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Hydrographic analysis of Iluh River (Batman) in relation to flood and torrent events

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Abstract

Iluh River, which flows through Batman city, Turkey, overflows almost every year and gives damage to its surrounding environment. The side branches that are linked to Iluh River in the city center cause flood events. The flood and torrent events experienced in the autumn of 2006 due to Iluh River and its branches caused 10 deaths and material damage of about 15 million Euros. Besides human factors, the hydrographic characteristics of Iluh River are also effective on the occurrence of such catastrophic flood and torrent events. The analyzing of these characteristics and determination of their effect on the occurrence of flood and torrent events are of utmost importance for Batman city. The basin of Iluh River, which has a pyramidal shape and seasonal flow, covers an area of 316 km². In this study, morphometric and hydrographic analyses were made on digital maps in order to reveal the hydrographic characteristics of the basin. GPS measurements were performed with granulometry and infiltration experiments in field surveys. The results of the analyses reveal that the slope is low, the stream intensity is high, the soil is clayey, and the infiltration capacity is low in the basin of Iluh River. Furthermore, it was shown that the rivers in the city had shifted outside their natural streambeds and the canal constructed on Iluh River was designed according to the basin area and maximum flow rate. Such factors and the basin are among the hydrographic characteristics which give rise to flood and torrent events of great intensity and frequency in the city.

Keywords: Batman city, Iluh River, flood and torrent, hydrographic characteristics

1. Introduction

Hydrographic analyses conducted in various regions of the world are evaluated within the scope of Fluvial Geomorphology. Researchers involved in the field of fluvial morphology, the foremost being Horton [1] and Strahler [2] have examined the fundamental laws of fluvial morphology via hydrographic analyses. The major studies in this regard in Turkey were carried out by Atalay [3] and Hoşgören [4]. In recent years, fluvial morphology, especially hydrographic analyses, have been performed on DEM images using Geographical Information System (GIS) methods. Hydrographic analyses on a basin basis are so far limited in Turkey. A large number of these investigations do not include flood studies but are based on morphometric and digital analyses [5, 6, 7, 8, 9, 10].

Hydrographic analyses made on a basin scale reveal the general characteristics of that basin. Such analyses are of importance with regard to flow and thus rank first in flood and torrent city protection works. Measures to be carried out for protection of settlements are determined according to these characteristics. In order to explain the flood and torrent events occurring with increasing frequency in urban areas in the last two to three decades, basin-wide works must be carried out. This study examines the effect of the hydrographic characteristics of the basin of Iluh River on the occurrence of flood and torrent events with increasing incidence rate and frequency in last two to three decades. Other characteristics of the basin which are of importance with regard to the occurrence of flood and torrent events were evaluated in different studies [11, 12, 13].

2. Study Area

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Iluh River is a seasonal stream which drains the waters of an area located between Kira Mountain and Raman Mountain in the Southeastern Anatolia Region. This river is linked to Batman Stream to the west of Batman city (Fig. 1). With its pyramidal shape, the river collects the waters of an area of 316 km². The wide basin area and seasonal characteristics of the river are of utmost importance with regard to the occurrence of flood and torrent events following downpours.

Fig. 1. Location map of Iluh River.

Batman city was founded in an area of Iluh River which was once not linked to Batman Stream. The city developed rapidly and became a medium-sized industrial city after 1970. From then onwards, an increase was observed in the incidence rate and frequency of flood and torrent events causing great loss of life and property. The flood and torrent events occurring almost every year in the city after intense precipitations are based on Iluh River and its branches. The last catastrophic flood and torrent event experienced on October 31 to November 1, 2006 resulted in 10 deaths and material damage totaling millions of Turkish liras.

3. Methods

In order to determine the hydrographic characteristics of the basin of Iluh River, analyses were performed via digital maps (Fig. 2) using field observations and surveys and Geographical Information System technologies. In recent years, DEM (Digital Elevation Model) images have been widely used for performing hydrographic analyses [14].

Fig. 2. Basin of Iluh River according to DEM (Digital Elevation Model).

