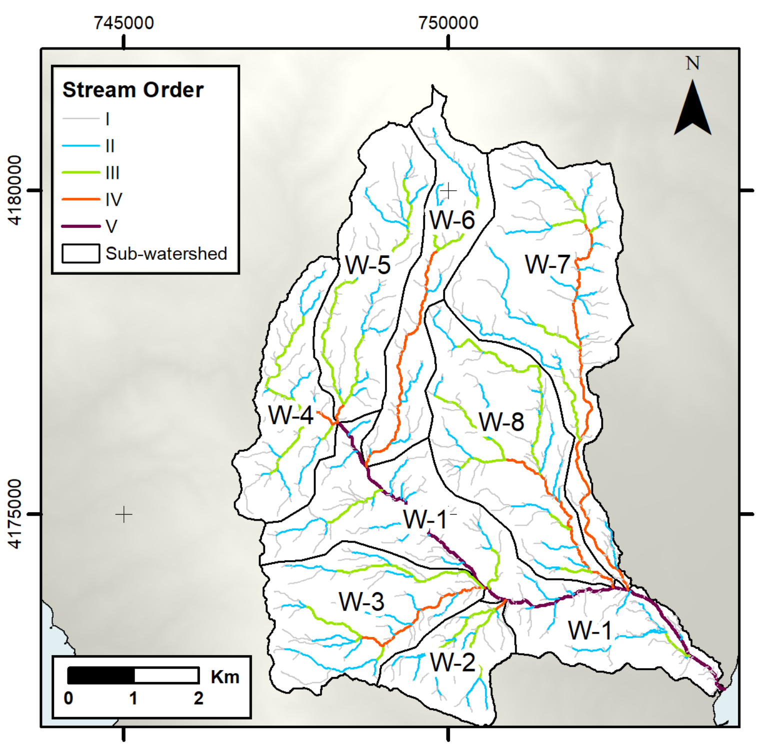

Fig. 2. The sub-watersheds of Imvrasos river and the river network stream order classified after Strahler [11]

3) Stream Frequency (F_s) is calculated as the ratio of total number of streams (N_u) in a catchment to its catchment area and is mainly related to the lithological conditions of an area [13]. The F_s value is positively correlated with the D_d value for a specific basin but a comparison can only be valid for sub-basins of comparable area [16]. Flood risk in small watersheds increases when stream frequency is high.
4) Texture Ratio (T) refers to the ratio of the total number of streams of first order (N_1) to the perimeter (P) of the basin. It combines D_d and F_s in one single variable and high values are typical for basins with increased flood risk [17].
5) Length of Overland Flow (L_g) represents the distance that water travels before it starts flowing in a definite stream channel. L_g has an inverse relationship with the average channel slope [6] and is a very important morphometric parameter for the identification of the hydrological characteristics of a sub-basin, and in particular to calculate time of concetration of water in this sub-basin. Low values of length of overland flow are correlated with low time of concentration and high flood risk.
6) Elongation ratio (R_e) is the ratio between the diameter of a circle of the same area as the sub-basin to its maximum length [18]. The values of R_e generally vary between 0.6 and 1.0 over a wide range of climatic and geological environments [14,11]. Lower values describe mountainous basins with high relief and steep slopes which are usually elongated. With increasing values of R_e the basins tend to be circular and relatively flat. Time of concetration is lower in circular basins, which tend to be more efficient in runoff [19], and flood risk is higher in these basins.
7) Circularity Ratio (R_c) is the ratio of basin area (A) to an equal sized circle that has the same circumference as the perimeter of the basin [20]. Rc is affected by many factors (length and frequency of streams, lithology, land use, climate, relief etc) and higher values are an indication of a circular shape and higher flood risk.
8) Form Factor (R_f) can be defined as the ratio of the area of a basin to the square of its maximum length [21]. The value of R_f is always less than 0.79 in the case of a perfectly circular basin. The basins with high form factor values (circular) are characterized with high peak flow of shorter duration, whereas elongated ones show a low form factor, and have a low peak flow of longer duration.

