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Full Length Research Paper

Effects of geological and hydrological factors on the creation of flooding in Kozlu, Zonguldak, NW Turkey

Hulya Keskin Citiroglu[1]* and Gulseren Baysal[2]

[1]Zonguldak Karaelmas University, Engineering Faculty, Department of Geological Engineering, Zonguldak, Turkey.
[2]Ministry of Public Works and Housing, General Directorate of Technical Research and Application, Ankara, Turkey.

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The settlement of Kozlu in Zonguldak province located in the Western Black Sea Region of Turkey has e x perienced flood disasters since 1955 which has caused life losses and property damages. The study area comprises, order of age from the oldest to the youngest, Kozlu, Karadon and Inalti formations, Incigez Detritic member and alluvium. The fact that the Kozlu and Karadon formations are hydrogeologically impermeable units is an important factor that causes flooding. Construction on soil bearing the permeable Inalti formation and alluvium has a decreasing effect on soil infiltration. Water surplus constitutes 22.7% of the total precipitation that the study area receives. In the period from October to April, the area experiences heavy precipitation and therefore has large surplus water reserves. During the months between November and March, surplus water runs off. The study area experiences more flooding in the period from November and March than in the other months. During the months between April and October, when there is scarce or no water reserves, short-lived and heavy precipitation may result in flooding. The geological structure, hydrogeological and hydrological properties, slope gradient as well as damage to the vegetation cover and uncontrolled constructions cause the study area to suffer major floods.

Key words: Flooding, Kozlu, sediment, hydrology.

INTRODUCTION

The expansion of settlements, opening of new roads and construction of new installations in river basins bring about changes in the ground as well as the destruction of forests and pastures, disturbing the hydrological balance in the entire basin. The resultant heavy rainfall and long lasting light showers lead to flood disasters which, in turn, cause life and property losses. Every year floods affect some 500 million people and their livelihoods in an adverse manner. The costs of floods and other water-related disasters on the world economy amount to 52 to 58 billion US dollars (Sentürk et al., 2010). 49% of some 560 million people worldwide who have lost their lives due to floods, earthquakes, fires, storms, and volcanic eruptions in the last 20 years are those who were killed by floods alone. Between 1975 and 2010, Turkey suffered 695 flooding incidents, 634 people were killed, a total area of 810,000 ha was flooded and the total damage inflicted amounted to 3,717,000,000 US dollars (Table 1) (Altundal, 2010). As the Black Sea Region has a rugged topography, receives heavy precipitation and the terrain is not utilized to its full capacity, it is one of the regions where floods are the most widespread (UCTEA, 1999).

MATERIALS AND METHODS

General properties of the study area

Kozlu is located in the Western Black Sea Region of Turkey at latitudes 41°-27' N and longitudes 31°-49' E (Cizgi City Planning Ltd, 2009). It borders Zonguldak to the northwest, Eregli to the southwest, Caycuma to the north, and Beycuma and Devrek to the southeast. The coastline forms the north-northeast boundary of the study area (Figure 1). Kozlu is divided into 7 districts, namely Merkez, Tasbaca, İhsaniye, Kilic, 19 Mayis, Güney and Fatih (Figure 2). The settlement of Kozlu is completely surrounded by mountainous areas. The streams within the study area include

*Corresponding author. E-mail: keskinhc@yahoo.com

Table 1. Floods that have occured in Turkey in the last 35 years and their unfavourable effects (Altundal, 2010).

Years	Number of floods	Death toll	Submerged area (ha)	Total financial damage ($)
1975-1979	160	85	120.000	57.000.000
1980-1989	152	63	190.000	1.500.000.000
1990-1999	102	310	250.000	2.000.000.000
2000-2009	281	176	250.000	160.000.000
Total	695	634	810.000	3.717.000.000

Figure 1. Location map of the study area.