Granulometry experiments were performed in order to determine the type of soil which directly affects the flow. Infiltration experiments were made for the purpose of finding infiltration capacity. Soil samples were taken from 11 different points to find the granulometry of the basin of Iluh River and these samples were analyzed in the ground laboratory. Furthermore, the infiltration capacity of the basin was measured by performing infiltration experiments at 6 different points.

Measurements were performed on Iluh River via portable GPS device and profiles were extracted. Slope and profile analyses were made on digital maps using ArcGIS 9.2 in the GIS analyses. Thus, the intensity and bifurcation ratios of the stream were calculated. The low slope in a major part of the basin of Iluh River and wide coverage area of the settlements complicates the drawing of flow lines DEM (Fig. 2). Therefore, a hydrographical map digitalized topographical map with a scale of 1/25,000 was used in order to calculate the stream intensity and bifurcation ratios.

According to findings obtained as a result of hydrographic analyses, Hec-RAS modeling was performed for the part of Iluh River which remains in the city center. With these analyses and studies, the effect of Iluh River on the occurrence of flood and torrent events experienced in Batman was determined.

4. Hydrographic Characteristics of Iluh River
The hydrographic characteristics of a stream basin are determined according to various digital parameters. In global studies performed within the last three decades, different hypotheses were used in order to model of damping effect [15, 16, 17, 18, 19]. Most of these studies are based on classification of the branches in the stream basin according to the model developed by [20]. Şen [21] stated that infiltration is the most important characteristic, especially in arid and semi-arid regions. Consequently, the importance of the stream network and infiltration capacity was revealed by various models in hydrographic analyses. Although the amount of precipitation in Batman is low, flood and torrent events occur frequently. This is due to the low infiltration capacity of the basin of Iluh River. According to the results of infiltration experiments, the infiltration capacity of the basin is 28.9 mm/h. Considering the 16 kg precipitation falling within 15 minutes in Batman on 31st October 2006, it may be stated that the basin is of high risk with regard to flood and torrent events.

The area of Iluh River which drains the waters of an area located between Kıra Mountain and Raman Mountain is 220,468.982 m² at the entrance of Batman city. The total basin area of the river is 316,793.423 m². This value was found according to calculations performed with an original topographical map. The basin area was calculated as 306.22 km² in processes on DEM.

The drainage network of the pyramidal-shaped basin of Iluh River is dendritic. Various characteristics of the dendritic drainage type are based on the density or sparsity of the stream network, precipitation, permeability, slope and time. Time is of utmost importance with regard to the density degree of dendritic drainage (Erinç and Bilgin, 1956).

Other striking characteristics with regard to flooding were also established in the stream bed of Iluh River during field observations. Most important is that the stream uses different streambeds in normal times and in flood periods. Iluh River is located within its natural stream bed in the upper basin and thus does not give damage to the environment in flood periods (Fig. 3a). On the other hand, the river becomes incapable of carrying water in the lower basin and this leads to flood events due to sediment aggregation in the streambed, distortions in coastal areas, and human interventions in the streambed (Fig. 3b).

![Fig. 3. Valley of Iluh River. a) The valley of Iluh River located to the east of Binatlı has the capacity to carry maximum water in the basin. b) The condition of Iluh River at the entrance to Batman city after the flood event in 2006. As a result of interventions in the streambed of Iluh River, an increase was observed in flood and torrent events.](image)

The branches which previously converged on the older area of the city now cannot be discharged into Iluh River due to urbanization. The most important river affecting Batman city is Iluh River. This is followed by Çay River. Other side rivers include Savaro, AŞağıkonak and Şakuli rivers. Except for Iluh River, the stream beds of all other branches no longer exist in the city due to urban development.

4.1. Slope Analysis

The degree of topographic surface slope affects runoff and flow amount. The evaporation and penetration in a field decreases as the slope increases. Therefore, the water loss of the stream on these paths is minimized [4].

When the slope map of Batman city and its surroundings is examined, it is noted that the slope regularly increases from the bottom of the basin towards the mountainous areas in the surroundings (Fig. 4).