2.2.3 Prioritization of sub-watersheds

Other researchers have prioritized sub-basins of large watersheds by taking into consideration that R_b, D_d, L_g, R_f have a direct connection with flooding susceptibility [22,23,24] and the remaining variables have a reverse relation with flood susceptibility. However in small mountainous watersheds with intermittent flow this is not the case, and we use a different way of assigning ranks than in previous works of other researchers. The main difference, in this type of watersheds, comes from the fact that peak flow of a river and flood risk increases, since all water arrives at the channel rapidly rather than being stored on the landscape and in the soil [25].

Most morphometric variables have a direct connection with flood susceptibility and as a result we assigned a rank of 1 to the highest values of these variables, followed by second-rank to second highest value a third rank to the third highest value etc. The only factors that have a reverse relation with flood susceptibility in our study are the bifurcation ratio and length of overland flow. These ranks were applied because: (a) time of concetration (closely related to the shape of the sub-watershed) is very important when we examine flash floods in small watersheds and (b) infiltration rates and river drainage efficiency (closely related to the river network characteristics) define runoff potential. In the previous chapter we analyzed in details how flood risk fluctuates with different values of each morphometric variable.

We used the compound factor [6] to prioritize each sub-basin based on their morphometric characteristics. This factor is computed by aggregating the assigned ranks of the various morphometric variables and then dividing by the number of morphometric criteria used for sub-watersheds prioritization. Finally, all sub-watersheds were grouped into four priority categories based on the range of compound factor values [23,26]:

I) Very high priority (< 3.0)
II) High priority (3.0 - 3.9)
III) Moderate priority (4.0 - 4.9)
IV) Low priority (>5.0)

Table 1. Basic and secondary parameters calculation

Parameter (Units)	*Method*	Reference
Drainage Order	***U***: GIS	Strahler [11]
Drainage Area (km^2)	***A***: GIS	
Basin Perimeter (km)	***P***: GIS	
Nr. of streams in order u	$\boldsymbol{N_u}$: GIS	Strahler [11]
Length of Streams in ord. u (km)	$\boldsymbol{L_u}$: GIS	Strahler [11]
Basin Length (km)	$\boldsymbol{L_b}$: GIS	
Secondary parameters (morphometric indices)		
Bifurcation Ratio	$\boldsymbol{R_b} = N_u/N_u + 1$	Schumm [18]
Stream Frequency	$\boldsymbol{F_s} = \Sigma N_u/A$	Horton [21]
Drainage Density (km/km^2)	$\boldsymbol{D_d} = \Sigma L_u/A$	Horton [21]
Drainage Texture	$\boldsymbol{T} = D_d \times F_s$	Smith [17]
Length of Overland Flow (km)	$\boldsymbol{L_g} = A/2L_u$	Horton [13]
Elongation Ratio	$\boldsymbol{R_e} = (2/L_b) \times (A/\pi)^{0.5}$	Schumm [18]
Circularity Ratio	$\boldsymbol{R_c} = (4\pi \times A)/P^2$	Miller [20]
Form Factor	$\boldsymbol{R_f} = A/{L_b}^2$	Horton [21]

The final data are visualized through ARGIS PRO to produce the final flash flood prioritization map, which ranks the sub-watersheds according to their susceptibility to flash flooding.

3. RESULTS AND DISCUSSION

Firstly we calculated through G.I.S. the basic morphometric parameters as they were discussed in the methodology section. Imvrasos river basin has an area of ~44 km^2 as calculated by G.I.S: ranging from 3.8 km^2 for sub-watershed W-4 to 8.75 km^2 for W-1. Imvrasos river main channel is of 5th order and flows through sub-watershed W-1, while on higher altitudes we have a series of 4th order channels flowing through the rest of the sub-watersheds (W-2-W-8). This area is characterized, in most of its part, as mountainous. Average altitude is 376 meters, ranging from 215 meters (sub-watershed W-1) to 626 meters (sub-watershed W-6), while the maximum altitude is 1153 meters in the case of W-6. Average slope is 18.3^o ranging from 15.4^o (W-1) to 22.1^o (W-7). Most of the sub-watersheds are elongated with the exception of sub-watershed W-2 that is circular: the length of the sub-watersheds ranges from 2.4 km (W-2) to 7.6 km (W-1).

