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Assessment of big floods in the Eastern Black Sea Basin of Turkey

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Abstract In this study, general knowledge and some details of the floods in Eastern Black Sea Basin of Turkey are presented. Brief hydro-meteorological analysis of selected nine floods and detailed analysis of the greatest flood are given. In the studied area, 51 big floods have taken place between 1955–2005 years, causing 258 deaths and nearly US $500,000,000 of damage. Most of the floods have occurred in June, July and August. It is concluded that especially for the rainstorms that have caused significantly damages, the return periods of the rainfall heights and resultant flood discharges have gone up to 250 and 500 years, respectively. A general agreement is observed between the return periods of rains and resultant floods. It is concluded that there has been no significant climate change to cause increases in flood harms. The most important human factors to increase the damage are determined as wrong and illegal land use, deforestation and wrong urbanization and settlement, psychological and technical factors. Some structural and non-structural measures to mitigate flood damages are also included in the paper. Structural measures include dykes and flood levees. Main non-structural measures include flood warning system, modification of land use, watershed management and improvement, flood insurance, organization of flood management studies, coordination between related institutions and education of the people and informing of the stakeholders.

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Introduction

Human beings have a great capacity to adapt to varying climatic conditions and environments, but remain vulnerable to adverse impacts of weather and climate. In addition to the direct impacts of loss of life and property damage, there are indirect impacts such as increased exposure of survivors to other damages such as contaminated water supplies and landslides, and the disruption of traffic and trade. The indirect impacts are quite numerous and often difficult to quantity.

Floods are among the most common natural disasters and in terms of economic damage, the most costly. Flooding is a natural damage that is becoming a greater threat rather than a constant or declining one. It is a natural phenomenon which occurs inevitably from time to time in a river or drainage basin and cannot be prevented, but of which effects can be mitigated. The problems associated with disastrous flooding arise because of man's deliberate occupancy of flood-prone areas, undertaken for a variety of good reasons. These include the suitability of flood plains and river banks for agriculture and other forms of primary production, for convenience for transport and navigation, for appropriate topography for towns and cities, and for proximity to domestic, industrial and irrigation water supply.

Due to geographical location, geology and topography, Turkey undergoes mainly three different types of natural disasters related to gravity flows; floods, landslides and snow avalanches. Flooding is second important natural damage after earthquakes. Devastating flood events have occurred in various river basins of Turkey, especially in recent years. In many cases, floods have caused deaths, suffering and extensive damages to both public and private properties. A flood inventory of 776 cases was prepared using a simple computer program for PC use for easy access to 68 different parameters encompassing the geographical, topographical, hydrological, meteorological and synoptic characteristics of each flood. By categorization of the available data in hand, spatial and time distributions of past flood events were determined. For this purpose, floods during the period from 1945 to 1995 from economic and social perspectives by creating a database that has 68 different parameters to define a single flood event and it was being updated till 2003. Accordingly, on the average 18 flood events occur in a year and they take about 23 lives. Almost after each flood, the government has paid a large proportion of the damage, in addition to losing significant revenues due to the consequences of economic disruption. (Gürer and Özgüler 2004). According to flood reports prepared by General Directorate of State Hydraulic Works (DSİ), annual average flood damages are calculated nearly US $86 million damage per year (DSİ 1970–2005).

The spatial occurrence of floods is not spread uniformly over Turkey. The valleys all along the Black Sea and Aegean coasts are particularly threatened. Floods in the coastal zones in Turkey are mainly produced by heavy rainfall in combination with geomorphologic features. (Gürer 1996, 1998).

Floods are due to heavy rainfall on the coastal areas of the western and southern parts of Turkey or to a sudden snowmelt in the eastern, mountainous part of south-eastern Turkey. In the northern and central parts of the country, including the Eastern Black Sea, both factors may occur depending on the time of the year. Precipitation types are frontal, orographic, or convective. During occluded fronts, long-lasting intense rainfall may produce flooding, depending on the season of the year. Most of the coastal precipitation in the Black Sea region, where the mountain ranges run parallel the shore sea, is of the orographic type. Convective precipitation mostly occurs during the transition seasons of spring and autumn and affects central Anatolia. The most dangerous type of flood occurs in coastal regions when orographic and frontal lifting of the saturated air masses causes surface convergence, leading to very intense rainfall. The snow accumulated in the upper reaches of the drainage basins of Anatolian rivers melts as of the beginning of May or June, and can cause flooding in downstream areas of the rivers. (Ceylan 2004).

Land-use, particularly wrong and even illegal land-use, is a most important factor in Turkey when dealing with natural damages, especially the flood damage. The consequences of flooding are strongly influenced by the commercial development and urbanization of many areas. In order to absorb the increasing population, new settlements have been built, mostly illegally. The capacity of the storm sewers and flood detention structures in the cities is often inadequate to control large floods. The conveyance capacity of the creeks is greatly reduced during floods by building the walls of houses in the stream beds. Such non-meteorological factors aggravate effects of the floods.

Very big and destructive floods have occurred in The Eastern Black Sea Basin (EBSB) of Turkey. In this basin, 51 big floods have taken place between 1955–2005 years, causing 258 deaths and nearly US $500,000,000 of damage. The studied region is the rainiest one in Turkey. The annual average rainfall height of the region is 1,400 mm. The strata are generally made of impermeable or semi permeable volcanic rocks. Steep slopes cover great areas, causing to increase of surface runoff velocities (Üçüncü et al. 1994). Most of the floods have occurred in July, June and August. In these months, the superposition of intensive rainfall with snowmelt of upland areas has caused big floods.

In this study, general knowledge of the floods in EBSB is presented. Brief hydro-meteorological analysis of selected nine floods and detailed analysis of the most devastating flood are presented. The main reasons of the flood damages and some structural and non-structural measures to mitigate these damages are also concluded in the paper.

The Eastern Black Sea Basin

General hydro-meteorological properties of Turkey and the basin

The EBSB is located on the north eastern coast of Turkey. The basin is surrounded by the Eastern Black Sea Mountains on the south and Black Sea on the north. The basin starts from Terme stream in the east of Samsun to reaches Georgia boundary. Total basin area is 24,077 km^2, yielding 14.9 km^3 water with an average 19.5 l/sn/km^2 yield (Bayazıt and Avcı 1997 and Uzlu et al. 2011; Fig. 1). The region is split by valleys reached from the sea into south zones. The strata of the studied area are generally made of impermeable or semi-permeable volcanic rocks, which prevent the rainfall from percolation and force the water to flow as runoff (Üçüncü et al. 1994).

Although Turkey is situated in a geographical location where climatic conditions are quite temperate, the diverse nature of the landscape and the existence in particular of the mountains that run parallel to the coasts result in significant differences in climatic conditions from one region to the other. The annual average rainfall height of Turkey is 643 mm. Turkey's diverse regions have different climates, with the weather system on the coasts contrasting with that prevailing in the interior. The Black Sea coast receives the greatest amount of rainfall and is the only region of Turkey that receives rainfall throughout the year. The studied region averages 1,019 mm annually; this figure can reach 2,300 mm near Rize Province.

