Evaluation of Factors Contributing to Floods in the Outlet Part of the Kura River, Azerbaijan

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Introduction

Rainfall and intense snowmelt have long been considered as the major flood formation factors in rivers (Booij 2005; Istomina et al. 2005; Simonovic and Carson, 2003). Therefore, flow regulation has long been thought as the most effective method for the flood prevention. However, this experience has shown its limitations over the last few decades when the strong floods have been observed in regulated rivers (e.g. Yongqiang and Xiqing, 2000). Since most of rivers have been highly affected by human activities, there are obvious changes in the genesis and nature of floods (Abbasov and Mahmudov 2009). Recently, there is a growing awareness that, the magnitude of peak flow is not the only factor of flood risk (Lane et al. 2007).

Factors that contribute to river floods can be divided into two categories: direct factors which cause the level rise by affecting the magnitude and duration of water flow; and indirect factors, which affect the size of the active channel and the function of the riverbed (Figure 1). These two categories can also be further defined as climatic and non-climatic factors. Climatic factors (intense snowmelts and rains) have a climatic origin and directly increase the water level and volume in the channel, impacting the main flood characteristics-peak, duration and volume. Floods which have purely climatic origin are caused by intense rains, as well as snowmelts (e.g. Hartvich et al., 2007). Over the past century there is an increasing contribution of climate changes to flood formation processes as well. There is a growing awareness that rising sea levels in the future will be major contributors of floods in downstream parts of the rivers (Booij, 2005; Monirul et al., 2003).

Non-climatic factors include changes in land use (Jackson et al., 2008), deforestation and erosion (Abbasov and Mahmudov, 2009; Mohapatra and Singh, 2003), flow regulation, water withdrawals (Istomina et al., 2005) and channel siltation (Hoogendoorn and Weltje, 2008). Non climatic factors of floods refer to factors that are related to reductions in channel capacity and result in floods. Floods in the rivers fairly close to the northern circle are also caused by ice jams and ice gorges (Beltaos, 2003). Landslides and snow avalanches can also be considered as one of major non-climatic factors.

The experience of the last decades shows that in some rivers flow regulation and other advanced water management practices may not be rather useful, since there are some gradual changes in the origins of floods. Due to wrong land use practice and water management, the role of non-climatic factors in flood formation processes continuously increases and erosion and channel siltation have become major reasons of floods in many rivers of the world (Johnson and Warburton, 2002). Unlike the practice of the previous decades, floods at the downstream part of the Kura River in Azerbaijan has not purely climatic origin.

The goal of this study was to evaluate the long-term changes in flood formation factors contributing to floods in the downstream part of the Kura River. Over the past century, notable floods in the Kura River were observed in 1915, 1936, 1942, 1944, 1946, 1952, 1961, 1969, 1976, 2002, 2003, 2004 and 2008. More recently, there are numerous additional factors occurring in and around the basin that have increased the occurrence of floods. Over the past years, there had been an increased frequency and duration of floods in the downstream part of the Kura River. Heavy deforestation in the river basin, flow regulation and, intense water withdrawals have contributed to sedimentation problems in the channel, decreasing channel capacity (Abbasov and Mahmudov, 2009). Reduced flows lead to decrease of velocity of water flow, which may lead to intense accumulation of the channel, although subsequent high flows are often not high enough to flush riverbeds from accumulated silt. Over the past 40 years the level rise of the Caspian Sea, into which the Kura empties, has also contributed to floods with long duration. As a result of the backwater effect from the sea, large territories rather far from the outlet were inundated for a long time. As a result, agricultural lands of the Kura-Araks lowlands are inundated and colossal economic and social damage is caused to municipalities and households located near the banks. High conductivity of soils in surroundings also increases local groundwater levels and can affect the normal activity of households both along the river banks and the territories located far from the river. The problem is exacerbated by the absence of integrated basin management traditions in the region and lack of capacity to stop the hazardous processes at the local and regional level.

Study area

The Kura River, together with the Araks River, forms the largest transboundary river system of the South Caucasus region. This river originates from Turkey, and then it reaches the territory of Georgia and Azerbaijan respectively. In the territory of Azerbaijan, the Kura joins with the Araks River and flows into the Caspian Sea. The Kura catchment is approximately 188000 km^2 in size and the main channel is over 1515 km long (figure 2). This river is mainly fed by snow waters and rains. The majority of the annual discharge of the Kura River is in the form of seasonally high flows in the springtime, triggered by intensive snowmelt and constant rains. These high flows, observed in April-June, contribute approximately to 50-60% of the volume of annual river flow (Rustamov and Kashkay, 1989).

The downstream part of the Kura basin is characterized by growing rate of agricultural activity and oil industry. This territory has rather high rates of urbanization along the coastal territories. Nearly 150 small towns and villages with 320.000 residents are located on the coastal territories of the Kura river. These towns are located in the high flood risk territories and regularly experience floods. The main facilities damaged by floods which observed in 2002, 2003, 2004 and 2008 were housing, infrastructure and agricultural lands. These floods seriously affected agricultural and industrial production and caused immense suffering to people.

