The 3rd International Geography Symposium - GEOMED2013

The flood risk of the Yeşilirmak basin (upper course), Turkey

Türkan Bayer Altın*

Niğde University Faculty of Science and Letters, Niğde and 51100, Turkey

Abstract

This paper presents the flood potential of the sub-basins, which are located in upper course of the Yeşilirmak River, Tokat Province. This potential was determined by analysing shape indices which have been used for several decades to describe the characteristics and hydrological properties of drainage basins. These indices are Form Factor, Basin Elongation, compactness, circularity Ratio, Lemniscate ratio and shape index. Drainage networks for sub-basins were prepared with a topographic map scaled 1/25000 and 10-m resolution DEM using GIS. The study area was divided into six sub-basins. The shape indices show that six sub-basins have an elongated shape causing low-magnitude peak flood. In spite of a moderate amount of rainfall and elongated shapes, the main problem of this area is that it has been subjected to flood since 1950. The results indicate that the steep slopes, impermeable lithology and thick vegetation accelerate the flow of rainfall. In other words, flood events are also formed in an elongated basin. This result will help in better understanding relationships between the flood events and basin shape for basin area planning and management.

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Keywords: Tokat Province; Yeşilirmak River; Flood Potentiality; Basin characteristic; Shape indices

1. Introduction

Flooding potential is one of the critical factors for a hydraulic structure design (Sorrell, 2003). In general, the watershed characteristics can be identified by basin shape indices, channel geomorphology and physical hydrological parameters (Tantanee and Prakarnrat, 2006). Clearly, the shape and character of a stream flood

* Corresponding author. Tel.: +905387364916; fax: +903882112100.
E-mail address: turkanaltin@yahoo.com

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doi:10.1016/j.sbspro.2014.02.125
hydrograph should be affected greatly by the manner in which a basin collects and routes water through its network (Ritter, Kochel and Miller, 1995). The application of geomorphic principles to flood potential has led to a noteworthy amount of research attempting to identify relationships between basin morphometry and stream flooding (Patton and Baker, 1976; Patton, 1988). Morphometric characteristics of drainage basins provide a means for describing the hydrological behaviour of a basin (Bardossy and Schmidt, 2002). Evaluation of the shape indices used in drainage basin morphometry necessitates establishing correlations between flood potential and basin shape. Most authors have defined flood potential using shape indices (Horton, 1932; Chorley, 1957; Bardossy and Schmidt, 2002; Senadeera, Piyasiri and Nandalal, 2004) Others have used both morphometric parameters and shape indices (Verstappen, 1983; Kumar et al., 2000; Singh, 2006; Vijith and Satheesh, 2006; Thakkar and Dhiman, 2007; Monsef et al., 2008; Nageswara et al., 2010; Onosemuode et al., 2010; Bayer Altun and Altun, 2011; Mishra et al., 2011; Das, Mondal and Das, 2012; Senthilvelan, 2012; Altaf et al., 2013). Drainage characteristics of hydrographical basins and sub-basins in many areas of the world were studied using conventional geomorphological approaches (Horton, 1945; Strahler, 1964; Rudriaiah, 2008; Negeswara et al., 2010).

In this study, the upper course of Yeşilirmak River basin was divided into six sub-basins and their potentiality was investigated using GIS. Shape indices of drainage networks were applied to these sub-basins to examine the effect of basin shape on flood and assess them with regard to the flooding effect on the main channel. The purpose of the study is to evaluate the flood potentiality areas, which can be considered as one of the most important natural hazards in the Yeşilirmak Basin, and provide information about floods in drainage networks in the surrounding area of Tokat, using shape indices.

2. Study area

The study area covers the upper course of the Yeşilirmak River Basin located within the southern Middle Black Sea Section (Fig. 1). This basin is situated between the coordinates 29°40’ N, 31°40’ N and 44°71’ E, 44°61’ E (UTM, ED 50, Zone 36 N) in the southern part of Tokat province, Northern Turkey. This area is located between Tokat Province and Almus Dam and covers an area of approximately 165km². The study area generally consists of the valleys that have collapsed because of faulting and plains lying within valleys. Furthermore, the area is found in the North Anatolian Fault Zone (NAFZ), which causes landforms having significance from tectonic and morphologic points of view.

The study area is affected by both the Black Sea climate and steppe climate because it is situated within interior part of the Middle Black Sea section. Annual rainfall is 443mm usually received during the months of May and April. Annual temperature is 12°C. The hottest month is July with an extreme maximum temperature of 40°C. The coldest month is January with an extreme minimum temperature of -23.4°C. Snow cover duration is 21 days and the number of days with snow is 13 days (DMGM, 2013). Predominantly flowing from east to west, the Yeşilirmak River is the main river in the study area. Its tributaries Yelpe, Kılıç and Şenköy streams enter the main channel from the north, while the Ağacaköy, Kuru and Korucuk streams join from the south.