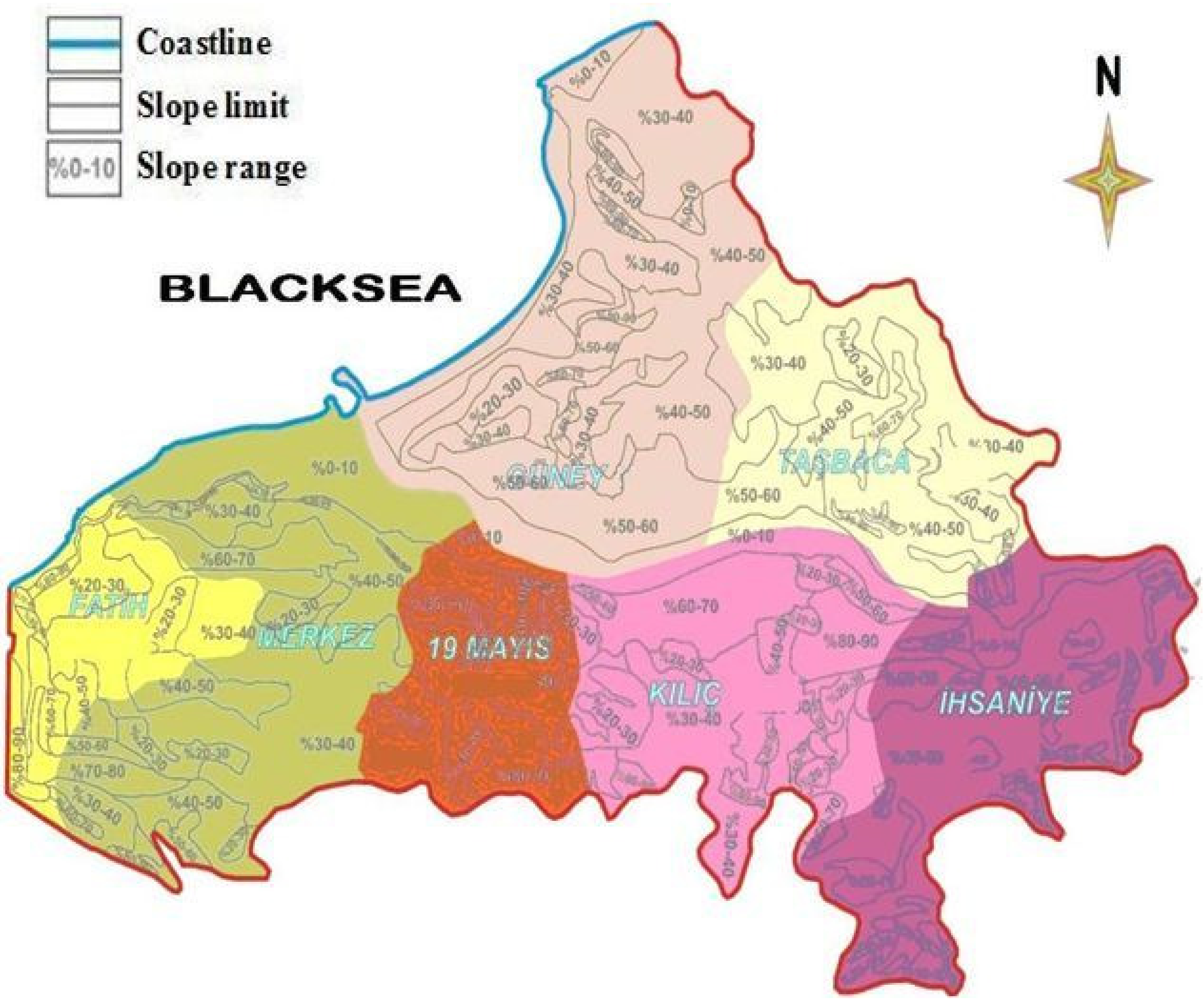

Figure 2. Districts within the boundaries of Kozlu and their slopes (Are jeoteknik Ltd, 2008).

Kozlu Stream and its branch Kilic Stream (Ekinci, 2005).

Slope

In an area with a steep slope, even if the other conditions are the same, less rain water is infiltrated into the soil compared with an area with a slope of a relatively low inclination. As a result, rain waters are not drained and runoff occurs. This increases the flow rate, which, in turn, increases the amount of sediment carried by running water, especially in areas with little vegetation cover. The slopes that the study area covers were divided into nine categories: 0-10,10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80 and 80-90% (Figure 3). The regions with a slope inclination of 30-40% form the large portion of the study area. The regions with 40-50 and 50-60% slopes rank second. These parts cover the mountainous regions to the north of the study area. The third-ranking regions with slope inclinations of 0-10 and 20-30% include coastal plains, valley bottoms and plains between mountains. The regions with 70-80 and 80-90% slopes which constitute very narrow and limited areas are the sides of deep steep valleys, and sea cliffs (Are Jeoteknik Ltd, 2008).

Geological properties of the study area

The study area consists of, in order of age from the oldest to the youngest, Kozlu (Cko), Karadon (Cka) and Inalti (Jki) formations, Incigez Detritic member (Jkii), alluvium (Qal), the present-time beach sand (Qp) and landfills (Qd) created by The Turkish Coal Enterprises (TTK) (Figures 4 and 5). The Kozlu formation (Cko) with a thickness of more than 700 m comprises the intercalation of medium-and-coarse-grained sandstone, conglomerate, mudstone rich in organic matter and coal lithologies. The Karadon formation (Cka) 300 to 400 m in thickness is made up of conglomerate, sandstone, siltstone, claystone, coal and refractory clay. The Inalti formation (Jki) grey and brown in colour consists of limestone, sandy limestone and conglomerate intercalation. The carbonated layer of this formation varies between 20 and 80 cm and the layer of sandstone between 10 and 30 cm. On the other hand, it has also limestone layers of thickness as high as 2 to 4 m (Yergok et al., 1987). The Incigez Detritic member (Jkii) consists of conglomerate, coarse-grain sandstone, sandstone, siltstone and limestone intercalation which has a grey, ashen and reddish brown colour (Alan and Aksay, 2002). Alluvium occurs in stream beds as very thin bands and sometimes as Quaternary formations covering large