3.1 Morphometric Indices

We calculated the secondary morphometric parameters using the formulas presented in Table 1 for each of the sub-watersheds of Imvrasos river. The results of our analyhsis are presented in Table 2. We observe that:

- Bifurcation ratio ranges from 3.27 (W-4) to 5.73 (W-1). The circular shaped sub-watersheds (W-2-W-4) demonstrate the lowest R_b values while the elongated ones have significantly higher bifurcation ratio (e.g. W-1 has the maximum R_b value).
- Stream frequency ranges from 2.72 in sub-watershed W-6 to 5.48 in W-2, depending mainly on their lithological properties but also size. These differences between the sub-basins indicate that there are lithological differences across Imvrasos river.
- Drainage density ranges from 2.28 (W-5) and 3.03 (W-3). Sub-watersheds W-2-W-3 show significantly higher values of D_d and this is an indication that they are prone to flash flooding.
- Texture ranges from 6.45 (W-5) to 16.52 (W-2) indicating an increasing flood risk when its values are high.
- Length of Overland flow ranges from 0.17 (W-2 & W-3) to 0.22 (W-5). Circular basins tend to have lower L_g values a strong indication of high flood risk.
- Elongation ratio ranges from 0.35 (W-6) to 0.72 (W-2). Higher values are indicative of a circular basin and W-2 is the most prone area for flooding in this respect.
- Circularity ratio ranges from 0.19 for W-1 (most elongated sub-basin) to 0.50 for W-2 and W-3 which again are prone to flash flooding according to this shape index.
- Form factor ranges from 0.10 (W-6) to 0.41 (W-2). As we have seen, from other morphometric indices, form factor indicates also that the circular, small watersheds (W-

2, W-3), seem to be the most sensitive to flood events.

This morphometric analysis, takes into account all factors affecting flash floods (land cover, lithology, climate, morphology). For example the elongation ratio is representative of the prevailing climatic conditions and the underlying geology. The circularity ratio indicates the land cover in the area, climatic conditions, elevation, morphology, stream frequency and lithology. Drainage density shows the natural properties of the bedrock. Low values indicate an area where permeable lithological formations are present with well developed vegetation and low slopes. Coarse drainage texture is usual in hard rock formations and sparse vegetation, while fine texture is indicative of weathered, permeable rock and dense vegetation [6].

3.2 Priority Ranking

After the calculation of the basic and secondary variables we rank the morphometric indices, based on the methodology presented in the methods section. Stream frequency, drainage density, texture, elongation ratio, circularity ratio and form factor have a direct connection with flash floods. For these morphometric indices we rank as first priority the highest value, followed by second-rank to second highest value and so on. For the bifurcation ratio and length of overland flow we apply a reverse ranking. These ranks were applied because: (a) time of concetration (closely related to the shape of the sub-watershed) is very important when we examine flash floods in small watersheds and (b) infiltration rates and river drainage efficiency (closely related to the river network characteristics) define runoff potential. In the previous chapter we analyzed in details how flood risk fluctuates with different values of each morphometric variable. The results of our ranking procedure are presented in Table 3.

We observe that sub-watershed W-2 demonstrates first priority to most morphometric variables (F_S, D_d, L_g, R_e, T, R_f), second rank for R_b and third rank for R_c. Sub-watershed W-3 demonstrates second priority to most morphometric variables (D_d, L_g, R_e, R_c, R_f), third rank for T and fourth rank for R_b and F_S. Sub-watershed W-4 demonstrates mixed ranks, having first priority for R_b , third priority for F_S, R_e, and R_f and higher priorities for the remaining morphometric indices. Sub-watersheds W-5 & W-7 demonstrates low priority values (4 to 8) for all morphometric indices, while W-6 is assigned a third priority for bifurcation ratio and lower priorities for the other indices. Sub-watershed W-8 has high priority ranks for some of the indices (first priority for R_c , second priority for F_S and T, third priority for and D_d and L_g , forth priority for R_e and R_f and a low priority rank for R_b. Finally, the main watershed of the river (W-1) demonstrates high values in all variables.