According to a field trip, forestland covers upland of the valleys which consist of Pinus nigra, Fagus, some species of oak (Quercus sp.) and steppe species (Verbascum sp., Euphorbia sp.). Natural vegetation was restricted to high rocky areas and inner valleys due to forming agriculture areas and ensuring firewood. The great part of the sub-basins to be unsuitable to agriculture is found inclined down to the main river.

Flooding occurred around Tokat Province in the years of 1908, 1949, 1951 and 1955. The largest disaster occurred in 1908. During this flood, bridges, more than a thousand houses and shops were destroyed, and two thousand people were killed. Erosion control works were launched in the basins located around Tokat Province in 1955 and flood disasters have been partly prevented since then (Üzen, 2010; OGM, 2013).

Geologically, the study area is situated within Tokat Massive, which is a major metamorphic complex of the south-central Pontides (Yılmaz et al., 1997). Four types of lithological units are found in the study area. These rocks are metamorphic basement rocks of Paleozoic-Mesozoic, basic and ultrabasic rocks of Mesozoic, continental clastic rock of Tertiary, alluvium of Quaternary (Yılmaz and Yılmaz, 2004) (Fig.2). Basement rocks such as shist, phyllite, marble are exposed north and south of the Yeşilirmak River. A lower coherent metamorphic sequence and an upper blocky volcano-sedimentary series have undergone low grade greenschist facies metamorphism, and bears imprints
of the Alpide and Cimmeride orogenies (Şengör, 1987). Gravel, sand, silt and clay and the transported younger alluvium lie along the Yeşilirmak River and its tributary.

Fig. 1 Location of the study area

Fig. 2. Geology map of the study area.
3. Methodology

The drainage network was obtained from Turkey topographical maps on scale 1/25000 that were registered using UTM projection plane, which is the national co-ordinates system of the topographic maps. Furthermore, the drainage network was extracted from the 10-m resolution DEM (Digital Elevation Model) using GIS (Geomorphologic Information System).

Using the shape indices for drainage basins, the most well-known are probably the Compactness index, C (Gravelius, 1914), the Form factor, F (Horton, 1932), the Basin Circularity, c (Miller, 1953), the Basin Elongation, E (Schumm, 1956), the Lemniscate ratio, K (Chorley, Malm and Pogorzelski, 1957) and the Shape index, SW (Horton, 1945) (Table 1). The compactness index, C is defined as the ratio between the length of the drainage basin boundary (the perimeter) and the perimeter of a circle with the same area. It is always greater than 1 and approaches unity when the basin approaches a circular shape. While C and c combine the perimeter and the area of the drainage basin, SW, F, E and K combine the basin length and area (Bardossy and Schmidt, 2002). The shape of the drainage basin along the length and relief affect the rate of water and sediment yield (Gregory and Walling, 1973). Namely, SW, F, E and K have direct relation to the stream flow and the shape of the watershed (Vijith and Satheesh, 2006). Furthermore, the relationship between flood potential, slope and geological units are evaluated for sub-basins.

Table 1: Shape indices mathematical expressing drainage basin shape. A is the drainage area in km², L is total length of streams in km (for shape index, the meandering curve is not measured). P is Pi value 3.14. P is perimeter of drainage area.

<table>
<thead>
<tr>
<th>Index</th>
<th>Formula</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compactness</td>
<td>$C=\pi P/2A$</td>
<td>Gravelius, 1914</td>
</tr>
<tr>
<td>Circularity ratio</td>
<td>$c=4\pi A/P^2$</td>
<td>Miller, 1953</td>
</tr>
<tr>
<td>Form factor</td>
<td>$F=A/L^2$</td>
<td>Horton, 1932</td>
</tr>
<tr>
<td>Basin elongation</td>
<td>$E=2\sqrt{A}/L\sqrt{\pi}$</td>
<td>Schumm, 1956</td>
</tr>
<tr>
<td>Lemniscate ratio</td>
<td>$K=L^2/4A$</td>
<td>Chorley et al., 1957</td>
</tr>
<tr>
<td>Shape index</td>
<td>$SW=L^2/A$</td>
<td>Horton, 1945</td>
</tr>
</tbody>
</table>

4. Results and discussion

4.1. Elevation and slope

The mean height of the study area is 1072m above sea level (asl). The elevation of the sub-basins varies from 600 to 1780m (asl) and ranges from 1200-1800m (asl), which is mainly associated with hills and upstream of narrow valleys. The slope of the sub-basins results from the undulating topography of the area.