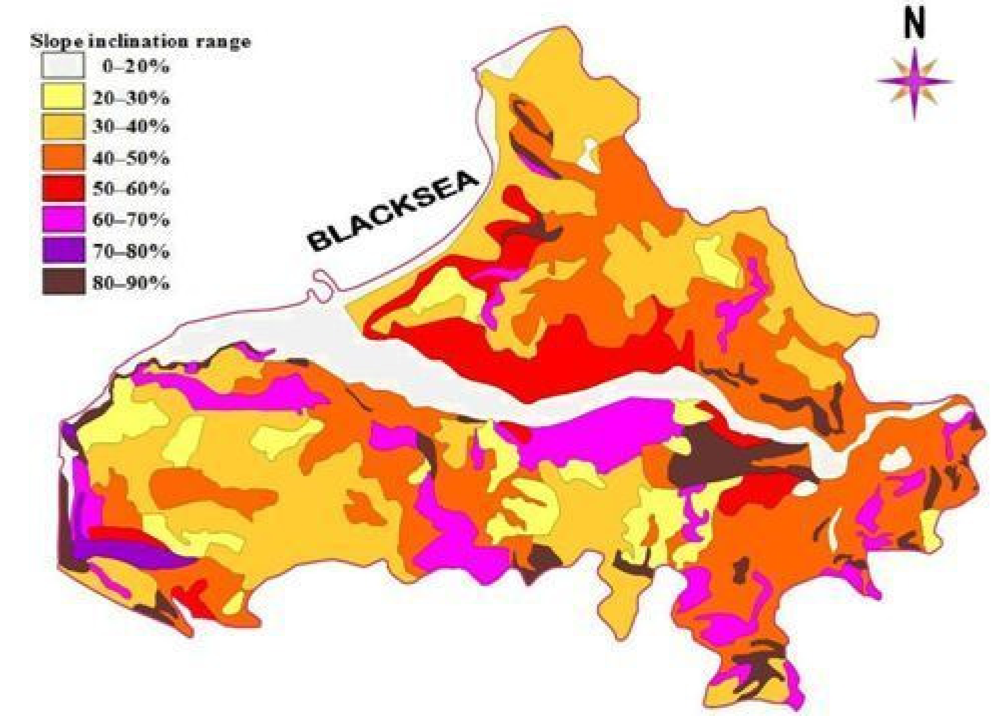

Figure 3. An overall slope map of the study area (Are Jeoteknik Ltd, 2008).

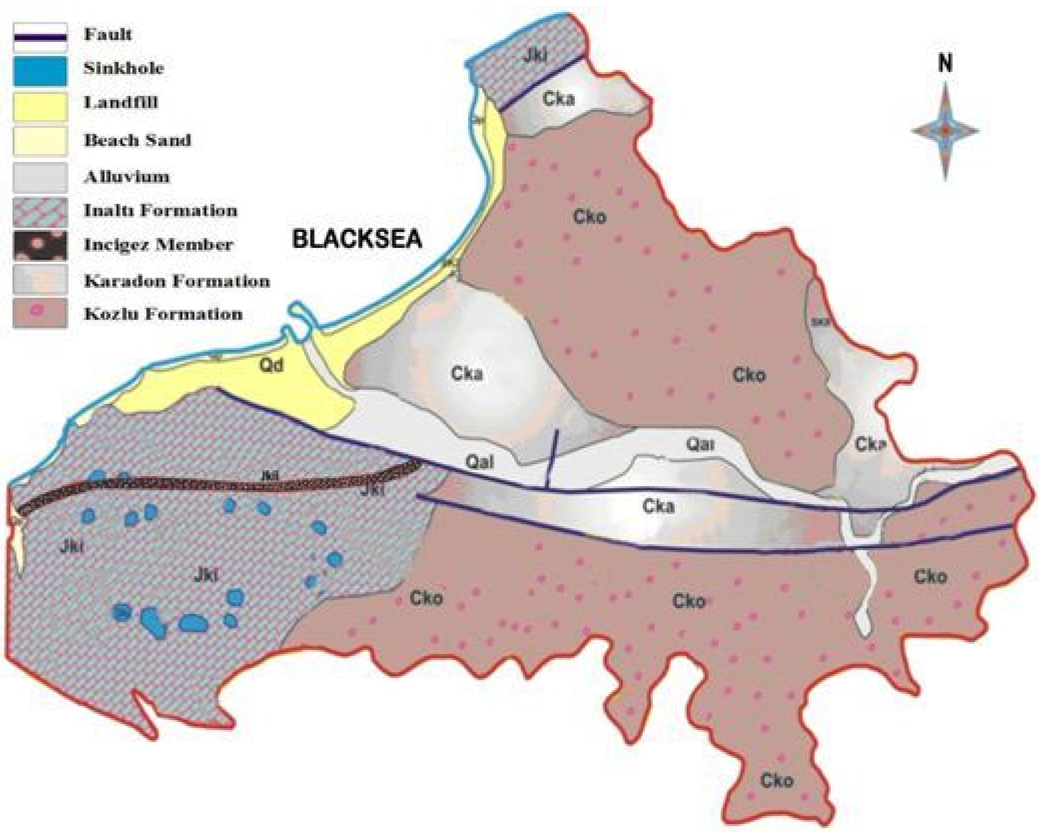

Figure 4. The geological map of the study area (Alan and Aksay, 2002).