In an effort to reduce the frequency and severity of floods the Mingechaur Water Reservoir was constructed in 1953. This reservoir is located in the middle zone of the Kura River. With a normal support level of 83 m its maximum depth reaches 75 m, and its area is 625 km^2, its volume is 16 km^3. The length of the reservoir is 75 km and - has a coastline of 227 km. After the reservoir construction, the highest peak flows were reduced and floods were almost entirely eliminated during the first 15 years after construction (Mamedov 1989). Recently, there have been constructed four large dams on the Kura and two on the Araks River. The largest dam on the Araks river is the Araz Water Junction, which has 145 km^2 of surface area and 1.35 km^3 of water volume. The Mil-Mugan reservoir is the second one by volume and surface area, which has partially regulation effect. Tandem reservoir systems on the Kura River include Mingechevir, Shamkir, Yenikend, and Varvara Reservoirs. Some small reservoirs are also built on the small mountain rivers, mainly for irrigation. The total capacity of operating water reservoirs in Azerbaijan is about 20.6 km^3, the net storage volume is 12.4 km^3, the total area is 877 km^2, and the total capacity of hydroelectric power station is 978,500 kilowatt.

A well-developed network of canals between the Kura and Araks rivers makes it possible to irrigate a major part of the lowland. The Upper Karabakh Canal, 172 kilometres long, provides a vital link between the Aras River and the Mingacevir Reservoir on the Kura River. The Upper Karabakh Canal alone irrigates more than 100,000 hectares of fertile land and in addition supplies the Araks River with water during dry summer periods. The Upper Shirvan Canal, the second most important canal, is 123 kilometers in length and also irrigates about 100,000 hectares. The channel capacity of the Upper Karabakh and Upper Shirvan canals are accordingly 114 m^3/s and 78 m^3/s (Shiklomanov, 1989).

Climatic factors

The hydrological data observed and collected in Salyan, located 85 km from the mouth at the Caspian Sea was used to characterize variability of peak discharges in the mouth part of the river. Since 1937, flow discharges were regularly measured here, however, in some years flow for this site was not determined because of the low quality of the measurements. The missing data were restored by Mikhaylov et al. (2003), by using correlation relationships of the different hydrological sites located on the Kura River.

Main climatic factors of floods in the Kura River include intense snowmelt episodes and intense rain, which come into sight as peak discharges during spring months. Nevertheless, long-term yearly regulation of flow has deeply impacted the natural regime of the flow and significantly reduced peak discharges. In addition to flow regulation, the flow in the downstream part of the river has been affected by human activity. Since the beginning of 1960s the river discharge in the Kura River began to decrease due to intense water withdrawals (Shiklomanov 1989; Demin 2007). The development of the irrigation farming and intensive water use in the watershed of the Kura had increased fresh water consumption in Azerbaijan, which is largely supplied by resources of the Kura. Most of the water resources of small tributaries of the Kura are withdrawn by the industry and agriculture (Abbasov and Smakhtin, 2009; Hoogendoorn and Weltje, 2008; Bousquet and Frenken 1997) and the annual flow in the Kura has been diminished.

The effects of water withdrawals on the river discharges in the study area have been studied by Shiklomanov (1989) and according to those results, there is strong evidence to suggest that irrigation and water withdrawals in the past century have made a significant affect on the flow of the Kura river and small streams of the Kura-Araks basin. The results received by Fatullayev (2003) and Demin (2007) are in agreement with those of the study carried out by Shiklomanov. According to these authors, the annual water withdrawals in the Kura basin consists about 230 m^3/s, which is about 35-40% of the water resources of the Kura River. Abbasov and Smakhtin (2009) also suggest that the flow regulation and water withdrawals are major factors in the Kura-Araks basin, affecting not only large rivers, but also small mountain streams.

In order to detect chronological changes in hydrological and meteorological characteristics, different trend detection methods are widely applied (Helsel and Hirsch 1992; Hamed, 2007; McBean and Motiee 2008). Most of these methods applied to estimate trends in time series (TS) of flow, precipitation and temperature. Linear trend detection methods and Mann Kendal test statistics are considered as the most used methods in hydrology (Burn and Hag Elnur, 2002; Hamed, 2007). Student statistics are also used to test homogeneity of two samples taken from the same population (Press at al. 1992) and in this study it was used to test equality of the average values of two samples which represent TS of annual flows and peak discharges.

In order to test the equality of average values of the same population, TS of annual discharges has to be split into two samples and for each of them average values and standard deviations must be computed. After this procedure, the test statistics which follows Student distribution must be computed:

$$t = \frac{\overline{q}_1 - \overline{q}_2}{\sqrt{n_{q1}\sigma_{q1}^2 + n_{q2}\sigma_{q2}^2}} \sqrt{\frac{n_{q1} n_{q2} (n_{q1} + n_{q2} - 2)}{n_{q1} + n_{q2}}} \qquad (1)$$

Where, t -is a Student test statistics, $\overline{q}_1$ -average value of the first sample, $\overline{q}_2$ -average value of the second sample, n_{q1} -is the size of the first sample, n_{q2} -is the size of the second sample, σ_{q1}^2 and σ_{q2}^2 are the standard deviations of the first and second samples.