The compound factor was calculated for each watershed and is also presented in the same table. With reference to the eight sub-watersheds of Imvrasos river, sub–watershed W-2 is given rank: 1 with the lowest compound factor at 1.38. It is succeeded by W-3 and W-8 with compound factor values of 2.63 and 3.13 respectively. Sub-basin W-1, W-5 and W-6 demonstrate high values of the compound factor.

By grouping, as discussed before, the compound factor to four prioritized ranks (Table 3) we get the final result: out of the eight sub-watersheds, W-2 and W-3 are classified as very high priority (rank I), W-8 is classified as high priority (rank II), W-4 is classified as moderate priority (rank III) and the remaining sub-watersheds are classified an low priority (rank IV).

Table 2. Morphometric Analysis on a sub-watershed level for Imvrasos river

Sub-basin	R_b	F_s	D_d	T	L_g	R_e	R_c	R_f
W-1	5.73	3.43	2.57	8.79	0.19	0.44	0.19	0.15
W-2	3.47	5.48	3.02	16.52	0.17	0.72	0.49	0.41
W-3	3.92	3.89	3.03	11.64	0.17	0.69	0.50	0.38
W-4	3.27	4.21	2.38	10.01	0.21	0.67	0.32	0.35
W-5	4.32	2.84	2.28	6.45	0.22	0.52	0.43	0.21
W-6	3.71	2.72	2.61	7.10	0.19	0.35	0.24	0.10
W-7	4.51	2.82	2.55	7.19	0.20	0.44	0.24	0.15
W-8	4.39	4.33	2.76	11.94	0.18	0.55	0.54	0.24

Table 3. Calculation of the compound factor values & priority ranking for the 8 sub-watersheds of Imvrasos River

	Rank								Compound factor	Prioritized ranks
Sub-basin	R_b	F_S	D_d	L_g	R_e	R_c	T	R_f		
W-1	8	5	5	5	6	8	5	6	6.00	IV
W-2	2	1	1	1	1	3	1	1	1.38	I
W-3	4	4	2	2	2	2	3	2	2.63	I
W-4	1	3	7	7	3	5	4	3	4.13	III
W-5	5	6	8	8	5	4	8	5	6.13	IV
W-6	3	8	4	4	8	7	7	8	6.13	IV
W-7	7	7	6	6	7	6	6	7	6.50	IV
W-8	6	2	3	3	4	1	2	4	3.13	II

The smaller, more circular watersheds in the southern part on Imvrasos river (sub-watersheds W-2, W-3) are prioritized as very high (Rank I) showing a compound factor of 1.38 and 2.63respectively. These watersheds have a low bifurcation ratio, high drainage frequency, density and texture indicating a low infiltration rate a relatively high density of streams and a very rapid concetration time which increases their runoff potential. Length of overland flow is low (about 170 meters before a channel is formed) and the elongation ratio, circularity ratio and form factor have very high values in comparison with the rest of the sub-watersheds. This is an indication of their round shape which describes the sub-watersheds that have lower slopes and are usually smaller. These watersheds present a very low concetration time of water and tend to be more efficient to runoff increasing flood risk potential. Sub-watershed W-8 demonstrates a high priority (Rank II) with a compound factor of 3.13. The shape of this basin is relatively round and the river network is well developed, leading to rapid concetration of water to its outlet.