Turkey is under the influence of many atmospheric conditions. First, the influence of Aegean, Marmara and Black seas are felt frequently. Second, various meteorological conditions can occur in the different regions of the country. Tracks of atmospheric cyclones affecting Turkey are shown in Fig. 2 (Toros et al. 2005). The tracks of cyclones that are effective in Turkey are classified in four groups. Path 1 originates from the southwestern parts of Russia and passes over the Black Sea region and reaches Turkey from the north. Path 2 originates from the Balkans and affects Marmara and the Black Sea region. Path 3 is generated in the Genoa Gulf and affects Turkey. This path can be divided into two sections: Both sections extend from the Genoa Gulf to the western Aegean Sea on the same track but split up later. Path 3a moves to the northeast and affects the North of the Aegean region, the entire Marmara region and western and middle Black Sea region. Path 3b moves towards the east and affects western Turkey and passes over middle Anatolia, later moves towards the northeast and affects the middle-eastern Black Sea direction. Path 4 originates from the west or middle Mediterranean Sea and in some cases from south of Genoa Gulf and in other cases from north of the Sahara Desert and moves towards the eastern Mediterranean. It affects southern parts of Turkey, Crete, Cyprus and the Middle East. As is shown in Fig. 2, EBSB is under the effects of path 1, path 2 and to some extent path 3b.

A study on the seasonal variability of the cyclone frequencies has revealed that the highest number of cyclones detected in Turkey occurs in winter (Karaca

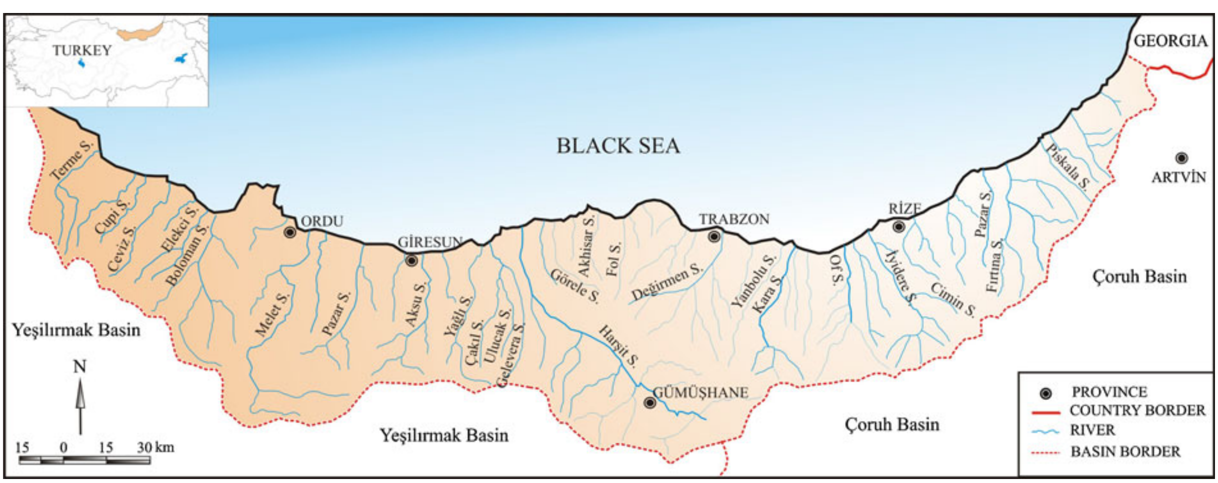

Fig.1 Location map of Turkey and studied area

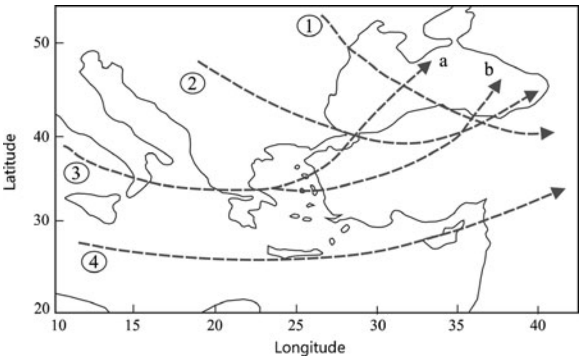

Fig. 2 Paths of atmospheric cyclones over Turkey

et al. 2000). Although northern parts of Turkey have been accepted as having a transition climate type between the Mediterranean and temperate regions, they have been under the effect of low pressure systems originating in the Mediterranean. It was also illustrated that there was a positive impact of the number of cyclones on the precipitation amounts of the stations located on the trajectories of cyclones. It can be concluded that paths 1 and 2, including the EBSR, are typical summer-time trajectories that bring summer storms over the northern parts of Turkey. They bring abundant rain with them and in some cases flooding is not a surprise.

Most of the drainage areas of the rivers in the basin are featured by short main courses, their steep slopes and rather dissected with deep valleys and the tributaries have river bed slope bigger than 10 to 20 % at upper reaches. Floods are due to heavy rainfall or to a sudden increase in air temperature, resulting in snow melt in the mountainous parts. During the flood, due to high sediment, the river flow is muddy and viscous has high velocity. The forest cover has been damaged by man and the water retaining capacity of drainage basin was decreased, therefore erosive energy is very high. The large amount of erosion and debris materials dragged by the flowing water and deposited in the flatter low lying areas. Sudden floods especially at the short main courses are common and these produce widely devastating flash floods in the project area and in the country, which usually occur more frequently on June, July and August.

Due to topography, local people use the flood plains of rivers located in very narrow V-shaped valley floors, both for settlement at urban areas, and agriculture at rural areas. In order to control the floods, local municipalities asked the central government to help them to build the longitudinal protection walls on both banks of the river section crossing the urban areas. Since the fertile land is very limited to the narrow valleys, it is very dear and utilized under any risky conditions.

Devastating floods

Flood data used in this study are collected analyzing various flood reports prepared by DSİ (DSİ 1970–2005). A brief knowledge of these floods is given in Table 1. In this table, "area" means that the inundated area by flood; as is seen, the inundated area data before 1970 are not available. During the studied 50-yearly period (1955–2005), totally 51 big floods occurred in the EBSB, causing 258 deaths. On the average 18 flood events occur in a year in Turkey and 1 flood event in the basin, which means that 5 % of the Turkey's floods have occurred in the EBSB. Annual average deaths are 23 and 5 in Turkey and in the area, respectively; in other words, 22 % of the deaths have taken place in this area. Annual average flood damages are US $86 million and US $10 million for Turkey and the studied area, respectively; implying that 12 % of the flood damages occurred in the EBSB. All of the damages included in Table 1 are direct damages, mostly including damages on property, agricultural and flood control facilities. Indirect damages, such as interruption of economical activities and traffic flow, people's demoralization, environmental damages etc., cannot be quantitatively evaluated and therefore are not included in the table.

As can be seen in Table 1, the most devastating flood is the 20 June 1990 flood with respect to all of three criteria, i.e. number of death (22.1 %), inundated area (70.4 %) and damage (69.0 %). This is an extraordinary event and will be analyzed in detail in "The 20 June 1990 flood" section. It is also interesting that there is an increasing trend in flood deaths and damages. This trend is obvious after the 20 June 1990 flood.