The slope in the bottom of basin, which covers a wide area, gets considerably low values ranging from 0% to 12%. The slope is not so high on the hillsides other than the bottom fields. This characteristic of Iluh River basin is generally considered an advantage with regard to flood and torrent events. However, the impervious and argillaceous structure of the soil in the basin has eliminated this advantage. In fact, the precipitation waters accumulating in the main streambed due to the low slope spread to the environment and affect an extensive area.
4.2. Profile Analysis

Two different profile analyses were made in the basin of Iluh River according to digital maps and land measurements. The longitudinal profile of Iluh River extracted via digital maps has a structure similar to the graded profile. The longitudinal profile of Iluh River (except for the spring area) is considerably aslope and there exist no apparent slope faults (Fig. 5). The aslope nature of the longitudinal profile makes it easy for waters starting to run off following downpours to overflow the streambed and give damage to the environment. The aslope characteristic of the longitudinal profile of Iluh River is of importance with regard to flood events.

Fig. 5. Longitudinal profile of Iluh River.

As a result of GPS measurements performed on the part of Iluh River streambed which remains in the city center in order to determine transverse profiles, it was found that Iluh River flows outside its natural streambed (Fig. 6). The flowing of rivers in urban areas outside of their natural streambeds is based on changes in morphological structure as a result of urbanization.

4.4. Stream Bifurcation Ratio and Intensity Analysis

Under this heading are included aspects such as the shape of the basin, length of streams, stream bifurcation ratios, and stream intensity. The bifurcation ratios of streams in the basin of Iluh River were calculated according to the model developed by Strahler [20, 3]. Considering the basin and drainage system of Iluh River, the following results were obtained:
The stream network and basin shape are directly effective on the runoff of precipitation waters and thus cause flood and torrent events. Equal or close values for the width and length of the stream basin, the convergence of side branches close to the main branch, and a high number of side branches have a triggering role on the occurrence of flood and torrent events [3].

The duration of flooding is lower but the peak flow rate is higher when the stream basin is wide and spread [23].

As previously stated, the basin of Iluh River has a pyramidal shape and a typical dendritic drainage network (Fig. 7). Due to this structure, the waters starting to run off are simultaneously accumulated in the main streambed and cause flood events in the city. Various coefficient applications are employed to determine the shape of basin. The calculation of shape coefficient is among these applications \((\text{Shape coefficient} = L^2/A)\). The ratio of the square of thalweg length \((L^2)\) to the basin area of a stream \((A)\) gives the shape coefficient. As the value obtained according to this formula increases, the basin gets narrower and longer. The value of shape coefficient for Iluh River is as follows:

\[
\text{Shape coefficient} = \frac{(31.2)^2}{306.22} = 3.17.
\]

As this value is not so high, there is not much difference between the width and length of the basin. This is of importance with regard to the occurrence of flood events.

As the length of rivers in the north is correspondingly equal to those in the south of Iluh River, the waters starting to run off in the upper basin are simultaneously accumulated in the main streambed. Likewise, the thalweg divides the basin into two equal parts and this also contributes to the accumulation of waters in the main streambed (Fig. 8). There is no clearly apparent asymmetry in the basin of Iluh River. The asymmetry in drainage basins reveals the effect of tectonics on the development of basins. The asymmetry index of the drainage basin \(T = \frac{D_a}{D_d}\) is frequently used in order to determine the effect of tectonics on the development of basins [24, 25]. \(D_a\) denotes the distance between the basin midline and active meander belt and \(D_d\) denotes the basin midline and watershed. According to this formula, the transverse topographic asymmetry of the basin of Iluh River is close to 0.

The basin of Iluh River was divided into two parts, north and south (Fig. 8). Then, bifurcation ratios and the length of stream (km) per km² were calculated in both parts (Table 1, 2).
Table 1. Stream intensity ratio in basin of Iluh River.