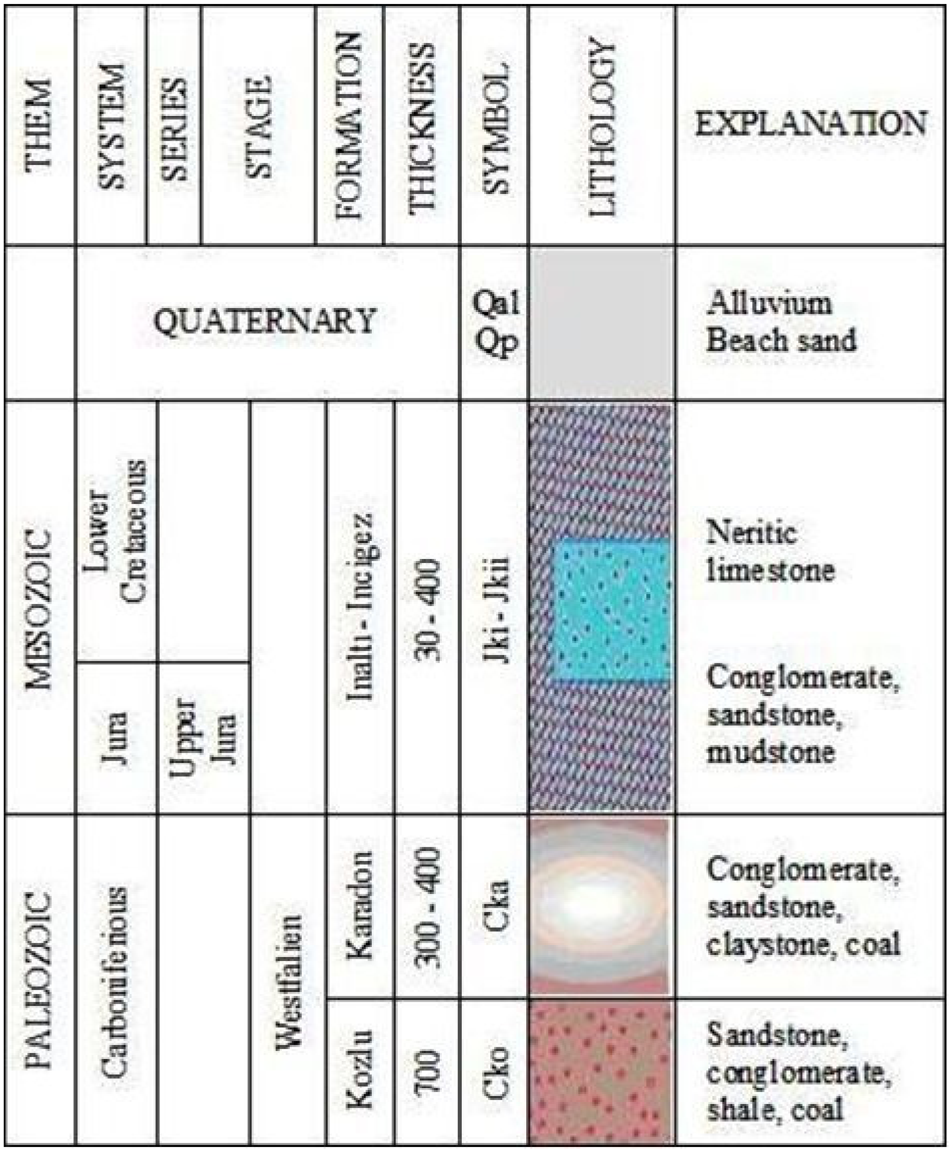

Figure 5. Stratigraphic columnar section of the study area (Alan and Aksay, 2002).

areas. It includes clay, silt, sand, gravel and blocks of varying sizes. Alluvium is observed along Kozlu Stream and the sea shoreline.

The study area is located within The Second Degree Earthquake Zone according to the Seismic Hazard Map of Turkey. About 150 km to the South of the area is the 180 km long Gerede segment of The North Anatolian Fault Zone (AFAD, 2010).

Hydrology of the study area

Detailed meteorological studies have been carried out in order to reveal insights into the effect of climate on flood causing mechanisms in the study area. By taking the arithmetic average of the data from Zonguldak Meteorological Station covering a period of 35 years since 1975 (Table 2), the precipitation and evaporation characteristics of the study area were determined.

The maximum amount of water lost due to evaporation and transpiration depending on climatic conditions gives potential evapotranspiration (Etp). The values for potential evapotranspiration (Etp) and real evapotranspiration (Etr) were calculated using the Schendel method (Schendel, 1968) on the basis of the data on monthly average temperature and relative humidity obtained from Zonguldak Meteorological Station (Equation 1).

$$Etp = t/h \times 480 \qquad (1)$$

where Etp denotes potential evapotranspiration (mm), t monthly average temperature (°C) and h relative humidity (%).

Previous floods and measures taken

From time to time Kozlu Stream and its branch Kilic Stream overflow their banks. According to the report dated 14.01.1986 issued by the 23. Regional Directorate of State Hydraulic Works

Table 2. Average meteorological data on the study area covering a long period of time (35 years). (TSMS, 2010).

Parameters	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual average
Temperature °C	6.1	6.1	7.6	11.3	15.3	19.1	21.8	21.8	18.6	15	11.1	8.1	13.5
Precipitation mm	131.6	85.7	86.2	57.9	52.5	69.1	83.9	90.8	121.1	152.7	150.8	152.2	102.9
Relative humidity %	67.1	67.1	67.2	67.7	70.9	67.1	71.4	72.3	71	72.1	67.2	66.6	69
Wind speed m/s	2.8	2.8	2.7	2.4	2.1	2.1	2.1	2.3	2.5	2.5	2.6	2.8	2.5
Number of precipitation days	18.1	15.5	14.6	12.5	10.7	8.9	8	7.5	9.8	13.3	14.5	18.2	12.63
Number of days with snow cover	4.3	4.7	2.3	_	_	_	_	_	_	_	0.4	1.8	1.13
Number of stormy days	1.5	1.3	0.7	0.6	0.3	0.1	0.2	0.2	0.5	0.4	1	1.2	0.67
Number of frosty days	4.6	5.9	2.9	0.1	_	_	_	_	_	_	0.2	2.2	1.3

Figure 6. Damage to the wall along Kilic Stream (DSI, 2007).