Hydro-meteorological analysis of the floods

In this section, a hydro meteorological analysis of the EBSB floods is presented. The scope of this analysis include: To investigate the dates of the floods, to determine the general trend of floods between 1955

Table 1 Summary of date, death, inundated area and damages of the floods

No	Date	Death	Area (10^3 m^2)	Damage (US$)	No	Date	Death	Area (10^3 m^2)	Damage (US$)
1	02 Sep 1956	–	–	1,009,088	27	30 July 1977	6	3,470	96,796
2	20 May 1959	13	–	923,036	28	03 Jan 1979	–	24	30,842
3	25 Aug 1959	–	–	2,506,264	29	14 June 1981	–	200	2,547,294
4	31 Dec 1962	–	–	60,207	30	04 Sep 1982	–	80	109,149
5	02 Jan 1963	3	–	43,450	31	19 July 1983	27	2,573	2,297,539
6	11 June 1963	–	–	461,385	32	21 July 1983	–	100	321,360
7	21 Sep 1963	2	–	308,181	33	01 July 1988	–	193	1,580,915
8	25 June 1965	2	–	1,517,660	34	21 July 1988	3	61	251,837
9	05 July 1966	6	–	1,168,007	35	01 Aug 1988	–	180	358,427
10	04 July 1967	–	–	1,206,243	36	02 Aug 1988	–	115	67,004
11	17 July 1967		–	179,881	37	27 Apr 1990	–	158	1,456,185
12	27 July 1967	–	–	113,742	38	20 June 1990	57	74,358	347,863,008
13	06 Aug 1967	–	–	51,175	39	31 July 1992	–	–	256,000
14	02 Sep 1967	–	–	847,623	40	27 June 1994	–	1,100	1,273,345
15	09 Apr 1968	–	–	119,787	41	08 Aug 1994	–	15	488,111
16	17 July 1971	–	1,256	1,021,486	42	06 July 1995	4	170	1,294,650
17	22 June 1972	–	4,384	640,068	43	31 July 1995	5	670	3,099,304
18	14 June 1973	–	3,610	5,163,450	44	31 Aug 1995	2	150	3,432,777
19	07 July 1973	7	–	38,693	45	08 Aug 1998	50	1,365	44,479,204
20	14 July 1973	7	5,293	41,457	46	12 Nov 2001	10	–	8,346,241
21	01 June 1974	–	–	5,206	47	24 July 2002	27	–	11,363,317
22	06 June 1974	–	–	514,317	48	10 June 2004	–	–	1,610,383
23	28 July 1974	–	70	44,400	49	02 Aug 2005	10	–	21,607,143
24	19 Aug 1974	6	2,780	513,966	50	21 Aug 2005	4	–	30,849,624
25	12 June 1975	–	2,125	46,160	51	03 Oct 2005	7	–	150,376
26	19 May 1977	–	1,146	162,420					
						Total	258	105,646	503,938,183

and 2005, to research a relationship between floods and meteorological parameters to be effective in the genesis of the floods and finally to analyze the 20 June 1990 Flood in detail. Since the inundated area data are not available for 1955–1970 period and this parameter is supposed to be less important than the other three parameters; the analysis of the floods are performed from the viewpoint of three parameters; number (quantity) of events and resulting death and damage.

Data used in the analysis

The data used in this analysis include flood and rainfall data. The flood data were obtained from Annual Flood Reports prepared by DSİ (DSİ 1970–2005). The main data related to the floods are their dates of occurrence (year, month and day), basin features, rainfall and discharge data, affected terrain, deaths and damages and possible causes and measures. In the analysis, only the data of discharge stations of which peak discharge were directly measured by rating curve (either by interpolation at low stages or by extrapolation at high stages) are employed. The data estimated by indirect methods (such as Manning Formula or rainfall–runoff analysis) are excluded, because of the problems related to reliability of these kinds of data.

The rainfall data were measured by the Turkish State Meteorological Service (DMİ) and DSİ at gauging stations. The main problem that had arisen in these data was the fact that many of the stations were equipped by pluviometers, not by pluviographs; which caused some problems at determining the rainfall intensity, the most important meteorological parameter on floods. In general, most of the rainfall data were daily (24 hourly) total values. In the studied region, six meteorological stations (Giresun, Akçaabat, Trabzon, Gümüşhane, Rize and Pazar) were equipped with pluviograph to measure the rainfall intensity of various durations (DMİ 2001). In the analyses, the maximum annual rainfall height data with various durations (5, 10, 15 and 30 min and 1, 2, 3, 4, 5, 6, 8, 12 and 24 h), prepared by the DMİ were also used (DMİ 2001)

Dates of the floods

By analyzing the dates (months) of floods from Table 1, the percentage of number of floods as well as deaths and damages are presented in Fig. 3. It is obvious that most of the floods in the EBSB have taken place in three months; June, July and August. Thirty-eight floods (74.5 %) occurred in these months, causing 223 deaths (86.4 %) and nearly US $490 million damage (97.3 %). In these months, heavy rainfall has been superposed by snow melt, as a result of increase in air temperature, in the mountainous valleys and has resulted in big floods. Everybody and every official or civil institution should be aware of a big flood especially in these three months.

General trend of the flood parameters

The main objective of this section is to discuss general trend of floods, from the viewpoint of their number (quantity) of event and the resulting death and damage. One, who has a glance at Table 1, easily perceives that although the numbers of floods do not change significantly from 1956 to 2005, both the death and damage figures are going up as the years elapse. This may be considered as a cursory indication of an increase trend for the flood effects. To get more adequate and reliable opinion about this trend, however, a more sensitive analysis should be carried out. Observation years are classified for 5-yearly periods (1956–1960, 1961–1965, etc.). The results are presented in Figs. 4 and 5. Figure 4 shows the variation of percentage of three parameters (quantity, death and damage) for 5-yearly periods. Cumulative percentage values of the parameters are given in Fig. 5. By analyzing these figures, one can conclude the following:

Quantity of flood events. There are some fluctuations in the quantity of floods. There is only one flood between 1996–2000 years. The quantities of the other five-yearly periods change between 3 and 10, without denoting a time-dependent trend.

Number of deaths. Unlike the quantity of the floods, the numbers of death have drastically increased from 1956 to 2005. The 20 June 1990 flood seems to “trigger” and “incite” the other floods that have resulted in considerable deaths. Before this flood, a total of 82 deaths occurred in 35 years (average 2.3 deaths per year); however, after (excluding) this flood, the figure has gone up 119 deaths in 15 years (average 7.9 deaths per year).

Quantity of damages. Similar trend is observed in the damages. The 20 June 1990 flood comprises nearly 69 % of the total damages, the annual