The statistical significance level associated with the t value is the probability that, under null hypothesis of equal averages, the absolute value of t could be that large or larger just by chance- in other words it is a two-tailed test, testing whether the averages are different when, if they are, either one may be larger. The computed values of t are compared with the values for different significant levels, which is determined by the Student distribution. These values can be estimated or taken from the Student tables (Mitropolski 1971). Many software programs, such as Excel and MINITAB also offer to estimate Student statistics. If computed t value is larger than determined ones, then the null hypothesis is rejected and long-term changes in average values of naturalized data were observed, with high guarantee that they were due to climatic changes. TS that tested by Student statistics must follow normality and be tested for it. At the same time, in hydrology this statistics is used on TS which has more than 30 years of records. In such cases equality of standard deviations for each sample has to be checked and for that purpose Fisher statistics can be used.

Fisher statistics is estimated by this formula:

$$F = \frac{\sigma_{q1}^2}{\sigma_{q2}^2} \qquad (2)$$

Detailed information regarding Fisher statistics is given by many authors (e.g. Mitropolski 1971). The main concern when using Student statistics is to clarify where TS has to be split into samples, since this aspect might completely change the results of computations, sometimes illustrating wrong outcomes. In this study, TS of annual flows and peak discharges were split into two periods: before and after major human impact on flow regime. For the Kura river, the first part may be represented by the period before the year of the Mingechevir reservoir construction and the second part – after it. The first part represents natural flow regime and the second – regulated one. Therefore, in order to check homogeneity of taken samples, TS of annual flows and peak discharges of the Salyan hydrological station were split into two samples and checked by Student and Fisher tests, which are given by formulas (1) and (2). The STOK STAT software was used to determine homogeneity by Student and Fisher tests. The tests which were taken for downstream sites illustrate that there are considerable changes in both annual flows and peak discharges. As it seen from the table 1, the flow regulation has made considerable changes in long-term alteration of peak discharges. Results of the tests illustrate that the samples, taken from the TS of the peak discharges are not homogenous, in all significant levels. This circumstance may be explained by the great impact of the flow regulation, which was observed after the dam construction in 1953. Continuous water withdrawals by the Upper Karabakh and Upper Shirvan canals have impacted annual flow TS as well. As result of these changes, average annual water discharge in Salyan station site varied from 550 m^3/s in the 1950s to 462 m^3/s in the 1990s (table 1) and samples, which represent a various periods of observations are not homogenous for 5% and 10% significant levels and only for 1% significant levels standard deviations can be considered as homogenous values.

In accordance with author's opinion, trend of moving (running) averages give good opportunity to evaluate changes in average annual flow better. To detect changes in

TS of annual flows, TS of moving averages that was observed at Salyan site was constructed as:

$$
\begin{aligned}
& I_1 = N_1; \\
& I_2 = N_1 + N_2/2; \\
& I_3 = N_1 + N_2 + N_3/3 \qquad (3) \\
& \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
& I_n = N_1 + N_2 + N_3 + \ldots N_{n-1} + N_n/n
\end{aligned}
$$

Where, N_1, N_2, N_3, N_n-are annual flows m^3/s, I_1, I_2, I_3, I_3, I_n –long-term average values for each year.

Constructed graph illustrates that since the beginning of 1960s, there has been a decreasing of annual water discharges at Salyan site. Such situation can be understood as a weakened contribution of hydrologic factors to the flood formation processes (figure 3).

Caspian Sea level fluctuations and its contribution to water level rise at mouth reach

The Caspian Sea is the biggest enclosed body of water in the world. This gigantic lake is located inside the Eurasian continent, where the South-Eastern Europe meets the Asian continent, between latitudes 47.07N and 36.33N and longitudes 45.43 E and 54.20E. It is approximately 1,030 km long and its width ranges from 435 km to a minimum of 196 km. It has no connection to the world’s oceans and its surface level at the moment is around –27 m below the average ocean level. At this level, its total coastline is some 7,000 km in length and its surface area is 386,400 km^2. The water volume of the lake is about 78,700 km^3 (Aliev, 2001; Kosarev, 2005). The level fluctuations of the Caspian Sea largely depend on the river inflow which is caused by long-term climatic oscillations and the most important contribution belongs to large rivers, such as the Volga, Ural and Kura (Meshcherskaya and Golod, 2003; Kosarev, 2005).

Formation of the modern Kura Delta also was under a great influence of variations in the mean Caspian Sea level, particularly in the past decades (Mikhaylov et.al. 2003; Hoogendoorn et al. 2005). Due to the long-term climatic oscillations, the Caspian Sea has rapid level fluctuations. The instrumental observations over the Caspian Sea level were carried out during the period of 1830–2000 and, according to the analysis of these observations; there are great extent in the levels of the sea over the past century. From the mid of the XIX century to 1977, with diminutive vibrations, sea level dropped from –25.5 to –29.0 m abs., i.e. by 3.5 m. From 1977 to 1995 rapid increase in the level has been observed and the sea level reached to -26.6 m, i.e. by 2.3 m. In 1995 the Caspian Sea level reached its maximum mark −26.6 m abs in 1995; then since 1996. Recently, it is remained nearly stable, varying slightly near −27.0 m abs (Mikhaylov et al. 2003; Hoogendoorn et al. 2005).