Authority (DSI), as the mouth of Kozlu Stream where it flows into The Black Sea is open to northerly winds, the streambed is filled by sediment washed away by rough waves. Kozlu Stream and Kilic Stream floods on 31.07.1955 and 01.08.1955 killed 7 people (DSI, 1986a). The streams also experienced floods in 1975, 1982, 1985, 1991, 1998 and on 12.11.2006. It is stated in reports issued by the General Directorate of State Hydraulic Works (DSI) that, since the 1955 flood, studies have been undertaken aimed at preventing Kozlu and Kilic Streams overflowing and minimizing damage caused. Between 1975 and 1982, Kozlu Stream was rehabilitated and the streambed was cleaned every year. A concrete wall of 1930 m was built on both banks of the stream as well as concrete walls on either the right or left bank with a total length of 1475 m. In addition, an 88 m portion of the existing wall was reinforced to withstand overflows (DSI, 1986b).

It was decided that a reinforced concrete canal 722 m in length would be built along Kilic Stream. The overflow of the stream on 01.08.2007 due to heavy rain caused serious damage to 23 houses (DSI, 2007). A 40 m portion of the wall along the left bank collapsed (Figure 6) and depressions created in the streambed led to slopes as high

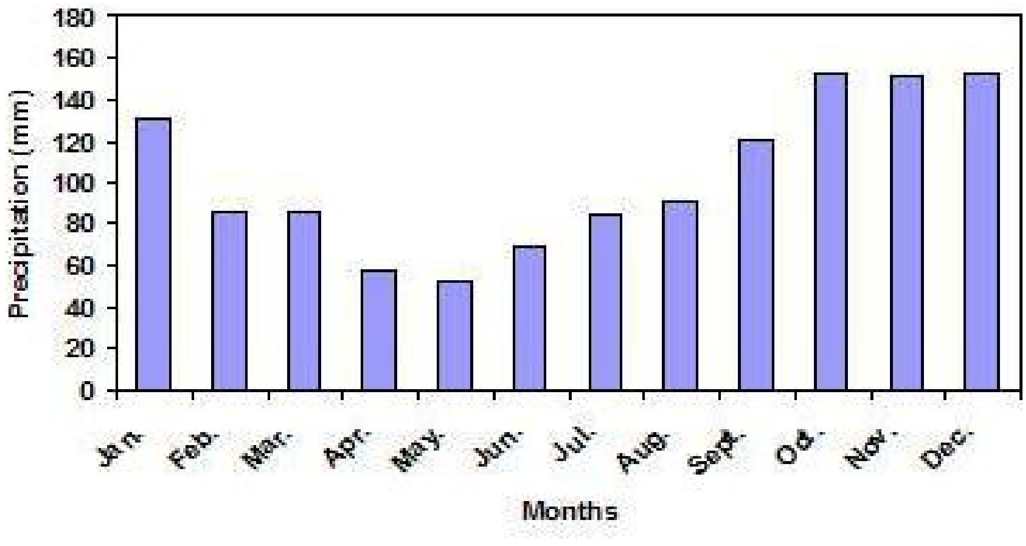

Figure 7. Average precipitation between 1975 and 2009.

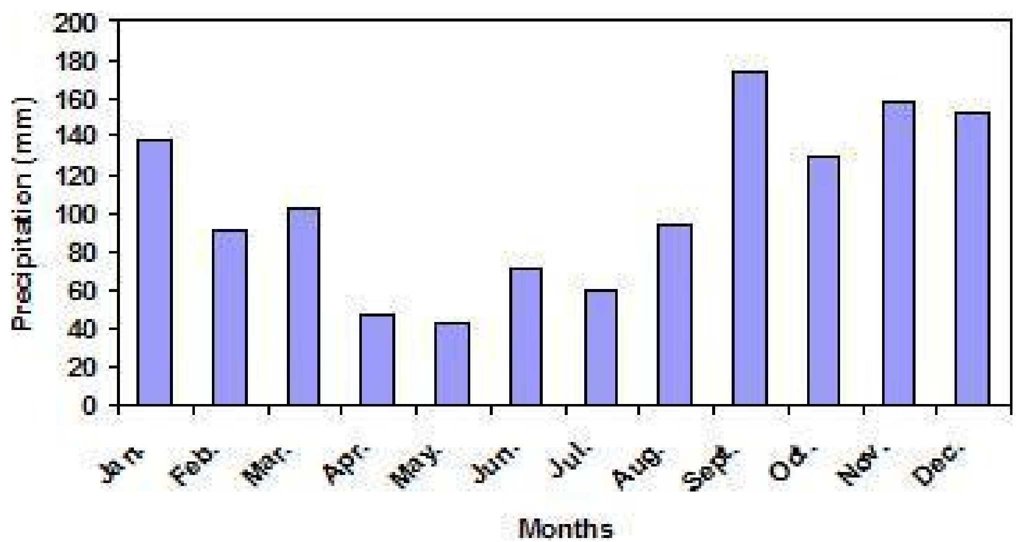

Figure 8. Monthly precipitation for the years 2000-2009.

as 4 m between the streambed and the road on the left bank. It was established that there would be land losses due to land failures on both the right and left banks and the proposed 722 m reinforced concrete canal would be insufficient (DSI, 2008).

RESULTS

Precipitation

It is clear from meteorological data covering the last 35 years that precipitation displays an increase in September and continues heavily through February. The total precipitation height for the last 35 years is 1234.5 mm. The area receives more precipitation in April and May compared to the other months, with autumn getting the most precipitation. 30% of the total annual precipitation falls in winter, 16% in spring, 20% in summer and 34% in autumn (Baysal, 2010; Figure 7).