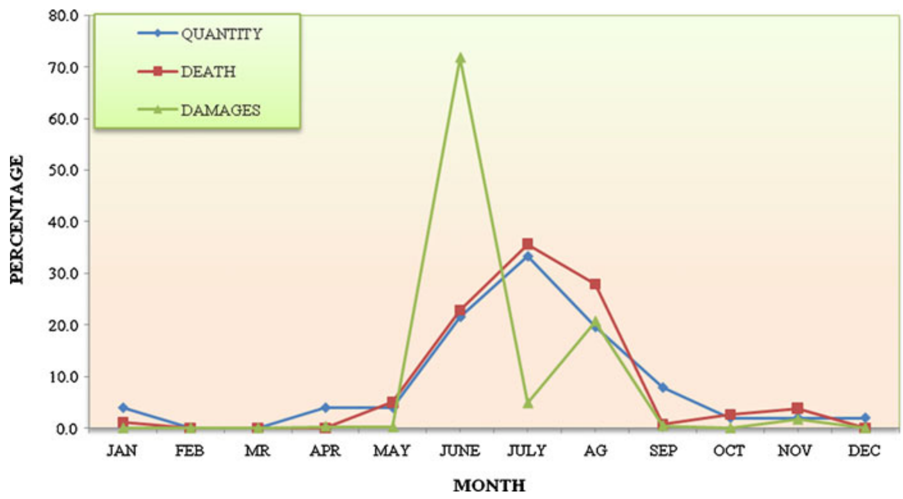

Fig. 3 Percentages of number, deaths and damages according to occurring months

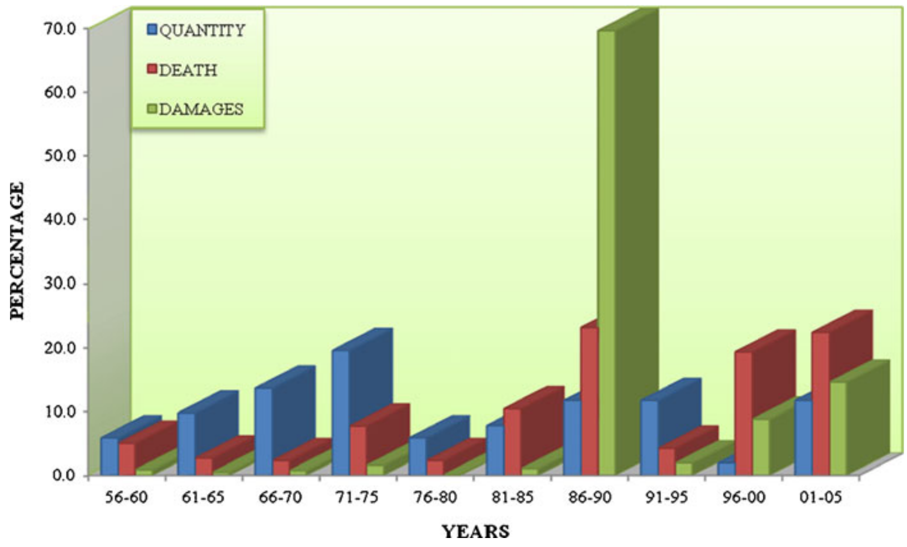

Fig. 4 Variation of percentage of number, deaths and damages for 5-yearly periods

average damages before and after this flood (excluding it) have increased from US $820,000 to US $8,540,000, respectively (nearly tenfold).

In brief, it is evident that even though no increase has been perceived in the numbers of the floods, there is an upward trend both in deaths and damages of the floods, especially after 1995.

Analysis of the selected floods

A list of brief properties, including the date and the location as well as the losses (to life and property), of the selected nine devastating floods is given in Table 2. In selecting the floods, the main factor is the magnitude of losses both to life and properties. There is no hydro-meteorological data for the floods of the period of 1956–1969, therefore these floods have not been included in the table. The data used in the analysis were collected by using flood reports prepared by State Hydraulic Works (DSİ 1970–2005). Since the devastating flood occurred in 20 June 1990 is analyzed in "The 20 June 1990 flood" section in detail, this flood is not included in Table 2 and in the analysis.

The rainfall heights (*h*, millimetre) were analyzed by comparing the measured heights at the same station at other dates; and by using the most suitable statistical distribution function, which was determined by chi-square test, the return periods were estimated.

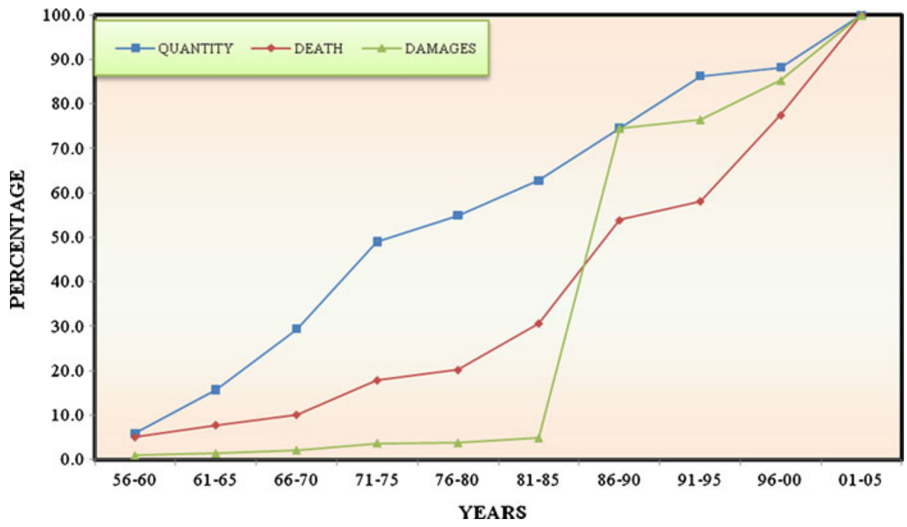

Fig. 5 Cumulative percentages of number, deaths and damages for 5-yearly periods

Table 2 Brief properties of the selected nine devastating floods

No	Date and location	Death	Damage ($)	Maximum flow			Maximum rainfall			
				Station	Q (m^3/s)	T (year)	Station	t (h)	h (mm)	T (year)
1	14 July 1973	7	41,457	Güneysu	242	5	Pazar	1	44.5	5
	Rize						Pazar	3	63.2	5
							Cayeli	24	50.3	1
2	30 July 1977	6	96,796	Arılı	511	100	Pazar	6	143.4	50
	Trabzon,			Büyükdere	225	25	Pazar	12	157.4	25
	Rize			İyidere	1,200	500	Ardeşen	24	96.7	2
				Baltacı	432	500	Çayeli	24	89.3	1
				Taşlıdere	904	100				
3	19 July 1983	27	2,297,539	Abuçağlayan	651	500	Ç.Hemşin	24	64.9	2
	Rize			Hemşin	590	500	Arhavi	24	132.4	5
4	21 July 1988	3	251,837	Ardeşen	42	200	Pazar	8	116.0	10
	Rize			Hemşin	260	25	Pazar	24	118.0	5
							Ardesen	24	180.2	100
							Meydan	24	65.1	5
5	06 July 1995	4	1,294,650	Solaklı	183	20	Caykara	24	20.4	1
	Trabzon,			Sürmene	180	35	Rize	24	40.8	1
	Rize			Erenköy	107	100				
6	08 Aug 1998	50	44,479,204	Maki	195	100	Rize	24	45.5	1
	Trabzon,			Yanbolu	54	5				
	Rize			Baltacı	95	25				
7	12 Nov 2001	10	8,346,241	Abuçağlayan	109	5	Pazar	24	99.6	5
				Hemşin	171	10	Tunca	24	163.5	100
				Hala	164	25				
				Salarha	124	5				
	Rize			Fırtına	233	10				
8	24 July 2002	27	11,363,317	Şenöz	57	5	Rize	24	42.3	1
	Rize			Salarha	80	1				
9	02 Aug 2005	10	21,607,143	Sürmene	190	40	Of	24	80	2
	Rize			Solaklı	200	50				
	Trabzon									
	Total	144	89,778,184							

Similar to the rainfall data, the discharges were also compared with the measured data at the same station at other dates and the return periods were estimated by using the most suitable statistical distribution function. Log Pearson Type III (LP3) distribution was the most suitable one for both rainfall and discharge values. The other suitable functions were found as Gumbel (*G*), two-parameter gamma (G2P), two- and three-parameter log normal (LN2 and LN3) distributions.