<table>
<thead>
<tr>
<th>Stream Intensity</th>
<th>Area (km²)</th>
<th>Length of stream (km)</th>
<th>Length of stream (km) per km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>172.14</td>
<td>433.42</td>
<td>2.52</td>
</tr>
<tr>
<td>North</td>
<td>134.07</td>
<td>304.86</td>
<td>2.27</td>
</tr>
<tr>
<td>Basin of Iluh River</td>
<td>306.22</td>
<td>738.27</td>
<td>2.41</td>
</tr>
</tbody>
</table>

Table 2. Stream bifurcation ratio in basin of Iluh River.

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of bifurcation points</th>
<th>Number of bifurcation points per km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>348,00</td>
<td>2.02</td>
</tr>
<tr>
<td>North</td>
<td>231,00</td>
<td>1.72</td>
</tr>
<tr>
<td>Basin of Iluh River</td>
<td>579,00</td>
<td>1.89</td>
</tr>
</tbody>
</table>

It is observed that the bifurcation ratio is high in the north of West and East Raman mountains and in the north of Batman city (Fig. 9, 10). This causes the stream network to become dense and precipitation falling in these areas to be accumulated in the main branches in a short time.

The length of the basin is 1.5 times more than its width (Fig. 7, 8). Basins where this value (regarded as the number of forms) is 1 or higher are regarded as basins of high risk with regard to flood events [26, 3, 27, 28, 5, 29].

4.5. Flow Analysis

All of the streams in the basin are seasonal due to the climatic characteristics of the area and low flow rate of spring waters. As Iluh River has a seasonal flow pattern, regular flow data is not available. In such streams, the flow is calculated according to precipitation [30], slope, soil structure, natural vegetation and overall land use. These data were used for the calculation of flow in the basin of Iluh River.

The flood flow rates of rivers affecting Batman city were calculated by DSI X. Regional Directorate [31] according to their occurrence probability every 2, 5, 10, 25 and 500 years (Table 3).

Table 3. Flood flow rates of rivers affecting Batman city (DSI X. Regional Directorate Report 2006).

<table>
<thead>
<tr>
<th>Area</th>
<th>Q2 (m³/s)</th>
<th>Q5 (m³/s)</th>
<th>Q10 (m³/s)</th>
<th>Q25 (m³/s)</th>
<th>Q50 (m³/s)</th>
<th>Q100 (m³/s)</th>
<th>Q500 (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iluh River (At city entrance)</td>
<td>6.61</td>
<td>25.68</td>
<td>43.66</td>
<td>70.78</td>
<td>93.79</td>
<td>118.48</td>
<td>169.8</td>
</tr>
<tr>
<td>Iluh River (At city exit)</td>
<td>9.30</td>
<td>33.04</td>
<td>55.29</td>
<td>88.61</td>
<td>116.74</td>
<td>146.84</td>
<td>209.3</td>
</tr>
<tr>
<td>Çay River</td>
<td>2.79</td>
<td>10.26</td>
<td>17.20</td>
<td>27.58</td>
<td>36.35</td>
<td>45.74</td>
<td>63.30</td>
</tr>
<tr>
<td>Savaro</td>
<td>1.46</td>
<td>4.36</td>
<td>6.86</td>
<td>10.58</td>
<td>13.63</td>
<td>16.86</td>
<td>23.73</td>
</tr>
<tr>
<td>Aşağıkonak</td>
<td>0.35</td>
<td>1.54</td>
<td>2.70</td>
<td>4.48</td>
<td>6.01</td>
<td>7.65</td>
<td>11.05</td>
</tr>
<tr>
<td>Şakuli</td>
<td>1.53</td>
<td>5.92</td>
<td>10.05</td>
<td>16.29</td>
<td>21.57</td>
<td>27.25</td>
<td>39.07</td>
</tr>
</tbody>
</table>
Other than the calculations shown in Table 3 made by DSI (State Hydraulic Works) [31], the flow rate for 2006 was calculated by us. The peak flow rate was found to be 450 m$^3$/s taking into account the basin area, maximum precipitation falling in the flood period, slope, and penetration capacity. This value is equal to 3 times the capacity of the canal of Iluh River. The peak flow rate in the flood of 2006 was also observed to be 3 or 4 times higher than the capacity of the canal according to field observations and GPS measurements. Calculations made as a result of these observations were concluded to be accurate. Furthermore, it was observed that the peak flow rate in 2006 was much higher than the probable flow rates for 100 and 500 years, as calculated by DSI.