Figure 8 depicts the monthly distribution of precipitation height for the last ten years (2000 to 2009), reveals that there is an increase in precipitation in January, February, March, June, August, September and November as compared to a decrease in April, May, July, October and December. The average total precipitation height for the last ten years has increased by 25.64 mm reaching 1260.1 mm (Baysal, 2010).

Table 3. Water balance for the study area prepared using the Schendel method.

Features	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Precipitation P	131.6	85.7	86.2	57.9	52.5	69.1	83.9	90.8	121.1	152.7	150.8	152.2	1234.5
Etp	43.63	43.63	54.28	80.11	103.58	136.63	146.55	144.73	125.74	99.86	79.28	58.37	1116.39
P-Etp	87.97	42.07	31.92	-22.21	-51.08	-67.53	-62.65	-53.93	-4.64	52.84	71.52	93.83	118.11
Reserve water	100	100	100	77.79	26.71	00	00	00	00	52.84	100	100	-
Etr	43.63	43.63	54.28	80.11	103.58	95.81	83.9	90.8	121.1	99.86	79.28	58.37	954.35
Water shortage	00	00	00	00	00	-40.82	-62.65	-53.93	-4.64	00	00	00	-162.04
Water surplus	87.97	42.07	31.92	00	00	00	00	00	00	00	24.36	93.83	280.15

Temperature

The average annual temperature is 13.5°C, the average highest temperature in July and August 21.8°C and the average lowest temperature in January and February 6.1°C (Table 2). The table depicts that temperature e x hibits a downward trend in October and increases again starting from April.

Evaporation

The amount of evaporation was calculated by the Schendel method (Schendel, 1968) and the water balance values are given in Table 3. The real evapotranspiration (Etr) was found to be the highest (121.1 mm) in September and the lowest (43.33 mm) in January and February. Moreover, total annual real evapotranspiration (Etr) for the area was established to be 954.35 mm. As for potential evapotranspiration (Etp), it is the highest (146.55 mm) in July and the lowest (43.63) in January and February. The value of total annual evapotranspiration (Etp) for the area is 1116.39 mm. From October through April, precipitation is higher than potential evapotranspiration. From late April to mid-June, soil moisture reserves supposed to be 100 mm were depleted. The shortage of water experienced from mid-June to late September is 162.04 mm. It becomes necessary to irrigate cultivated land during this period. 954.35 mm, that is, 77% of an annual mean precipitation of 1234.5 mm evaporates back into the atmosphere through evapotranspiration. The water surplus is 22.7% of the overall precipitation.

Runoff

A 280.15 mm portion of the 1234.5 mm precipitation which constitutes 22.7% of the total runs over the surface without soaking into the ground. The months from November to March are those when water surplus and surface runoff occur. Kozlu Stream flows into the Black Sea. Accordingly, no surface runoff occurs within the study area which is discharged outside the catchment basin.

Water budget

Precipitation is the only source of water for the study area having an area of about 9 km^2. The total average precipitation is 1234.5 mm. Considering a 9 km^2 study area, the amount of precipitation that falls in the area is 111.1 x 10^5 m^3/year. The annual real evapotranspiration (Etr) of 954.35 mm is 85.9 x 10^5 m^3/year for the same area. The values of feed and discharge from limestones in the study area were assumed to be equal and, as the area has no open water wells, only evaporation values were used in calculating water discharge (Baysal, 2010). The difference between feed and discharge is 25.2 x 10^5 m^3/year (Table 4). In view of errors that may occur in measurements and calculations, 60% of the difference between feed and discharge can be taken as the amount of water that can be safely used. The reserves of underground water in the study area that can be used safely is 15.12 x 10^5 m^3/year.

Hydrological properties of the lithological units

The geological units present in the study area were classified as permeable, karstic-permeable, semipermeable and impermeable. The permeable units, that is, the uncemented medium, consists of alluvium (Qal), beach sand (Qp) and landfill (Qd).

Table 4. Water budget for the study area.

Feed	m^3/year	Discharge	m^3/year
Precipitation	111.1x10^5	Evaporation	85.9x10^5
Total	111.1x10^5	Total	85.9x10^5