In the following, very brief analysis of the selected floods is given, according to the number of the flood number given in Table 2. Reliable and adequate hydrometeorological data, necessary for a detailed rainfall-runoff analysis, was not available; therefore, a relationship was researched between the return periods (which was considered to be a quantity related to magnitude) of observed rainfall heights (h) with various durations (t, hours) and maximum discharge (Q) values (T_h and T_Q, respectively). The measured rainfall values were compared with maximum daily rainfall values as well as with maximum annual values with various durations (t=5, 10, 15 and 30 min, 1, 2, 3, 4, 5, 6, 8, 12 and 18 h), in order to estimate their return periods. However, in the studied region, only six meteorological stations were equipped with pluviograph to measure the rainfall intensity of various durations (DMİ 2001). These values are considered in the analysis but are not included in Table 2.

Flood 1. The flood was effective in Taşlidere and İyidere Basins. According to explanations of the residents, rainfall lasted nearly 2 to 3 h. Since there was no gauging station where the rainfall was effective, the rainfall could not be measured. The flood discharge in Güneysu Town, located in Taşlidere Basin, had 5-years return period. However, no discharge was measured in İyidere Basin. As can be seen in Table 2, the return periods of 1- and 3-hourly rains in Pazar, of which data can be used for Güneysu, were 5 years. Similar rainfall heights for short durations were not available for İyidere Basin. It was decided that the rainfall that lasted 1 to 3 h resulted in flood discharges.

Flood 2. The flood affected all of Rize and eastern regions of Trabzon. The rainfall was expressed by the residents to last for 6 to 12 h. The return periods of the flood discharges were 25 to 500 years. The return periods of rains with 24-h duration were 1 to 2 years; however, the return periods of shorter duration rains, i.e. 6 and 12 h, which were effective on flood generation, were 25 and 50 years. However, there was no precipitation data in İyidere and Baltaci Basins, in which the greatest flood discharges were measured.

Flood 3. The flood was very effective in the Eastern regions of Rize; Pazar and Hemşin Towns, with discharges of nearly 500-years return periods. However, due to insufficient gauging mesh, no intense rainfall was measured. It was surmised that unmeasured rainfall in the upper parts of the basins resulted in big flood discharges.

Flood 4. The terrain of the flood was Ardeşen and Fındıklı Towns, located in the eastern part of Rize. It was estimated that the rainfall that lasted 6 to 8 h caused flood and landslide. As can be seen in Table 2, 24-hourly rainfall in Ardeşen and 8-hourly rainfall in Pazar resulted in great discharges with 200 and 25-years return period, in Ardeşen and Hemşin, respectively.

Flood 5. Nearly 3-hourly orographic rains were effective in Solaklı, İyidere and Taşlıdere Basins. The return periods of discharges were 20 to 100 years. However, due to insufficient gauging mesh, no intense rainfall was measured and it was surmised that unmeasured rainfall in the upper parts of the basins resulted in big flood discharges.

Flood 6. The flood affected Sürmene, Solaklı and İyidere Basins. The most devastating flood that had taken place in Beşköy Town, located in Sürmene Basin, caused an important landslide, resulting in 50 deaths in Beşköy. The measured rainfall height in Rize cannot explain the cause of great discharges with 5 to 100-years return periods.

Flood 7. The terrain of the flood was eastern parts of Rize. There is a general similarity between the return periods of rainfall (5 to 100 years) and discharge values (5 to 25 years).

Flood 8. The flood was effective in Taşlıdere Basin. According to rainfall and discharge values, with return periods 1 to 5 years, this flood should not be a devastating one. However, the unmeasured intense rainfall in the upper zones of Taşlıdere Basin caused local floods and landslides, resulting in 27 deaths and great damage.

Flood 9. The flood was very active in the eastern basins of Trabzon and western basins of Rize. The most devastating damage was observed in Solaklı Basin. In this basin, very intense local rain, which took place in very steep tributaries, caused considerable landslide and sediment transport; resulting in blockage of river sections and invasion to properties and roads. However, as a result of insufficient measuring stations, the rainfall could not be measured.

In brief, it is evident that there is a general relationship between rainfall and resulting discharge values, yielding a general agreement between their return periods. Statistically, however, the reliability of this relation and agreement is questionable. The main reason for the difference between magnitudes and therefore return periods of rainfall heights and resultant flood discharges is supposed to be inadequate precipitation measuring stations, which in turn has caused incorrect or inadequate measuring of height and especially intensity of the rainfall. Because, many of the floods occurred in areas where no or insufficient rainfall gauging stations have been established.

The 20 June 1990 flood

As was previously expressed, in 20 June 1990, a devastating flood took place in the basin. In this division, general properties of this flood are presented.

Rainstorm analysis

The widespread rainstorm of 18 to 20 June 1990 comprised by orographic rainfall, mainly caused by a frontal system which was brought about by northerner cold and southerner hot weather conditions. Hot and humid weather was raised during movement from sea to high mountains in the southern areas, causing to get cold and resulted in rainstorm. The addition of unsteady weather movements to the above mechanism made the orographic rains more severe. As a result, more intense rainfall was observed on the northern parts of high mountains (Yılmaz 1990). This rainstorm was effective on 19 June and especially 20 June. The meteorological data are total rainfall heights measured with 3-h time intervals. Cumulative heights (h) and intensities (i) of ten meteorological stations with pluviographs are given in Table 3 (Üçüncü et al. 1994). In this table, annual average (h_{av}) and previously observed maximum daily (h_{max}) rainfall heights are also included. Rainfall hyetograph is presented in Fig. 6. As can be seen in Table 3 and Fig. 6, the rainfall intensities have increased between 3–6 and 6–9 h, and the rainstorm has been effective especially around Doğankent, Kürtün and Tonya. These towns have relatively high elevations (Doğankent 550 m, Kürtün 500 m and Tonya 900 m). The 12-hourly isohyets map of the rainstorm is given in Fig. 7, revealing a decrease tendency as going away from the rainstorm centre.

It is evident from Table 3 that for Kürtün, Tonya, Düzköy and Gümüşhane, the total (12 hourly) rainfall heights during the flood are greater than those previously observed daily values. It may be more interesting to perceive that 25.8 % of total average rainfall dropped in Kürtün during the flood. Similar percentages are 15.5, 15.1, 13.9 and 12.8 for Tonya, Gümüşhane, Düzköy and Doğankent, respectively.

By using the maximum annual rainfall height data with various durations (5, 10, 15 and 30 min and 1, 2, 3, 4, 5, 6, 8, 12 and 24 h), prepared by the DMİ (DMİ 2001), the return periods of the rainfall heights in Trabzon, Gümüşhane and Giresun Provinces were calculated and compared with the observed data. It has been concluded that the return periods of the rainfall heights were 25 and 50 years for 9 and 12-hourly rains in Trabzon; and 50 years for 6 hourly and 250 years for 9- and 12-hourly rains in Gümüşhane. In Giresun, the return periods were smaller than 1 year. In brief, the rainfall values during the flood denote a very extreme rainstorm, of which return periods can go up to 250 years.