Flooding occurs in mountainous areas with steep slopes causing the water to flow at high speeds. The majority of the study area is under moderately steep slopes (10-20%) and steep slopes (20-30%). These slopes in the study area occupy 28% and 21%, respectively, and occur largely in the southern and south-eastern part of the study area. Very gentle (0-2%) and gentle (2-5%) slopes that are observed along the main valley, occupy approximately 24% of the study area. The very steep slopes (+30%) causing high velocity of the flow correspond to hillsides of the valleys and occupy approximately 9% in the study area (Table 2). The highest slope values occur in Korucuk sub-basin followed by Kuru sub-basin. The steep slopes (20-30%) occupy 58% and 56% of these subbasins located within the southern study area. The moderate slope (5-10%) is observed in Kılıçlı, Şenköy and Yelpe sub-basins located within the north part of the study area. This slope occupies 67% of Şenköy sub-basin, 63% of Yelpe sub-basin and 53% of Kılıçlı subbasin.

An index of drainage shape is computed as a unit-less dimension of the drainage area divided by the square of basin length (Horton, 1932). It describes the elongation of the basin and is useful for comparing basins (Gallgher, 1999). If two basins have the same area, the more elongated basin will tend to have smaller flood peaks, although longer lasting flood flows (Gregory and Walling, 1973). With the help of the authors’ determinations, below flood potential of basins is evaluated by taking basin shape into consideration.
Fig. 3. Slope map of the study area

Table 2 Showing basin characteristics derived from topography map

<table>
<thead>
<tr>
<th>Subbasin</th>
<th>P (Km)</th>
<th>A (Km²)</th>
<th>L(Km)</th>
<th>C</th>
<th>c</th>
<th>F</th>
<th>E</th>
<th>K</th>
<th>SW</th>
<th>5-10</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>+40</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yelpe</td>
<td>21</td>
<td>16,8</td>
<td>8,6</td>
<td>1,44</td>
<td>0,47</td>
<td>0,22</td>
<td>0,53</td>
<td>1,1</td>
<td>2,9</td>
<td>5,7</td>
<td>4,1</td>
<td>2,6</td>
<td>0,7</td>
<td>0,05</td>
<td></td>
</tr>
<tr>
<td>Kılıçlı</td>
<td>15,2</td>
<td>10</td>
<td>7</td>
<td>1,36</td>
<td>0,53</td>
<td>0,04</td>
<td>0,23</td>
<td>1,2</td>
<td>3,6</td>
<td>3,3</td>
<td>3,2</td>
<td>2,1</td>
<td>0,5</td>
<td>0,06</td>
<td></td>
</tr>
<tr>
<td>Şenköy</td>
<td>22,1</td>
<td>15</td>
<td>9,4</td>
<td>1,61</td>
<td>0,38</td>
<td>0,16</td>
<td>0,46</td>
<td>1,4</td>
<td>5,4</td>
<td>5,1</td>
<td>5,1</td>
<td>2,2</td>
<td>0,7</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>Korucak</td>
<td>41,8</td>
<td>55</td>
<td>17</td>
<td>1,59</td>
<td>0,39</td>
<td>0,19</td>
<td>0,49</td>
<td>1,3</td>
<td>4,3</td>
<td>12,4</td>
<td>17,2</td>
<td>14,9</td>
<td>5,2</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Kuru</td>
<td>31,5</td>
<td>32,7</td>
<td>12,8</td>
<td>1,55</td>
<td>0,41</td>
<td>0,19</td>
<td>0,5</td>
<td>1,2</td>
<td>3,7</td>
<td>5,6</td>
<td>9,1</td>
<td>9,4</td>
<td>5,2</td>
<td>1,4</td>
<td></td>
</tr>
<tr>
<td>Ağacaköy</td>
<td>14,3</td>
<td>7</td>
<td>6,2</td>
<td>1,54</td>
<td>0,42</td>
<td>0,17</td>
<td>0,47</td>
<td>1,4</td>
<td>5,1</td>
<td>1,7</td>
<td>2,4</td>
<td>1,5</td>
<td>0,2</td>
<td>0,03</td>
<td></td>
</tr>
</tbody>
</table>

4.2. Basin shape index

The value of *form factor* varies from 0 (highly elongated shape) to 0.78 (perfect circular shape) (Horton, 1932). If the form is multiplied by the multiplier 1.27, the index would have a value of 1, corresponding to a circular shape, with values ranging down to zero, with distortions away from a circle. Therefore the higher the value of form factor the more circular the shape of the basin and vice versa (Senthilvelan et al., 2012). The form factor values (Table 2) in the area of interest varies from 0.04-0.22 in all the sub-basins. These sub-basins with low values represent an elongated shape. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than the circular basin (Negeswara, et
The sub-basin with the smallest the value of form factor is the Kılıçlı sub-basin. This sub-basin is more elongated than the other.