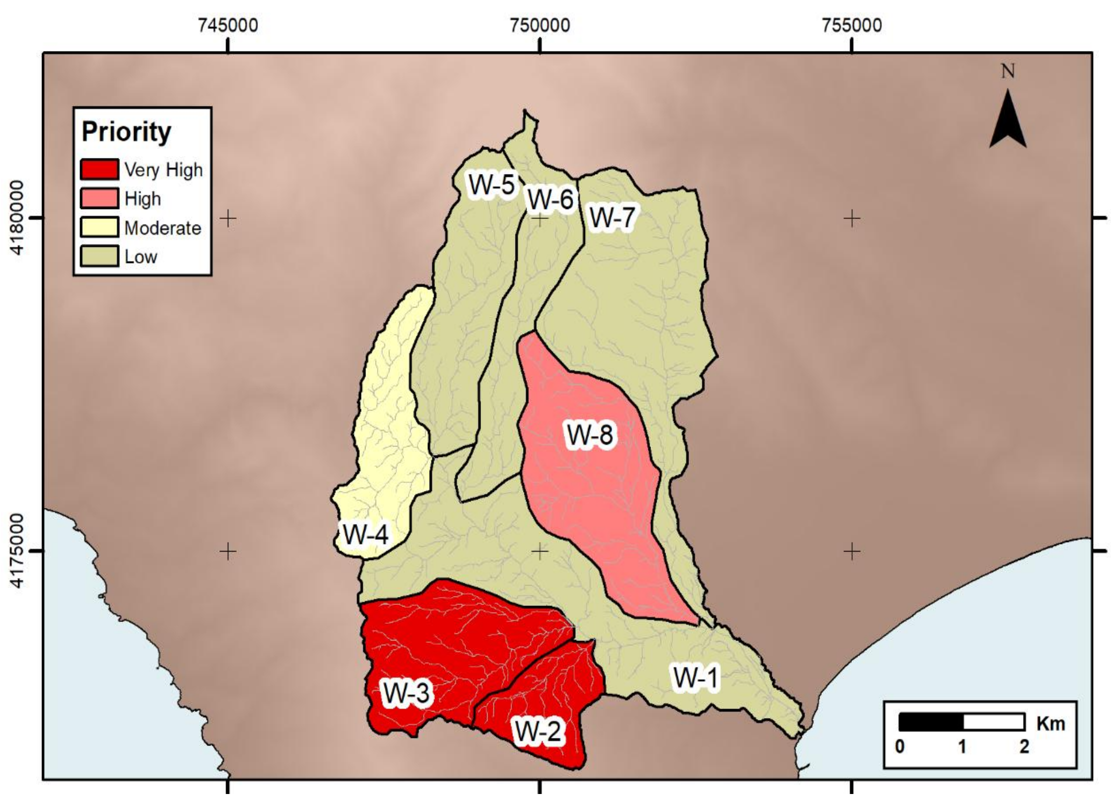

Fig. 3. Priority of Imvrasos sub-basins based on the conducted morphometric analysis

However the bifurcation ratio for this sub-watershed is high indicating that water tends to disperse amongst different smaller channels reducing the peak flow of the main channel and thus the compound factor is not as high as in W-2 and W-3. Sub-watershed W-4 has a moderate flood risk potential and is characterized as rank III. This particular sub-watershed demonstrates very high values of drainage texture and length of overland flow and this is the reason why flood risk is mitigated. The rest of the basins (W-1, W-5,W-6,W-7) are prioritized as low (Rank IV) and flood risk is relatively smaller in these basins. This is the result of a combination of: (a) an elongated shape for these watersheds that reduces time of concetration and (b) high infiltration rates (due to lithology) and not so well developed river network, reducing surface flow and as a result flood risk is lower.

4. CONCLUSIONS

This work demonstrates that the geomorphometric analysis of sub-watersheds can be a capable and easy to implement tool for their prioritization to flash flood risk. Since it is based on Digital Elevation Models, which are easily obtained for any area around the world this methodology can be applied worldwide, where many researchers have published similar works, usually for larger watersheds and rivers. In the case of small coastal watersheds with intermittent flows the ranking of the morphometric variables has to be adjusted according to the methodology that we propose in this paper. Our methodology combines, through a simple procedure, all the main factors that are controlling flash flood formation (climate, lithology, land use, geomorphology). This can be effectively implemented through G.I.S. to have a first prioritization of flash flood prone areas in a watershed. Scale of the topographic data plays a huge role for this analysis, since river network delineation is affected by scale of the DEM and subsequently all the morphometric analysis will be different for different scales. However, since we are prioritizing watersheds with the same data this problem is mitigated. In the areas that we prioritized as high, more detailed analysis (analyzing its sub-watersheds) should follow. Moreover, if actual data about land use, land management and lithology are available they can be used to improve our results.