Stream discharges

As previously explained, the flood has caused extraordinary discharges. The data were collected by the method which was explained in the "Data used in the analysis" section. The observed maximum discharges (Q_{max}) and their return periods (T) are presented in Table 4 together with area of the station, number of observation year (N) and most suitable distribution for Q values. In this table, 12-hourly maximum rainfall heights (h) and their return periods (T) for the nearest meteorological station(s) are also included. The

Table 3 Cumulative rainfall heights and intensities of meteorological stations for 20 June 1990 flood

Station	h_{av} (mm)	h_{max} (mm)	3 h		6 h		9 h		12 h	
			h (mm)	*i* (mm/h)	*h* (mm)	*i* (mm/h)	*h* (mm)	*i* (mm/h)	*h* (mm)	*i* (mm/h)
Doğankent	1,270	226	28	9.3	92	21.3	149	19.0	163	4.7
Kürtün	616	71	26	8.7	89	21.0	142	17.7	159	5.7
Tonya	1,003	56	24	8.0	86	20.7	139	17.7	155	5.3
Düzkoy	856	53	20	6.7	67	15.7	108	13.7	119	3.7
Vakfıkebir	1,238	171	19	6.3	62	14.3	102	13.3	114	4.0
Tirebolu	1,670	241	15	5.0	49	11.3	80	10.3	87	2.3
Trabzon	802	107	13	4.3	43	10.0	72	9.7	79	2.3
Gümüşhane	445	60	10	3.3	36	8.7	58	7.3	67	3.0
Maçka	686	78	8	2.7	33	8.3	51	6.0	56	1.7
Giresun	1,297	180	6	2.0	22	5.3	34	4.0	38	1.3
Average			16.9	5.6	57.9	13.7	93.5	11.9	103.7	3.4

locations of the discharge gauging stations are given in Fig. 7 by the number (No) of the station.

Relation between intense rainfall and flood discharges

During the hydro-meteorological analysis of the flood, the most important point that may arise is the relation between rainfall parameters and magnitude of the flood discharges. Since reliable and adequate hydro-meteorological data necessary for a detailed rainfall-runoff analysis are not available, it has been difficult to quantitatively research a mathematical (statistical) relation between rainfall and discharge values. However, it is possible to qualitatively investigate the relation by comparison of the magnitudes and return periods of both rainfall and maximum discharges. Therefore, a relationship was researched between the return periods (which was considered to be a quantity related to magnitude) of observed rainfall heights (*h*) and the resultant maximum discharge (*Q*) values (T_h and T_Q, respectively).

By taking into consideration Table 4 and Fig. 7, it is obvious that there is a general agreement between the return periods of the discharges and rain heights. The streams, which are located in or near the rainfall centre, i.e. the stations with numbers 2, 3, 4, 5 and 6, have discharges with greater return periods, 75 to 200 years;

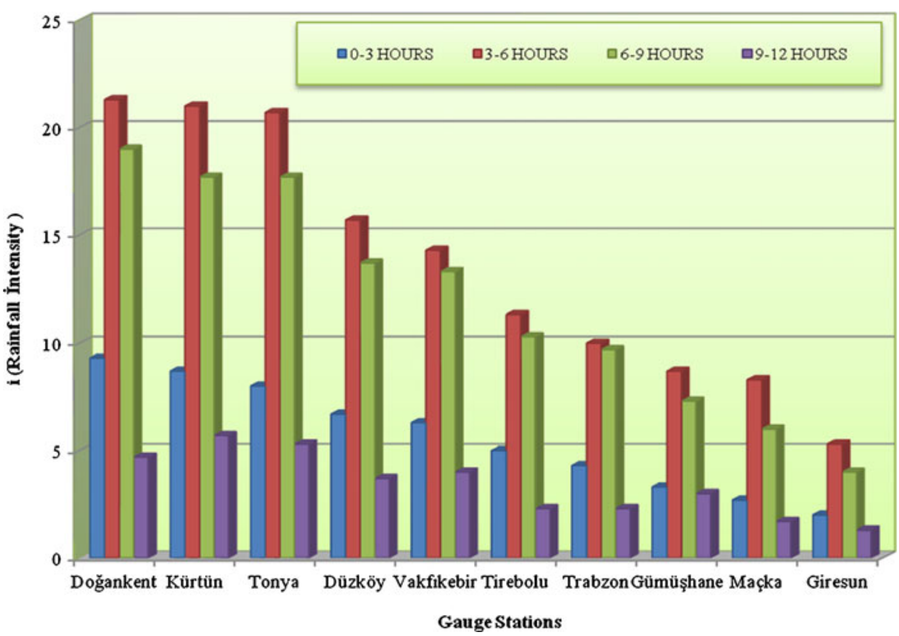

Fig. 6 Hyetograph of the rainstorm of 20 June 1990 flood

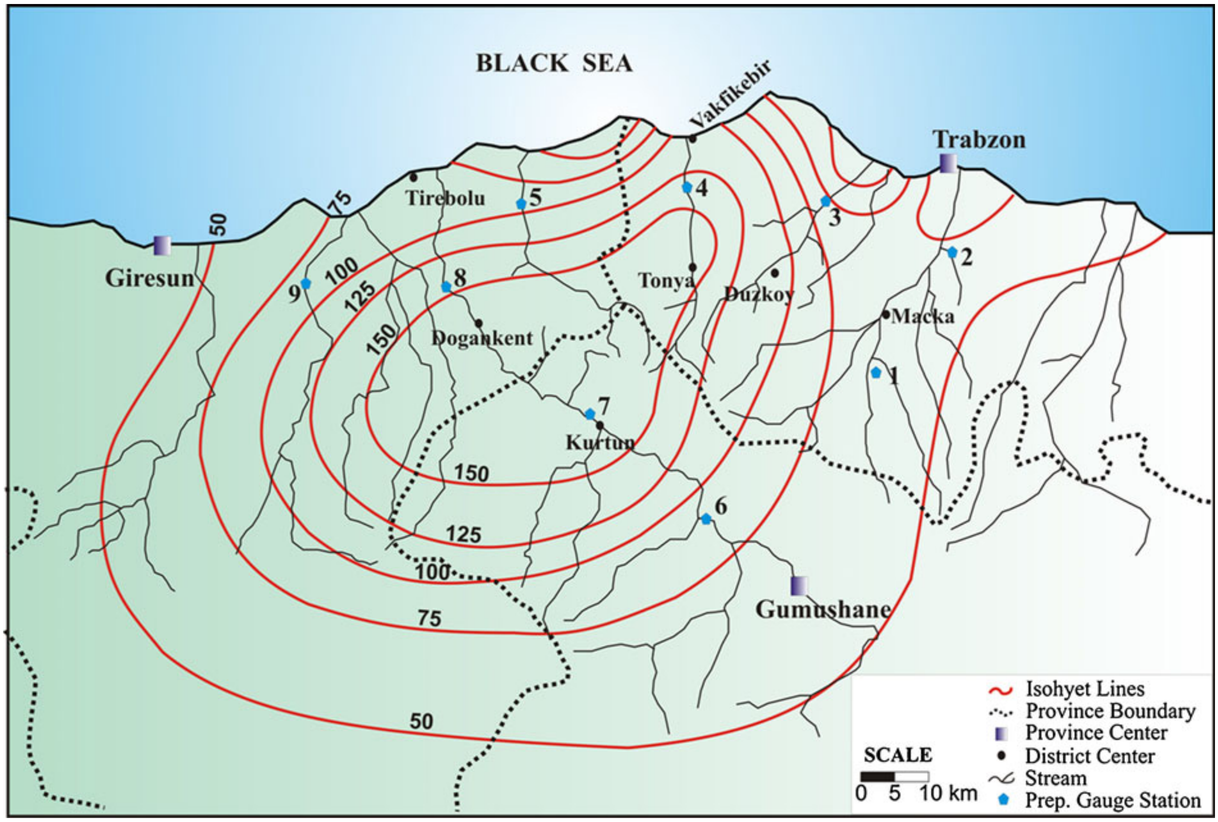

Fig.7 Twelve-hourly isohyets map of the rainstorm of 20 June 1990 flood

however, the return periods of the discharges of the other streams are smaller, 25 to 50 years. Therefore, it is concluded that there has been a relation between the magnitudes of flood discharges and rainfall heights.