According to Schumm (1956) the shape of any drainage basin is expressed by the elongation ratio (E), which is the ratio between the diameter of a circle with the same area as the basin and the maximum length of the basin. Similar to the elongation ratio Miller (1953) used a measure which is the ratio of circumference of a circle with same area as the basin to the basin perimeter. The value of elongation ratio generally varies from 0.6 to 0.1 associated with a wide variety of climate and geology (Strahler, 1964). Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope (Dar et al., 2013). These values can be grouped into four categories, viz., circular (>0.9), oval (0.9-0.8), less elongated (0.8 to 0.7), and elongated (<0.7) (Sentivelan et al., 2012). In the study area, value E for the sub-basins is less than 0.7 (Table 2). This value indicates that sub-basins are elongated with high relief and steep slope. Therefore, sub-basins show delayed time to peak flow. According to Horton (1932), the ideal form of a drainage basin developed on initially sloping ground closely resembles a pear or drop shape. The sub-basins in the area can be assumed to have non-ideal shaped characteristics.

Miller (1953) defined that the basin of the circularity ratios (c) range 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geologic materials, land use/cover, climate, relief and the slope of the basin. In the study area, values of circularity ratio for sub-basins are in the range of 0.53 to 0.38 indicating that the area is characterised by high relief, elongated resulting in greater basin lag times, although these sub-basins have impermeable surface. In this case, the low values of the circularity ratio (below 0.6) of the sub-basins do not corroborate Miller’s range, which indicated that the basin is elongated in shape. In the study area, the sub-basins associated with low values of c are prone to low flood hazard hardly noticeable at a particular point of time at a place, for the peak period of concentrated flow of flood in such cases hardly occurs at an outlet point (Singh, 2006).

The Compactness ratio (C) is equal to unity when the basin shape is a perfect circle, increasing to 1.128 in the case of a square, and may exceed 3 for a very elongated basin (Zavoianu, 1978). C of the studied sub-basins is found to be higher than unity (from 1.36 to 1.61), which suggests that the shape of the basin is elongated (Table 2). If C is greater than 1, basin shape is deviated from circular nature of the basin (Altay, Meraj and Romshoo, 2013). In this case, Şenköy, Korucak, Kuru and Ağacaköy sub-basins have the greatest deviation from circular nature and longest time of concentration before peak flow occurs in the sub-basins out of all the sub-basins in the study area.

The Lemniscate ratio (K) indicates the extent to which the shape of a basin approaches that of an ideal lemniscate and for a circle, its value is equal to unity. If value K is above unity the basin shape happens to be elongated (Zavoianu, 1978). The values for all the sub-basins range from 1.1 for Yelpe sub-basin to 1.4 for Şenköy and Ağacaköy, 1.2 for Kılıçlı and Kuru sub-basins, 1.3 for Korucak sub-basin (Table 2). K is expressed to determine the slope of the basin (Chorley et al., 1957). It will affect flow velocity of water and sediment yield.

The shape index (SW) values for sub-basins of the study area range from 5.4 to 2.9 (Table 2). These values mean shape of the basin is developing in length and width ratio and prone to extend drainage channels more to the width side from the north and south directions than the east and west directions. In terms of SW, all sub-basins will have a longer basin lag time. If the basin shape differs from the shape of a circle, the value increases again to reach unity for very elongated basins.

5. Conclusions

The quantitative analysis in terms of compactness ratio, circularity ratio, form factor, elongation ratio, lemniscate ratio and shape index together reveals that six sub-basins have an elongated shape with low run-off. This indicates that sub-basins will show delayed time to peak flow. In past and nowadays, forming flood events can be associated with impermeable lithology, steep slope, undulating topography and thick vegetation. These features of sub-basins cause about high run-off and peak flow. The greater the degree of slope increase, the more the flood risk increase whatever shape of the basins. In other words, the degree of slope is directly proportional to the flood risk. In this case, Korucak and Kuru sub-basins having high slope values have high flood potential after rainfall, despite these sub-basins being elongated in shape. The results of the study show that elongated shape does not reduce the flood possibility in a basin. Therefore, the results of this study are important from a land use planning and conservation point of view and will guide informed decision making for flood event risk reduction around Tokat Province.
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