In the current study we examined a small coastal watershed that has a rich history of flash floods (Imvrasos river, Samos island, Greece). In this area a lot of previous flash flood events have been recorded (e.g. 24/01/2019, 18/01/2010, 28/11/2001), affecting the outlet of the main channel but also upslope areas.

We divided the watershed to 8 sub-watersheds and applied our methodology through G.I.S. in order to prioritize them according to their flood risk potential by using a prioritization method for small coastal watersheds. Sub-watershed W-2 demonstrates first priority to most morphometric variables (F_S, D_d, L_g, R_e, T, R_f) and second or third rank for the rest having the highest compound factor, being classified as Very High Priority. Sub-watershed W-3 demonstrates second priority to most morphometric variables (D_d, L_g, R_e, R_c, R_f) and third or fourth rank for the rest of the variables and is also classified as Very High Priority . Sub-watershed W-4 demonstrates mixed ranks, having first priority for R_b, third priority for F_S, R_e, and R_f and priorities lower priority for the remaining morphometric indices and as a result it demonstrates a moderate to high compound factor and High flash flood risk priority. Sub-watershed W-8 has high priority ranks for some of the indices but the low priority rank for R_b mitigates the compound factor and this sub-watershed is prioritized as moderate. . Sub-watersheds W-5 & W-7 demonstrates low priority values (4 to 8) for all morphometric indices, while W-6 is assigned a third priority for bifurcation ratio and lower priorities for the other indices. These watersheds have a low priority.

We have to note that W-1 is the sub-watershed that is crossed by the 5^{th} order stream and flows to the sea, receiving water from all other sub-watersheds. In our study we examine each sub-watershed individually and rank them according to our methodology and we don't take into account the inputs of water from other sub-watersheds. This is commonly done by some researches [24] while other researchers prefer to omit the main channel watershed from their analysis [23]. However since water gathers to the outlet of sub-watershed W-1 flood risk is expected to be higher near Iraio village, and this can be confirmed by historical flash flood events. However the prioritization of upslope sub-watersheds can prove invaluable to mitigate flood risk in those watersheds but also to the main channel watershed.