Free water surface curves of the annual flows, constructed for south-east part of the delta shows that long-term increase in the water level of the sea contributed to the water level rise in the mouth, creating backwater effect. The curves for the years of 2007 and 1978 illustrate that during the last 40 years, the backwater effect from the sea has increased, which was caused by the level rise (figure 4). In order to estimate the backwater contribution to the level rise in the mouth area, a required average level (depth) of the cross section for the given water discharges was estimated:

$$H_{ave} = \frac{Q}{BC\sqrt{RI}} \qquad (3)$$

Where, H - a water level in the cross section for the given water discharge m, B - is a width of the cross sectional area m, Q is a water discharge m^3/s, C -Shezi coefficient m$^{0.5}$/s, R is a hydraulic radius m, I is a hydraulic lean.

The backwater contribution to the level rise was then estimated using the formula:

$$H_b = H_{est} - H_{obs} \qquad (4)$$

Where, H_{est} -is an estimated average water level for the given water discharge, H_{obs}-is an observed water level for the same water discharge.

To receive more reliable results, calculations were led for December that is considered as a month with lowest flow. The calculations show that backwater propagation from the mouth reach went into effect even in the areas that are rather close to Salyan site (85 km from the mouth). In Salyan, backwater effect to the level rise is rather low and equal to 1-2 cm. However, there is a gradual increasing of the backwater influence towards the mouth. The calculations illustrate that for the period of 1995-2007 the average increasing in the water level at Uzunbaba consisted 25 cm, at Mayak site 35 cm. In 1995, when the Caspian Sea had reached its highest level, areas near the South East site were fully inundated for a long time.

In 2007, in this site backwater contribution to the water level rise consisted about 110-120 cm.

As a result of long-term backwater effect, the delta of the Kura, near the South East site was completely changed. In 1993 the Kura delta had two main tributaries: north-east and south-east. As a combined effect of the backwater propagation and sediment accumulation in the south-east tributary the sediment has actually become an obstruction within the channel, and has forced new channels to form that flow from the riverbed in the direction of the right area, and has caused an entirely new channel network formation (Figure 5).

Channel siltation

The Kura is one of the muddiest rivers in the world. The natural volume of annual alluvium makes up 30-35 million tons. After the construction of the Mingechevir reservoir, the river’s sediment discharge and suspended bed load had decreased for some time, as significant sediment accumulation took place within the reservoir (Belyaev et al. 1971). A more detailed analysis of water and sediment discharge rates of the Kura River for the periods of 1930-1952 and 1953-1993 were presented by Mikhaylov et. al (2003) and Hoogendoorn and Weltje (2007). However, since the 1990s, an increase in suspended sediment in the river has been observed. This pattern may be a result of intensive deforestation occurring in the basin, and began during an energy crisis after the collapse of the Soviet Union, when forests were the only heating source for rural areas in Azerbaijan. The deforestation and the mass removal increase the speed and the quantity of soil flushing, increasing denudation from the deforested areas (Mohapatra and Singh 2003). Eventually, the sediment is transported through the channel and to the mouth area of the Kura, where the most accumulation takes place as a result of low flow velocity and smaller cross-section (Abbasov and Kondratyev 2006). According to Hoogendoorn and Weltje (2008) expected climate changes may also increase sediment loads in the Kura basin.

The analysis of the data on the muddiness in the Kura for the last years illustrates that between 1992-1994 the muddiness of the flow sharply increased from the 500-1000 m^3/g to 2000-4000 m^3 /g (figure 6). This tendency is an attribute of the deforestation that occurred during the last two decades in the Kura basin. The Riparian forests (local name of these forests is *Tugay*) along the main channel and its tributaries have especially suffered. Tugay forests carried out a significant role in minimizing surface runoff from contributing sediment to the channels and in prevention of coastal erosion (Balyuk and Kondratyev, 2004). The sediment (bedload and suspended load) of the Kura River upon entering the mouth part is predominately clay, silt and fine sand (Abbasov and Mahmudov, 2009; Hoogendoorn et al., 2005).

In order to identify changes in the channel capacity, stage-discharge curves for historical periods have been compared. The stage–discharge curves reflect the relationship between the water discharge and water level, and can appear as an equation:

$$Q = aH^{b} \tag{5}$$

Where Q is a water discharge for a given time, H is a water level in the channel, a and b are parameters of the equation.

The decreased channel capacity can be estimated according to this formula:

$$\Delta Q = aH_2^b - aH_1^b \tag{6}$$

Where, ΔQ-changes in channel capacity, aH_2^b and aH_1^b –are different values of water discharges, estimated from different curves for the same level. For the Salyan site growths in the channel stages over the past 10 and 50 years were defined as a difference between channel stages of different periods with same water discharges:

$$\Delta H = H_2 - H_1 \tag{7}$$

Where, ΔH - is a growth in channel stage, H_2 and H_1 –are channel stages of different periods with same water discharge.

The results illustrate that in the downstream part of the Kura river the sediment accumulation in the riverbed increased from the Salyan site to the outlet of the river, which is accompanied by the reduced velocities of the water. The analysis of the discharge rating curves for the Salyan for the years 1993 and 2003 confirm siltation of the channel with a total of about 100 cm and fully reveals the decrease of the channel capacity in the riverbed (Figure 7).