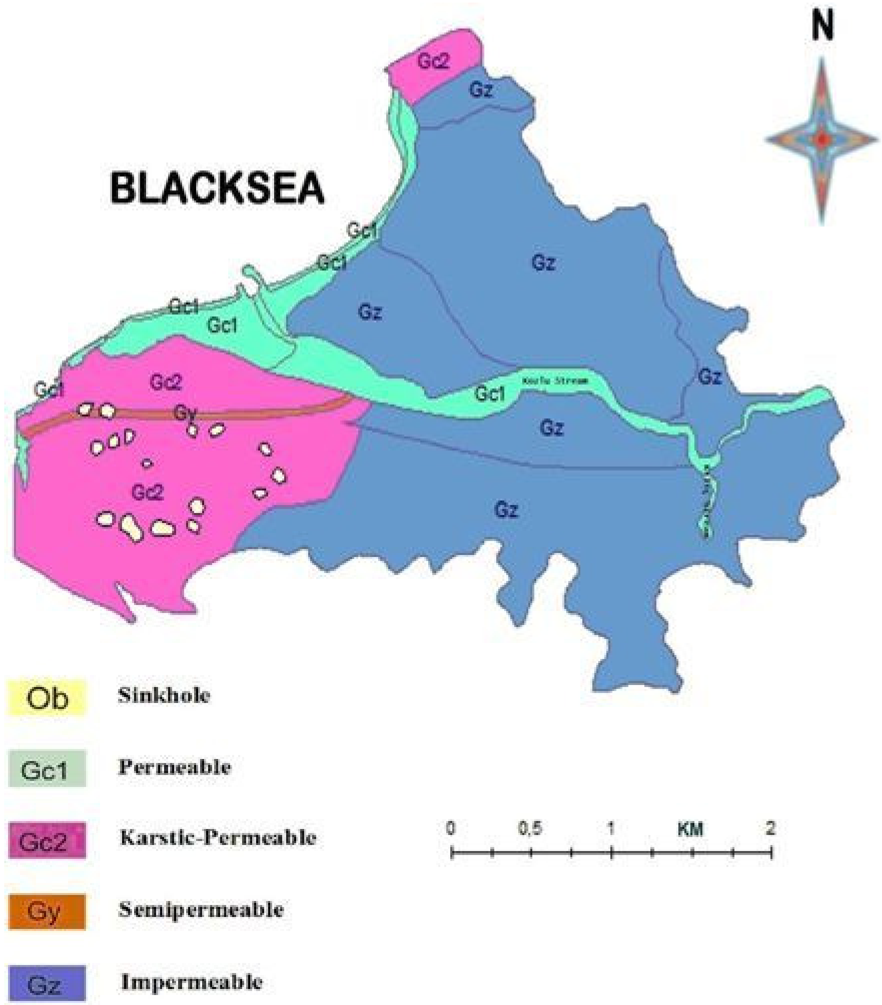

Figure 9. Hydrogeological map of the study area.

The Inalti formation (Jki) constitutes the karstic-permeable unit (karstic rock medium), the Ingicez Detritic member (Jkii) the semipermeable units, and the Kozlu (Cko) and Karadon (Cka) formations the impermeable units (Figure 9).

The uncemented permeable units and Kozlu Stream sediments flow into the Black Sea. In addition, uncemented sand extends along the shoreline in a narrow band. Materials of various sizes such as sand, gravel and blocks and waste, ash etc, remaining from coal mining make up the landfill stretching along the shoreline. The Inalti formation, a karstic-permeable medium, comprises limestone which runs in parallel to the shoreline. Limestone having karstic cavities and large fissures is capable of carrying a considerable amount of water. The fact that the Incigez Detritic member, which forms a semipermeable medium, is loosely cemented increases its permeability. In addition, fractures and fissures may also contain underground water. Claystone levels which are located in between and become larger towards the upper parts reduce permeability. Since conglomerates occurring in the Kozlu and Karadon formations are loosely cemented, they may display aquifer properties. However, as they are intercalated with

Figure 10. Sediments transported to Kozlu Stream.

a b

Figure 11a. Construction and demolition waste dumped into Kozlu stream b. Domestic waste disposed of in Kilic Stream.

other impermeable units, they constitute the impermeable units.

DISCUSSION

Sandstone, claystone and conglomerate intercalations contained in the Inalti formation settled to form a considerable amount of sediment in the basin. The Incigez Detritic member consists of sediment containing large amounts of materials and detritic coal. As the upper parts surfaces of the Kozlu and Karadon formations are deformed, these regions also have sediments. The transport of these sediments to streams through precipitations leads to flooding (Figure 10). Moreover, the disposal of waste from road construction and coal mining, and domestic waste in the stream results in the amount of sediments carried away increasing (Figure 11a, b).

Fine sediment transport is observed at the mouth of Kozlu Stream where it flows into the sea. When the sea experiences high tide, it retards the stream flow, thus causing sediments move upstream. The regions of the study area with slope inclinations of 50 to 90% lead to soil infiltration rate decreasing and larger amounts of

Figure 12. The slopes of Kozlu Stream containing sediment.

Figure 13. The unsupported slopes of Kozlu Stream.

sediment being transported (Figure 12). High slope inclination indicates that precipitation creates runoff immediately (Strahler, 1964). Due to the abrasive effect of water and the load brought about by construction, the slopes of Kozlu Stream have remained unsupported (Figure 13). Although, rehabilitation dikes have been built across Kilic Stream, the unstable slopes of the stream render dikes measures insufficient in reducing the chances of flooding (Baysal, 2010; Figure 14a, b).

Wrong agricultural practices and construction works have led to destruction of the natural vegetation, thus stripping soil of its protective cover. The vegetation cover has decreased in areas with relatively denser urbanization, at high altitudes of the study area and in some parts of the stream slopes (Figure 15). It is reported that destruction of the vegetation cover increases runoff, results in sedimentation and an increase in flooding incidents (Marston et al., 1996; Hofer, 1998).

On the basis of the data obtained using the Schendel method, a graph was plotted which depicts variations in precipitation and evapotranspiration (Etp) against time in months (Figure 16). Potential evapotranspiration is greater than real evapotranspiration due to a lack of soil moisture between the dry months of June and September.

Between the months of October to May comprising the wet season, as the soil is fully or half saturated with water, potential evapotranspiration (Etp) is supplied by soil moisture and precipitation, and in this period, potential evapotranspiration (Etp) is equal to real evapotranspiration (Etr). In the same period, the area has a total annual water surplus of 280.15 mm. The highest water surplus of 93.83 mm occurs in December. 77% of the total annual precipitation of 1234.5 mm evaporates back to the atmosphere through evapotranspiration. Water surplus accounts for about 22.7% of the total

Figure 14. a. The unsupported slopes of b. The rehabilitation dike across Kilic Stream.

Figure 15. The sections of the slopes of Kozlu Stream where the vegetation cover has decreased.