Deaths and damages

As can be seen in Table 1, a total of 57 people have died in the 20 June 1990 flood. The inundated area and the damage percentages of the flood out of all of the 54 floods were 70.4 and 69.0, respectively; however, the percentage of deaths were 22.1. Therefore, it can be concluded that the number of deaths of this flood was not very high and this flood may be considered a fortunate one, from the viewpoint of the number of deaths. The main reason for this fortune was the fact that most of the flood was befallen in rural areas, where population density was low. Although the centre of the flood was near Kürtün, Doğankent and Tonya, most of the death losses were in Trabzon city centre and its neighbourhood, with high population density. Most of the damages were on real property and agricultural damages and damages of flood control facilities. Most of the damages have occurred in Trabzon.

Main causes of flood harms

As is explained in "General trend of the flood parameters" section, although no increase has been perceived in the numbers of the floods, there is an upward trend both on deaths and damages of the floods, especially after 1995. In this section, the main reasons for the flood harms, including damages to lives and properties, are briefly presented. In general, the main reasons are similar worldwide and can be found in flood reports and papers. In Turkey and in the EBSB, however, there have been some local causes to accelerate and aggravate the harms. In this section, the main causes that aggravate the flood harms are evaluated as "natural causes" to represent any changes in the meteorological conditions, and as "human factors" to reflect the effects of the variations of terrain parameters on flood harms.

Table 4 Flood and rainfall properties of 20 June 1990 flood

No	Flood discharge values						Maximum rainfall values (12 h)		
	Stream/Station	Area (km^2)	N(year)	Suit. Distr.	Q (m^3/s)	T (year)	Nearest stations	h (mm)	T (year)
1	Yağlıdere/Sınırköy	297	20	LPT3	250	50	Doğankent	163	150
2	Yağlıdere/Tuğlacık	398	20	PT3	300	200	Doğankent	163	150
3	Gelevera Deresi/Hasanşeyh	257	14	PT3	345	75	Doğankent	163	150
4	Harşit Çayı/Torul	1900	31	LPT3	659	200	Kürtün	159	250
							Gümüşhane	67	250
5	Harşit Çayı/Eymür	3133	28	LPT3	2024	150	Doğankent	163	150
							Tirebolu	87	10
6	Görele Deresi/Cücen Köprü	163	24	LPT3	280	75	Doğankent	163	100
							Tirebolu	87	10
7	Fol Deresi/Bahadırlı	191	34	LN2	246	25	Tonya	155	250
							Vakfikebir	114	10
8	Değirmendere/Öğütlü	728	13	LPT3	610	40	Maçka	56	15
							Trabzon	79	25
9	Kalyon Deresi/Çiftdere	122	21	LPT3	135	50	Maçka	56	15
							Trabzon	79	25
10	Altındere/Ortaköy	261	19	LPT3	157	50	Maçka	56	15
							Trabzon	79	25

Natural causes

Main natural causes of floods in the EBSB, which have mainly occurred in summer months, are heavy rain and snowmelt. Therefore, in order to study the effects of natural causes, it is necessary to research whether or not there have been important changes in the meteorological parameters, in other words, if there have been climate change.

In a study, performed on the time histories of the number of the flood events and precipitation intensities in Turkey during the period of 1940–2002, it was concluded that an increase was observed in the number of the flood events after 1995, despite the fact that no increase trend in the precipitation intensities (Kömüşçü and Ceylan 2003). In order to research if there is an increase in the extreme rainstorms in the EBSB, the data of the DMİ (DMİ 2001), were analyzed and it was concluded that the maximum precipitation values for various rainstorm durations were occurred in 1957, in 1992, in 1981 and in 1979, in Rize, Trabzon, Giresun and Gümüşhane Gauge Stations, respectively. The rainiest 5 years for these four stations are presented in Table 5, together with observation durations. In the table, rank 1 means the rainiest year, rank 2 means the second rainy year, etc. As can be easily perceived, there is no increasing trend in the extreme rain values, which means no important climate change. It is also obvious in Figs. 4 and 5 in "General trend of the flood parameters" section that there is no increase trend in the number of flood events. In brief, there is no important climate change to cause increases in flood harms.

Human factors

Since no significant climate change has been perceived, the reasons for the increase in flood harms should be attributed to other factors, the so called "human factors". In the following, the most important human factors are summarized:

Land-use, particularly wrong and even illegal land-use, is a most important factor in Turkey when dealing with the flood damage. Deforestation is one of the main factors. During the past 30 years, continuous forest cutting to gain new agricultural areas, especially on the steep slopes of the Eastern Black Sea mountain range, and clear-cutting of shrub-size oaks as burning material in winter has increased the possibility of landslides and debris flows, while at the same time destroying valuable fertile soil and increasing the sediment loads in the river (Köse et al. 1990). Another cause is wrong urbanization. Despite the fact that the economical life of the residents of the region depends primarily on agriculture, the areas suitable for agriculture are rather scarce and expensive. Therefore, the residents have been forced to get some areas on the alluvial soils within the river beds and riverbanks. In addition, for the similar reasons, the people have established great settlement and industrial facilities near or within the stream zones (Üçüncü et al. 1994). In order to absorb the increasing population, new settlements have been built, mostly illegally. The increasing property value has made the flood risk worth taking and has encouraged people to settle in the flood-prone zones despite their known danger. Insufficient flood control structures and the lack of channel improvements in the creeks have further enhanced the flood damage. The capacity of the storm sewers and flood detention structures in the cities is often inadequate to control large floods. The conveyance capacity of the creeks is greatly reduced during floods by building the walls of houses in the stream beds, constructing roads on the stream beds and throwing garbage

Table 5 The rainiest 5 years in EBSB gauge stations

Station	Obs. dur.	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Rize	1940–2000	1957	1996	1960	1963	1975
Trabzon	1967–2000	1991	2000	1966	1982	1999
Giresun	1968–2000	1981	1972	1966	1992	1996
Gümüşhane	1968–2000	1979	1985	1972	1971	1968

and construction material into the creeks. These non-meteorological factors aggravate the consequences of the floods to a great extent (Bacanlı et al. 2003).

Various problems have been encountered during the execution of the flood control studies of the 22nd Division of DSİ, mostly because of insufficient coordination between the DSİ and other related institutions and due to authority disorder. Especially, the activities of municipalities, General Directorate of Highways (GDH) and General Directorate of Rural Services (GDRS) have caused serious problems. The main problems are as follows: The housing and land filling applications of municipalities near or within stream areas; the activities by GDH by not taking into account possibility of floods in tributaries; the carelessly filling of debris material excavated during road construction by GDRS into streams and carelessly sand and gravel dredging from streams by quarries (Ege et al. 2007). These kinds of problems have brought into light both insufficient coordination and authority disorder. Turkish Prime Minister's Office has published a circular entitled "Stream Areas and Floods" in order to solve these problems.