The channel elevation actively monitored at the Mayak site shows a 130–150 cm rise in the streambed level in some places during the last decade. A notable increase in the channel elevation occurred at all of the sites (figure 2), with the greatest increase in elevation occurring in the banks. This pattern is typical for a natural levee development, where the lowest velocities along the banks support higher rates of deposition.

Long term changes in duration of floods

In hydrologic planning and design it is very important to know information about flood volume and duration (Karmakar and Simonovic, 2008). Flood characteristics are random variables (Yue et al. 1999) and can be modeled using both univariate and multivariate approaches (e.g. Sen 1977). Most of these methods are based on statistic models and use various statistic distributions. However, the estimation of peak discharges and flood durations cannot be done on purely statistical basis, because these characteristics may change due to human activity and non- climatic factors. The channel siltation and backwater influence of the Caspian Sea has seriously decreased the channel capacity of the river and as a result floods were observed in water discharges with lesser peak values and consequently with longer durations.

It is widely accepted that floods occur when the volume of water passing through a channel per unit time exceeds the volume of the channel reach, or the channel capacity (Andrew 1992; Karmakar and Simonovic 2008). However, this general understanding does not approve its worth in coastal territories with high hydraulic conductivity. In low-lying areas along the floodplain groundwater table is driven upward by the surface water and intersects the land surface. For example, in the downstream part of the Kura rocks have high hydraulic conductivity, and flow event that falls under normal high water levels can lead to the rise in groundwater levels which may cause underground floods. Because of the potential for economic damage to be incurred without the need for the Kura River to physically spill over its surface channel banks, it is prudent to use the term “maximal acceptable flow” (MAF), rather than “channel capacity” (Abbasov and Mahmudov, 2009).

There is a direct relationship between the channel capacity and the flood duration, as the flood events which are observed with lesser discharges will have longer durations. Due to the long-term backwater effect and intense siltation, as well as high hydraulic conductivity MAF values over the past 50 years have been diminished gradually. To evaluate possible changes in duration of floods, annual hydrograph of 2005 with MAF values of different years have been constructed. According to the figure 8, when MAF value is equal to 1200 m^3/s, the length of the flood will approximately 7 days (T1) and, on decreasing MAF values floods with longer duration will be observed. E.g. if MAF value consists of 1000 m^3/s, flood with the duration of 50 days will be observed. Further decreasing of MAF rate will cause floods with longer duration (T3). In other words, growing contribution of sedimentation and the backwater influence to the water level rise can decrease value of MAF, which will be appeared as floods with long duration. For example, the flood in 1969 and the flood in 2002 in the Kura basin were both caused by similar climatic conditions, having almost the same water discharges, but they differed greatly in the duration of the floods. The flood event in 1969 having peak flow rate 2350 m^3/s had duration of nearly 19 days. Return period of this flood is 1000 year (Mamedov, 1989); simultaneously the floods with much lower water discharges in 2002 (1530 m^3/s) and 2003 (1670 m^3/s) had duration of 25 and 35 days, respectively. The flood of the 2004 (850-1250 m^3/s) had duration of several months with short intervals. As a result of this flood agricultural activity in coastal areas was considerably lessened. In some places, groundwater levels raised enough to disrupt the agricultural productivity in the irrigated fields along the bank, even though the channel itself did not overflow. In most places residents of the flooded area left their houses for a long time.

Evaluation of changes in flood genesis

All of the above-mentioned factors that contributed to water level rise in the mouth part of the Kura River are appeared as a joint contribution of main three items: increasing river runoff, sediment accumulation of the channel, and backwater propagation from the Caspian Sea. Therefore, in order to evaluate contribution of these factors separately, actual changes of the water level in the mouth area were broken into following components:

$$\Delta H = \Delta H_f + \Delta H_s + \Delta H_b \qquad (8)$$

Where, ΔH -is a change in the level of water for the given period, ΔH_f -changes in the water level as a result of climatic factors, ΔH_s is a change in channel capacity caused by riverbed siltation, ΔH_b -backwater influence of the sea on water level of the given hydrologic site.

In the table 2 long-term changes in contribution of flood formation factors to water level rise have been illustrated. Estimations were carried out for the December of 1978 (when the level of the Sea reached its lowest level), for the January of 1995 (with the highest level of the Sea), and for the December of 2007. As it is seen from the table 2, in the December of 1978 and 2007 water discharges were almost equal (575 and 605 m^3/s), however, monthly water level above the datum were much different (198 and 364 cm). It is an attribute of the sedimentation as well as the backwater influence of the Caspian Sea which are occurred over the last decades.

According to the estimations, during the last 30 years, an increased contribution of the sea level rise and sedimentation in flood level formation processes at mouth areas have been observed. E.g. while sedimentation of the channel in 1995 was consisting 23 cm; in 2007 it was consisting 136 cm, reaching its highest level. This situation resulted in increased level to 22 cm, despite the fact that water discharge in January of 1995 was much higher.

Conclusion

Rainfall and intense snowmelt have long been considered as the major flood formation factors in rivers. Therefore, flow regulation has long been thought as the most effective method for the flood prevention. However, this experience has shown its limitations over the last few decades when the strong floods have been observed in regulated rivers.