Careful planning and flood prevention actions should focus to sub-watersheds W-2 and W-3 in the southern part of Imvrasos river and also to W-8 in its central part. This study can prove useful for decision makers, private and government agencies who are trying to mitigate flash flood risk in coastal small basins with intermittent flows. More detailed research can be applied to the identified Very High priority sub-watersheds to create more detailed flash flood hazard maps by combining also other variables like land use, soil type, land management techniques etc.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Westra S, Fowler HJ, Evans JP, Alexander LV, Berg P, Johnson F, Kendon EJ, Lenderink G, Roberts NM. Future changes to the intensity and frequency of short-duration extreme rainfall. In Reviews of Geophysics. 2014;52(3):522-555. Available:https://doi.org/10.1002/2014RG000464
2. Frissel C, Liss W, Warren C, Hurley M. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environ. Manag. 1986;10:199-214.
3. Georgakakos KP. Analytical results for operational flash flood guidance. J Hydrol.2006;317:81–103.
4. Borga M, Stoffel M, Marchi L, Marra F, Jakob M. Hydrogeomorphic response to extreme rainfall in headwater systems: Flash floods and debris flows. Journal of Hydrology. 2014;518(PB):194–205.
5. Gournelos T, Kotinas V, Poulos S. Fitting a Gaussian Mixture Model to bivariate distributions of monthly river flows and suspended sediments, Journal of Hydrology. 2020;590:125166. Available:https://doi.org/10.1016/j.jhydrol.2020.125166
6. Patel D, Gajjar C, Srivastava P. Prioritization of Malesari Mini-watersheds through morphometric analysis: A Remote Sensing and GIS Perspective. Environmental Earth Sciences 2013;69: 2643-2656. Available:http://dx.doi.org/10.1007/s12665-012-2086-0
7. Patton PC. Drainage basin morphometry and floods. In: Baker VR, Kochel RC, Patton PC (eds) Flood geomorphology. Wiley, USA. 1988;51–65.
8. Poulos S, Kotinas V. Physio-geographical characteristics of the marine regions and their catchment areas of the Mediterranean Sea and Black Sea marine system, Physical Geography; 2020. DOI: 10.1080/02723646.2020.1762960
9. Kotinas V. Study of Soil Erosion and Flash Flooding with the use of Artificial Intelligence (fuzzy logic, artificial neural networks) and Geographic Information Systems. A study case in the island of Samos, Greece (PhD Thesis). National and Kapodistrian University of Athens, Greece; 2020.
10. Tsimplis MN. Tidal Oscillations in the Aegean and Ionian Seas. Estuarine, Coastal and Shelf Science. 39:201-208.
11. Strahler AN. Quantitative analysis of watershed geomorphology. Trans Am Geophys Union 1957;38:913–920.
12. Costa J. Hydraulics and basin morphometry of the largest flash floods in the conterminous United States. Journal of Hydrology 1987;93:313-338. *(In press)*.
13. Horton RE. Erosional development of streams and their drainage basins; Hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America; 1945. Available:https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2
14. Strahler AN Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) Handbook of applied hydrology. McGraw-Hill, New York. 1964;439–476.
15. Patton P, Baker V. Morphometry and Floods in small drainage basins subject to diverse hydrogeomorphic controls. Water Resources Research. 1976;(12:5):941-952.
16. Magesh NS, Chandrasekar N, Soundranayagam JP. Morphometric Evaluation of Papanasam and Mainmuthar Watersheds, Part of Western Ghats, Tirunelueli District, Tamil Nadu, India: A GIS Approach. Environmental Earth Sciences 2011;64:737-381. Available:http://dx.doi.org/10.1007/s12665-010-0860-4
17. Smith KG. Standards for grading texture of erosional topography. American Journ. Sci. 1950;248:655–668.
18. Schumm S. Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin. 1956;67:597-646.

Available:http://dx.doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2
19. Singh S, Singh MC. Morphometric Analysis of Kanhar River Basin. National Geographical Journal of India. 1997;43:31-43.
20. Miller VC. A quantitative geomorphic study of drainage basin characteristics in Clinch Mountains Area, Virginia and Tennessee. Technical report, 3 Office of the Naval Research. Department of Geology, Columbia University, New York; 1953.
21. Horton RE. Drainage-basin characteristics, Eos Trans. AGU. 1932;13(1):350–361. Available:https://doi:10.1029/TR013i001p00350
22. Javed A, Khanday MY, Rias S. Watershed Prioritization Using Morphometric and Land Use/Land Cover Parameters: A Remote Sensing and GIS Based Approach. Journal Geological Society of India. 2011;78:63-75. Available:http://dx.doi.org/10.1007/s12594-011-0068-6
23. Farhan Y, Anaba O. A remote sensing and gis approach for prioritization of wadi shueib mini-watersheds (Central Jordan) based on morphometric and soil erosion susceptibility analysis. Journal of Geographic Information System. 2016;8:1-19.
24. Jothimani M, Dawit Z, Mulualem W. Flood Susceptibility Modeling of Megech River Catchment, Lake Tana Basin, North Western Ethiopia, Using Morphometric Analysis. Earth Systems and Environment; 2020. Available:https://doi.org/10.1007/s41748-020-00173-7
25. Van Meter K, Thompson SE, Basu NB. Human impacts on stream hydrology and water quality. In Stream Ecosystems in a Changing Environment. 2016;441-490. Available:https://doi.org/10.1016/B978-0-12-405890-3.00011-7
26. Nooka Ratnam K, Srivastava YK, Venkateshwara Rao V, Amminedu E, Murthy KSR. Check Dam Positioning by Prioritization of Micro-Watersheds Using SYI Model and Morphometric Analysis—Remote Sensing and GIS Perspective. Journal of the Indian Society of Remote Sensing. 2005;33:25-38. Available:http://dx.doi.org/10.1007/BF02989988

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle4.com/review-history/70795