**Peak flow rate of 2006:**

Harmonic slope of the basin ($S$) = 0.025
Length of the main streambed ($L$) = 29550 m

Time of collection ($T_c$) \[ T_c = 0.00032 \times \frac{L^{0.77}}{S^{0.385}} \]  

\[ T_c = 0.00032 \times \frac{29550^{0.77}}{0.025^{0.385}} = 3.22 \text{ hours} \]  

Unit rainfall duration ($D$) = \[ \frac{2\sqrt{T_c}}{} \]  

\[ D = 2 \times \sqrt{3.22} = 3.58 \equiv 4 \text{ hours} \]  

Time to peak of hydrograph ($T_p$) = 0.5 $D$ + 0.6 $T_c$ \[ T_p = 0.5 \times 4 + 0.6 \times 3.22 = 3.932 \text{ hours} \]  

\[ Q = \frac{2.08 \times A \times R_D}{T_p} (m^3/s) A = \text{Basin Area (km}^2) \]  

Indirect flow level $R_D = P - \phi$ \[ P = 64 \text{ mm/h} \]  

\[ \phi = 29 \text{ mm/h} \Rightarrow R_D = 64 - 29 = 35 \text{ mm/h} = 3.5 \text{ cm/h} \]  

\[ Q = \frac{2.08 \times 242.93 \times 3.5}{3.932} \equiv 450 \text{ m}^3/s \]  

The HEC-GeoRAS program in ArcGIS software, developed for processing spatial data, was used to perform hydraulic modeling of data obtained as a result of the above-given calculations. HEC-RAS is hydraulic software which is widely used across the world and has a data storage and management capacity by which the water surfaces of permanent flows are calculated and the modeling of temporary flows can be made [32].

The HEC-RAS model was only applied to Iluh River in the area of investigation. Since the streambeds of other rivers affecting Batman city are not apparent, the modeling of these rivers could not be performed. Therefore, a digital analysis model of the surrounding area of Iluh River remaining in the city center of Batman city was developed (according to elevation intervals of 1 m) and geometric data of the stream bed were extracted using this model (Fig. 11, 12, 13). According to these data, the areas which will be or are affected by flood events in Batman based on Iluh River are shown on the Quickbird image (Fig. 13).

According to the peak flow rate of 2006 in Batman, the whole of Çay district and almost the whole of 19 Mayıs district were affected by the flood event. In this flood event, half of the districts of Yeşiltepe, Iluh, Kismet, Çarşı and Karsiyaka were under water. Furthermore, the effect of the flood was also observed in some parts of the districts of Akyürek, Petrolkent and Hürriyet (Fig. 13). According to Iluh River’s probable flow rate of 450 m$^3$/s, an area of 150 hectares, more than 4,000 buildings and more than 40,000 people in Batman were affected by the flood event (Table 4). These values were predicted only for Iluh River and they double with the combining effect of other rivers.
Fig. 11. Part of Iluh River remaining in Batman city center, with geometric data (left). Fig. 12. Geometric data generated according to Iluh River’s flow rate of 450 m³/s (right).

Fig. 13. Areas that will be affected by a flood event according to Iluh River’s flow rate of 450 m³/s.