Factors that contribute to river floods can be defined as climatic and non-climatic factors. Climatic factors have a climatic origin and directly increase the water level and volume in the channel, impacting the main flood characteristics-peak, duration and volume. Floods which have purely climatic origin are caused by intense rains, as well as snowmelts. Main climatic factors of floods in the Kura River include intense snowmelt episodes and intense rain, which come into sight as peak discharges during spring months. Nevertheless, long-term yearly regulation of flow has deeply impacted the natural regime of the flow and significantly reduced peak discharges.

Non climatic factors of floods refer to factors that are related to reductions in channel capacity and result in floods. Non-climatic factors include changes in land use, deforestation and erosion, flow regulation, water withdrawals and channel siltation. The results illustrate that in the downstream part of the Kura river the sediment accumulation in the riverbed increased from the Salyan site to the outlet of the river, which is accompanied by the reduced velocities of the water. The analysis of the discharge rating curves confirms siltation of the channel and fully reveals the decrease of the channel capacity in the riverbed.

Over the past 40 years the level rise of the Caspian Sea, into which the Kura empties, has also contributed to floods with long duration. As a result of the backwater effect from the sea, large territories rather far from the outlet were inundated for a long time.

Due to the channel siltation and the backwater propagation in the mouth reach, floods may occur even during lower discharges characterized with longer duration. Over the past century there is an increasing contribution of climate changes to flood formation processes as well. There is a growing awareness that rising sea levels in the future will be major contributors of floods in downstream parts of the rivers. The future increases of the sea level may result in floods not only in the areas close to the river outlet, but also in the territories rather far from the outlet. Therefore, there is a strong suggestion that Caspian experience may provide evidence of what may happen globally but on a longer time scale from rising sea levels induced by climate change.

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Summary

Evaluation of Factors Contributing to Floods in the Outlet Part of the Kura River, Azerbaijan

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Flow regulation has long been thought as the most effective method for the flood prevention. However, this experience has shown its limitations over the last few decades when the strong floods have been observed in regulated rivers. Since most of rivers have been highly affected by human activities, there are obvious changes in the genesis and nature of floods. Floods at the mouth part of the Kura River are observed as a combined result of climatic and non-climatic factors. Climatic factors directly impact flood characteristics-peak, duration and volume. Main climatic factors of floods in the Kura River include intense snowmelt episodes and intense rain as well as Caspian Sea level changes.

Non-climatic factors include changes in land use, deforestation, erosion, flow regulation, water withdrawals and channel siltation. Over the past century, there is an increased contribution of non climatic factors to the flood formation processes in the Kura River. At the same time channel siltation has increased the role of non-climatic factors. In addition, the Caspian Sea level rise became additional contribution to the level rise in the mouth area that causes backwater propagation on the free surface. Due to the channel siltation and the backwater propagation at the mouth reach, floods may occur even during lower discharges characterized with longer durations.

Key words: flood, erosion, sediment, deforestation

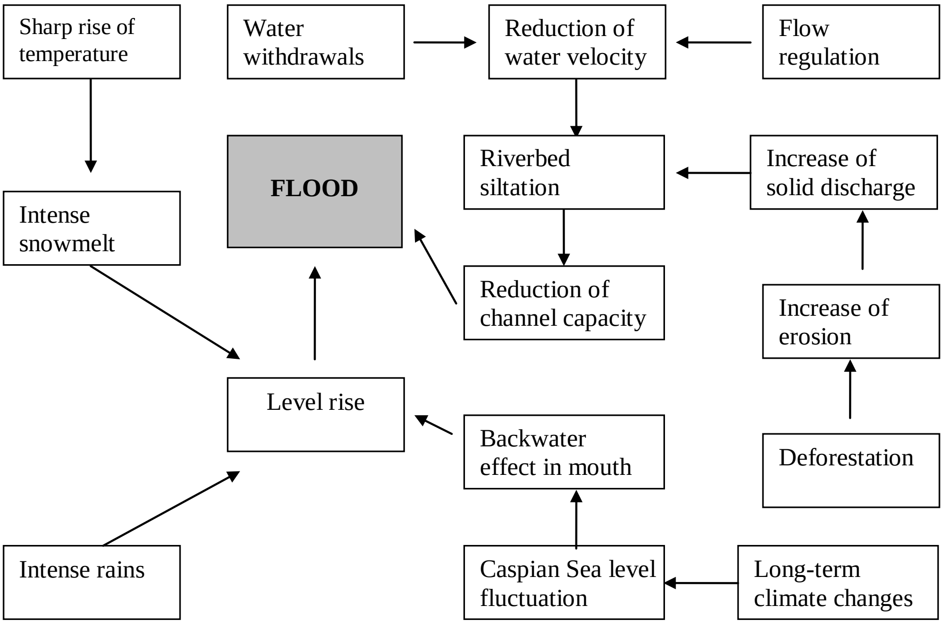

Figure 1: A scheme of factors contributing to flood in the downstream part of the Kura River