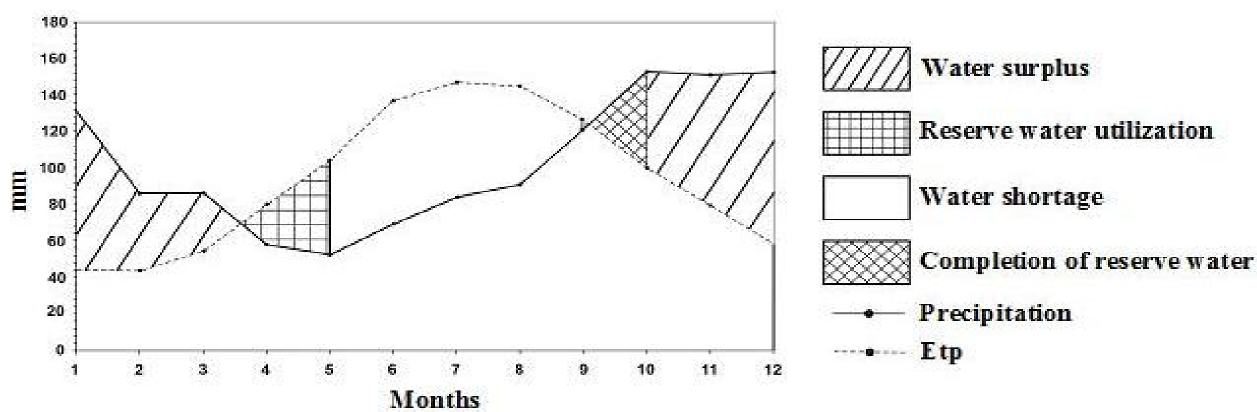

Figure 16. A graph illustrating variations in precipitation and evapotranspiration (Etp) in months.

precipitation and occurs in the period from October to April. Also, the period of October to April has high average monthly precipitation. During the months from November to March, a large amount of water runs off the surface due to water surplus. The months from May to October is the period when there is insufficient or no water reserves. Although, there is no water surplus in the soil in April and May, the area does not suffer water shortages in the soil either. For all these reasons, the chances of flooding in the months from November to March are greater compared to other months. Higher than average heavy sudden precipitations occurring in the period from April to October, even if they last a short time, increases the chances of areas with a high inclination in particular getting flooded. Meteorological data clearly reveal that the study area frequently suffers these kinds of precipitation. Heavy precipitation that falls on slopes of low inclinations and flat surfaces is not infiltrated into the soil owing to the lack of an appropriate drainage system and dense construction, and thus creates runoff flows. As the drainage systems are insufficient in areas where runoff water is transported into the sea by streams and materials to flow into streams are not put under control, flooding occurs.

One reason that is attributed to flooding in the study area is impermeable formations. Impermeable units prevent precipitation falling on the surface from being absorbed into the ground. As a result, precipitation that falls on the ground runs off the surface. If runoff is not appropriately drained, it creates flooding. Precipitation that falls on permeable and semipermeable units in areas with a low inclination is soaked into the ground and therefore does not run off, which reduces the risk of flooding. In contrast, soil infiltration rate decreases in areas with slopes of high inclinations. Although, high soil permeability along the shoreline partly reduces runoff, it causes underground water levels to rise, and so the soil gets saturated. Heavy and short-lasting precipitation falling on a saturated soil is effective in creating water surplus.

Therefore, coastal construction has an adverse effect in that it increases the risk of flooding and the soil is prone to liquefaction. In the districts of Merkez and Fatih, which are located in hydrogeologically karstic-permeable and semipermeable areas, as the amount of runoff water decreases during periods of heavy and longlasting precipitation, the risk of flooding will be lower. The districts of Guney, Tasbaca and Kilic as well as much of Ihsaniye and 19 Mayis districts, which are located in hydrogeologically impermeable soil areas of high inclinations are at risk of being flooded due to surface water runoff.

Conclusions

Apart from alluvium, the study area consists of the Kozlu, Karadon and Inalti formations, and the Incigez Detritic member. Alluvium is a permeable, the Inalti formation a karstic-permeable, the Incigez Detritic member a semipermeable, and the Kozlu and Karadon formations impermeable lithological units.

The average annual precipitation in the study area is 1234.5 mm and the average annual real evapotranspiration (Etr) 954.35 mm. The amount of precipitation that falls in the study area is 111.1 x 10^5 m^3/year and real evapotranspiration (Etr) 85.9 x 10^5 m^3/year. The difference between feed and discharge is 25.2 x 10^5 m^3/year. 77% of precipitation evaporates back into the atmosphere through evapotranspiration.

During the months from October to April, the area experiences high precipitation and, accordingly, has a surplus amount of water reserves contained in the ground. The excess water runs off in the months from November to March. More flooding incidents occur in the study area during this period as compared to the other months. During the months from April to October, when water reserves are scarce, short-lasting but heavy precipitation gives rise to flooding.

Water surplus that accounts for 22.7% of total precipitation should be drained in order to avert flooding. Since dense construction in areas with lithologically permeable formations reduce soil infiltration, the amount of runoff water increases. Lithologically impermeable formations do not allow runoff water to be drained into the ground and thus causes sediments to be transported into the streams. Dense urbanization in the study area to has led the forestland and vegetation cover across the alluvium soil decreasing.

The geological structure, hydrogeological and hydrological properties, slopes, destruction of vegetation cover and uncontrolled construction in the study area cause flooding. In order to avert flooding, integrated multiple measures should be adopted within a programme which regulates human activities ranging from reforestation to public education. No construction should not be allowed along the shoreline because it increases the risk of flooding and the soil is liable to liquefaction.

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