Table 4. Status of districts that are / will be affected by a flood event according to Iluh River’s probable flow rate of 450 m³/s.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Petrolkent</td>
<td>97</td>
<td>97</td>
<td>7</td>
<td>897</td>
</tr>
<tr>
<td>2</td>
<td>Karşıyaka</td>
<td>587</td>
<td>848</td>
<td>50</td>
<td>7758</td>
</tr>
<tr>
<td>3</td>
<td>Hürriyet</td>
<td>14</td>
<td>20</td>
<td>2</td>
<td>184</td>
</tr>
<tr>
<td>4</td>
<td>İluh</td>
<td>228</td>
<td>325</td>
<td>8</td>
<td>2510</td>
</tr>
<tr>
<td>5</td>
<td>Yeşiltepe</td>
<td>350</td>
<td>375</td>
<td>33</td>
<td>3398</td>
</tr>
<tr>
<td>6</td>
<td>Çay</td>
<td>425</td>
<td>450</td>
<td>36</td>
<td>4053</td>
</tr>
<tr>
<td>7</td>
<td>19 Mayıs</td>
<td>1007</td>
<td>1130</td>
<td>157</td>
<td>9742</td>
</tr>
<tr>
<td>8</td>
<td>Kışmet</td>
<td>583</td>
<td>1042</td>
<td>266</td>
<td>8438</td>
</tr>
<tr>
<td>9</td>
<td>Çarşı</td>
<td>583</td>
<td>307</td>
<td>618</td>
<td>2270</td>
</tr>
<tr>
<td>10</td>
<td>Akyürek</td>
<td>60</td>
<td>100</td>
<td>14</td>
<td>728</td>
</tr>
<tr>
<td>11</td>
<td>Beşevler</td>
<td>70</td>
<td>73</td>
<td>1</td>
<td>924</td>
</tr>
<tr>
<td>12</td>
<td>Buzur</td>
<td>19</td>
<td>23</td>
<td>1</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>4023</strong></td>
<td><strong>4790</strong></td>
<td><strong>1193</strong></td>
<td><strong>41105</strong></td>
</tr>
</tbody>
</table>

Note: These are estimated values according to the City Information of Batman.

The most striking feature in the hydrographic analyses of the part of Iluh River which remains in the city is that broad areas at the exit of the city affected by a flood event even at low flow rates (Fig. 13). However, the areas in the surroundings of the canal that would be affected by a flood event are fairly limited according to the probable flow rates calculated by the DSI for a period of 100 and 50 years.

5. Conclusion

Morphometric, hydrographic and hydrologic analyses were made in this study to determine the hydrographic characteristics of the basin of Iluh River. According to these analyses, the basin of Iluh River has a young structure formed under the effect of structural characteristics.
A major part of the basin of Iluh River is located on young basin fills. This structure caused the transverse profiles of the streams on basin fills to be considerably aslope.

The streams in the basin of Iluh River are seasonal due to the climatic characteristics of the region and low flow rate of spring waters. This prevented the stream beds from becoming apparent on the bottom of basin. All branches in the foundation (older) area of the city, except for Iluh River, were destroyed in the process of urban development. Seasonal streams in arid and semi-arid regions may cause fallacies with regard to urbanization. Batman city is the best example of such a fallacy.

The low slope in the basin of Iluh River is a disadvantage with regard to flood and torrent events. Although the low slope increases the penetration of water into the soil, the low infiltration capacity of the basin prevents the penetration of precipitation waters into the soil.

The length of stream km² in the basin of Iluh River is 2.41 km and the number of bifurcation points 1.89. According to these values, the stream intensity in the basin is not so high. Contrary to this characteristic of the basin, the stream intensity increases in mountainous areas. This characteristic of the mountainous areas causes drainage of precipitation waters, which gives rise to flood and torrent events in the lower basins.

The length of the basin is 1.5 times greater than its width. The small difference between length and width of the basin is effective on the occurrence of flood and torrent events. The shape of the Iluh River basin and location of the main stream bed in the center of the basin are also effective on the occurrence of such events.

The treatment canal constructed on Iluh River in Batman city was not designed according to the basin of Iluh River and maximum flow rate. A three-fold difference was noted between the calculation made by DSI according to the probable flow rate for a period of 500 years and the flood flow rate on 31st October 2006 as calculated by us. In calculations considering all characteristics of the basin, the peak flow in this period was found to be approximately 450 m³/s. According to this flow rate, an area of 150 hectares, more than 4,000 buildings and more than 40,000 people were and will continue to be affected by flood events in Batman city. These values were predicted only for Iluh River and they double when combined with the effect of other rivers.

To sum up, the hydrographic characteristics of Iluh River are of great importance with regard to the occurrence of flood and torrent events in Batman city and must be taken into account by the appropriate authorities

Acknowledgement

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