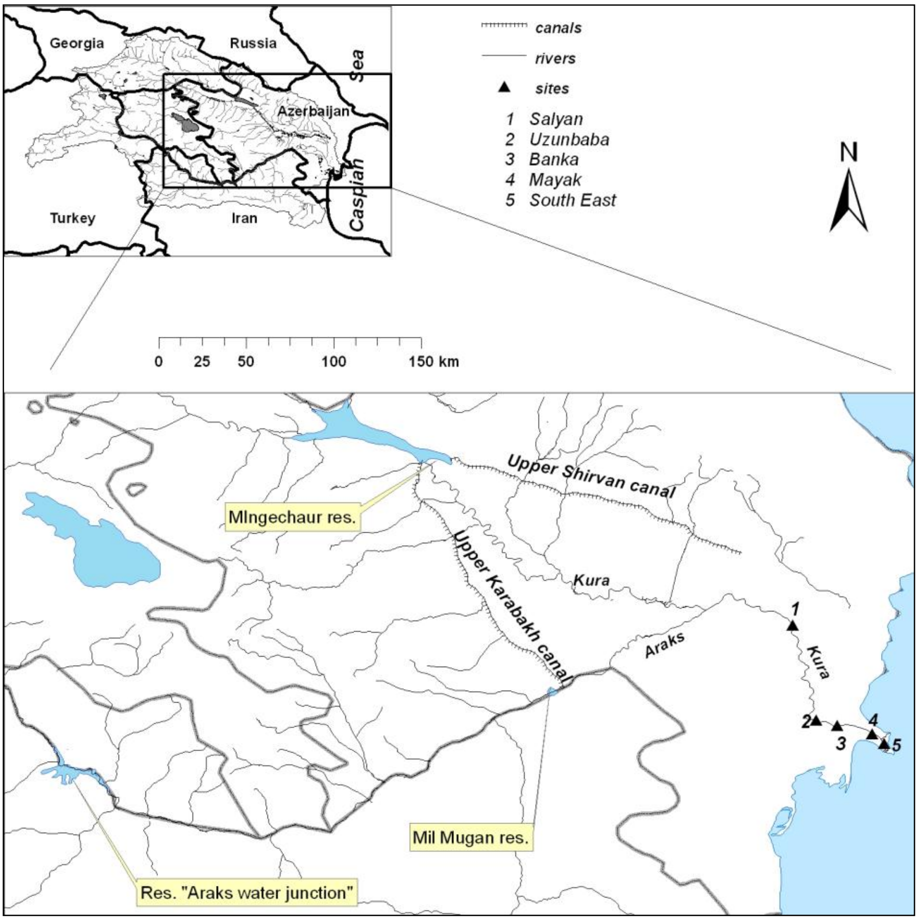

Figure 2. A map of the Kura river basin and a study area showing hydrological stations referred to in the paper