Psychological factors have become one of the prevailing human factors. Three great and widespread floods, which took place in 1929, 1959 and 1990 (nearly within 30-yearly time intervals) in EBSB, seemed to be forgotten by people and state; so, a possibility of another devastating flood may have took place could not be remembered. As a result of this indifference, private and official institutions have inexcusably interfered to the natural situation of stream zones, causing narrowing of stream sections and forcing the streams to flow within "artificially narrowed" conduits. Almost nobody has been able to get some lessons from these floods; and nobody has tried to answer to the question: "How can we cope with a great flood ?".

There have been some technical factors to aggravate the damages. Erroneous design (wrong site, span and bearing system selection), construction, usage and maintenance of the bridges have resulted in destroying. Another technical factor was insufficient design of urban rainfall drainage channels, causing seriously destroys (Üçüncü et al. 1994).

Possible measures

Existing flood measures in Turkey

The existing flood-related measures can be summarized as:

Structural projects: Structural projects keep flood waters away from an area with a levee or reservoir, or other measure that controls the flow of water, such as diversion structures, dykes and groins.

Hydro-meteorological observation studies: Observations have been performed to determine riverine flood hazard by catchment area characteristics, such as rainfall and flows.

Survey reports on past floods: The DSİ has been preparing survey reports soon after flood events to establish actual flood damage information and area of inundation. These reports also include date, time, duration, place, meteorology, hydrology and hydraulic of each flood event. The study method is based on field interviews, questionnaires, observations and flood records.

Structural measures

In the case study area, there are 243 flood control structures completed and in operation, and 45 are under construction. All the project activities, as the structural measures, regarding to the flood protection and harm mitigation are being operated by the DSİ. A list of flood control structures are presented in Table 6 (Filiz et al. 2006). These structures include dykes and flood levees. Modern solutions including flow diversions, reservoir detention and drainage improvement should also be planned and applied.

Non-structural measures

From the experiences gained during the flooding events, it can be concluded that building a flood control structure is neither the best solution nor the only solution to a flood problem. Non-structural flood protection measures such as early flood warning system and the modification of land use in the region should be initiated as soon as possible in the case study area. The other non-structural measures comprise watershed management and improvement, flood insurance,

Table 6 Flood control studies of DSİ

Province	Stage	Number of facility	Number of protecting town	Protecting area (ha)
Rize	Completed	40	35	569
	Under const	11	19	210
Trabzon	Completed	87	77	1,627
	Under const.	19	29	63
Giresun	Completed	59	56	956
	Under const.	12	16	365
Gümüşhane	Completed	57	59	751
	Under const.	3	1	248
Total		288	292	4,789

organization of flood management studies, education of the people and the informing of the stakeholders. One of the most important measures is especially enforcement of the laws related to flood control. Stopping the deforestation and improving the rain and discharge gauging mesh, which in turn permits more accurate flood prediction, also should be significantly considered as non-structural measures.

Planning of emergency response measures should include of inundation potential maps, which can be used for the planning of emergency response measures to select emergency shelters and evacuation routes. Propagation time of a peak flood wave at different inundation zones delimited in the maps can be used to estimate the emergency response time for different locations. Government agents should be trained to be capable of using basic information contained in maps for regulations and planning (Teng et al. 2006).

The main characterization of the land-use in the area is type of agriculture. However, recreational use of the riversides is common also. Because of high population rate and continuously dividing of agricultural properties and regarding to the continuous agricultural development, some problems have recently been seen to get the utmost benefits from the agricultural projects. In order to solve these problems, the land expropriation is being considered as primary issue. Among the major benefits of land expropriation are the applications of modern techniques in land use, the construction of network for irrigation and transportation in the agricultural areas, the lowering of loss regarding to the employment, and the prevention of over dividing of land areas (Gürer and Özgüler 2004).

According to the present laws and regulations on dealing with the natural disasters, the state is the main healer of the disaster hit area both economically and psychologically. Local interest groups should also include these studies. There are nongovernmental organizations; the unions of farmers, merchants, businessmen, chamber of commerce, mukhtar (elected head of village), elected representatives of the local people, mayor, in helping to shape up the local public mind to deal with the similar type of floods in future. There may be economic help from the banks, rich local people, some nationwide campaigns to help the disaster hit area but usually these types of helps come afterwards and not sure. There are no written rules to define the type of the service the NGOs are expected to give, but their service is voluntary. So the state is the main healer and organizer of the helps.

Turkish Prime Minister's Office has published a circular in order to solve the problems arisen by insufficient coordination and authority disorder between the DSİ and other institutions. It is hoped that by applying this circular, most of the problems may decrease

Summary and conclusions

In this study, general knowledge of the floods in EBSB of Turkey is presented. Brief hydrometeorological analysis of selected nine floods and detailed analysis of the most devastating flood are presented. The main reasons of the flood damages and some structural and non-structural measures to mitigate these damages are also concluded in the paper.

A flood inventory in Turkey has shown that on the average 18 flood events occur in a year and they take about 23 lives, causing US $86 million damage. The valleys all along the Eastern Black Sea are particularly threatened by floods which are mainly produced by heavy rainfall in combination with various geomorphologic features. Floods are due to heavy rainfall or to a sudden snowmelt, and both factors may occur depending on the time of the year. Precipitation types are frontal, orographic or convective. During occluded fronts, long-lasting intense rainfall may produce flooding, depending on the season of the year. The snow accumulated in the upper reaches of the drainage basins of rivers melts as of the beginning of May or June, and can cause flooding in downstream areas of the rivers.

Very big and destructive floods have occurred in the EBSB of Turkey. In this basin, 51 big floods have taken place between 1955 and 2005 years, causing 258 deaths and nearly US $500,000,000 of damage. The basin is among the rainiest in Turkey. Steep slopes cover great areas, causing to increase of surface runoff velocities.

Most of the floods in the EBSB have taken place in three months; June, July and August. Thirty-eight floods (74.5 %) occurred in these months, causing 223 deaths (86.4 %) and US $490 million damage (97.3 %). In these months, heavy rainfall has been superposed by snow melt, as a result of increase in air temperature, in the mountainous valleys and has resulted in big floods.

A brief analysis for selected nine floods has been performed to research a relation between the return periods of observed rainfall and maximum discharge values. Although a relation has appeared, this has not been satisfactory, mainly due to inadequate precipitation measuring stations, which in turn has caused incorrect or inadequate measuring of height and especially intensity of the rainfall. Detailed analysis of the most devastating flood, 20 June 1990 Flood, however, has shown that there has been a relation between the return periods of intense rainfall and extreme flood discharges. The number of deaths of this flood was not very high, mainly due to the fact that most of the flood was befallen in rural areas, where population density was low.

It is concluded that there has been no significant climate change to cause increases in flood harms, therefore the reason for harms has been attributed to human factors. The most important human factors are determined as wrong and illegal land use, deforestation, wrong urbanization and settlement, and psychological and technical factors. Because of insufficient coordination between the DSİ and other related institutions and authority disorder, various problems have been encountered during the execution of the flood control studies of DSİ.

Some structural and non-structural measures to mitigate flood damages are also included in the paper. Structural measures including dykes and flood levees are being constructed and operated by the DSİ, however, alternative techniques including flow diversions, reservoir detention and drainage improvement should also be taken into consideration. Despite the fact that building a flood control structure is neither the best solution nor the only solution to a flood problem, non-structural measures are not generally taken into consideration. Various kinds of non-structural measures are proposed in the paper. They include flood protection measures, watershed management and improvement, flood insurance, organization of flood management studies, education of the people, informing of the stakeholders, planning of emergency response measures, land expropriation, and including of local interest groups and nongovernmental organizations into flood mitigation studies.

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