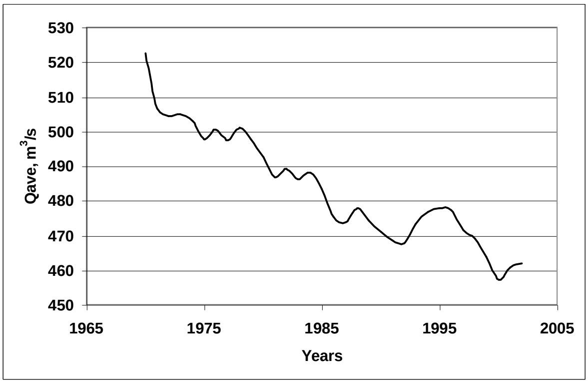

Figure 3: Long-term changes in annual flow at Salyan site

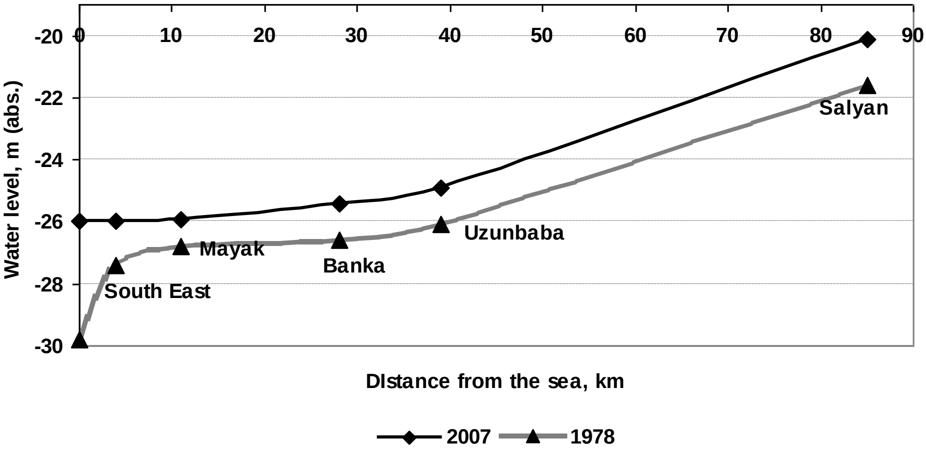

Figure 4. Free water surface curves in 1978, and 2007 near the mouth

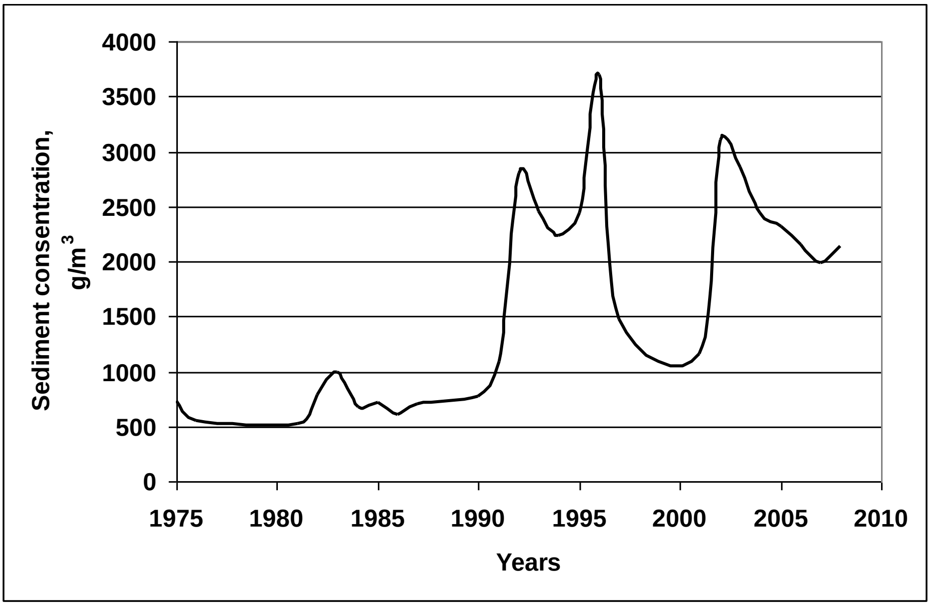

Figure 5. New channel network in outlet after reaching its highest level of the Caspian Sea

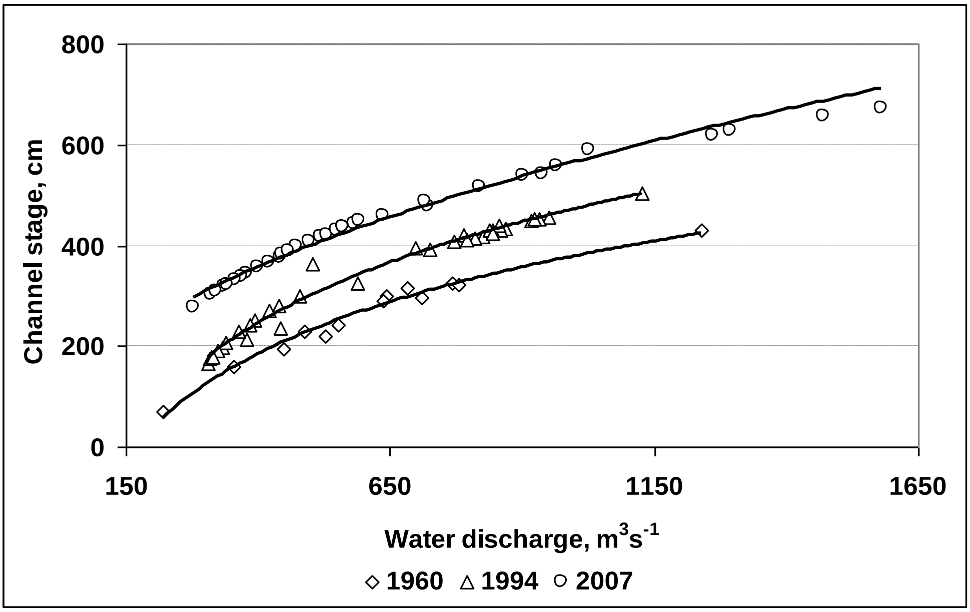

Figure 6. Suspended solid discharge at Salyan station during last 35 years

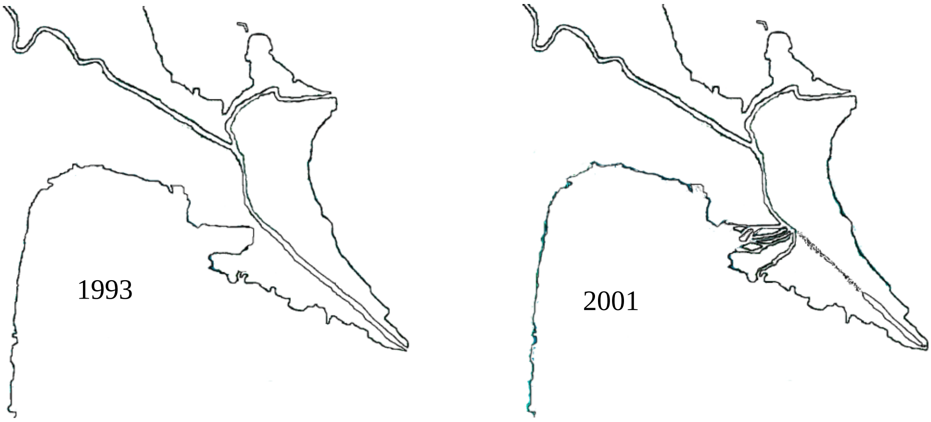

Figure 7. Discharge rating curves (Q=F(H)) in different years for Salyan site