IRSTI 37.27.33

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ANALYSIS OF MAIN PERIODS OF CATASTROPHIC FLOODS IN THE YESIL RIVER BASIN

The article analyzes the record of catastrophic floods for the Yesil river basin in the XIX, XX and XXI centuries. Information and data about floods are taken from hydrometeorological periodic publications, archival data, electronic resources, scientific articles and other sources. The study of hydrological aspects is of strategical relevance to ensure the sustainable development of river catchments of Kazakhstan. The studied Yesil River Basin is one of the most important regions of the country, with a need for comprehensive hydrological research as the capital city of Astana is rapidly developing. Analysis of existing materials allowed us to identify the flooded areas, the dates of flood occurrence, their causes and an assessment of flood damage. Following earlier research, the causes of flooding were classified into 7 main groups that are typical for flood conditions in the basin. As a result, the main factors that led to flooding were the contributions from melting snow and precipitation. Climate change and human activities were also noted to have an impact to flooding. The scale and amount of flood damage was assessed.

Key words: water level, flood, disaster level, snowmelt, Yesil River.

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Есіл өзені алабындағы апатты су басудың көрініс беру кезеңдерін талдау

Мақалада Есіл өзені алабы үшін апатты су басулар хроникасын талдау XIX, XX, XXI ғасырлар аралығына жүргізілді. Алаптағы су басулар жөніндегі ақпараттар гидрометеорологиялық мерзімді басылымдардан, мұрағаттық мәліметтерден, электронды ресурстардан, ғылыми мақалалардан және басқа да әдебиет көздерінен алынды. Стратегиялық маңызы үлкен аймақтарды гидрологиялық тұрғыдан зерттеу Қазақстанның тұрақты дамуын қамтамасыз етеді. Зерттеу нысаны ретінде алынған Есіл өзені алабы осындай маңызы үлкен өлкелеріміздің бірі, оның үстіне еліміздің астанасы Астана қаласын салу, көркейту, дамыту басты назарда тұрғандықтан жан-жақты гидрологиялық зерттеулер қажеттілігі күмән тудырмайды. Қолда бар материалдарды талдау су басу орындарын, байқалған даталарын, пайда болу себептері мен салдарын анықтауға мүмкіндік берді. Су басудың пайда болу себептері осы уақытқа дейін жүргізілген зерттеулерге сүйене отырып, алаптағы су басулардың қалыптасу жағдайларына тән 7 топқа жіктелді. Нәтижесінде алаптағы су басуды қалыптастырушы факторлардың басым бөлігі қар еру мен қарқынды жауын-шашынның қосылуы нәтижесінде болатындығы анықталды. Сондай-ақ, қазіргі таңдағы климаттық өзгерістер мен адамның шаруашылық іс-әрекетінің әсері бар екендігі де байқалды. Су басулардың масштабы және шығын мөлшері бағаланды.

Түйін сөздер: су деңгейі, су басу, апат деңгейі, қар еру, Есіл өзені.

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Анализ основных периодов проявления катастрофических наводнений в бассейне реки Есиль

В статье проведен хронологический анализ катастрофических наводнений, прошедших в XIX, XX и XXI веках в бассейне реки Есиль. Данные о наводнениях взяты из гидрометеорологических периодических журналов, архивных данных, электронных ресурсов, научных статей и других источников. Изучение гидрологических аспектов стратегически важных регионов важно для обеспечения устойчивого развития Казахстана. Объектом исследования является один из важнейших регионов страны – бассейн реки Есиль, более того необходимость всесторонних гидрологических исследований не ставится под сомнение, так как столица Астана ориентирована на строительство, благоустройство и развитие города. Анализ существующих материалов позволил выявить следующие аспекты наводнений: участки поймы, наблюдаемые даты, причины и последствия возникновения. Основываясь на результаты исследования предыдущих ученых, причины наводнения были классифицированы на 7 групп, которые типичны для условий формирования наводнений в данном бассейне. В результате, были определены основные факторы, приводящие к затоплению территорий, к которым относятся одновременное прохождение таяния снега и выпадение осадков. Изменение климата и хозяйственной деятельности человека тоже оказывает влияние на формирование наводнений. Масштаб и количество ущерба от наводнения были оценены.

Ключевые слова: уровень воды, наводнение, уровень бедствия, таяние снега, река Есиль.

Introduction

Worldwide, flooding is the leading natural hazard that affects humanity (Kellens, Terpstra and Maeyer 2012). In many countries of the world, floods are a main natural threat to the lives of people and the economy (Berz 2000), (Country Risk Profiles for flood and earthquake n.d.). Flood disasters are not uncommon for Kazakhstan. The beginning of the XXI century was marked in Kazakhstan by a series of catastrophic floods, with events occurring almost every year, causing great damage to the population, national economy and river valley ecology (Galperin et al., 2016). Over the past 15 years, more than 300 floods of various origins occurred in Kazakhstan, of which an estimated 70% were caused by spring floods (Galperin, 1994). The main reasons for an assumed increase in the frequency of flood hazards in the last decades are the increase in the number and density of the population living on the banks of rivers, the construction of vulnerable infrastructure (transport, energy, communications, water) objects in river valleys, the regulation of rivers and the state of hydraulic structures, as well as climate change, which is associated with anomalies of average annual air temperatures and annual precipitation amounts (Report, 2018), (Galperin, 2016). Climate change is expected to exacerbate flood hazard through an intensification of the hydrological cycle, which will likely enhance the magnitude, frequency, and seasonality of riverine flooding (Macklin and Rumsby, 2007).

The Yesil River is a left-bank tributary of the Ertis. The Yesil River has a total length of 2,450 km, of which 1,400 km are located on the territory of Kazakhstan. The catchment area covers 177,000 km^2, including an active 141,000 km^2. The main tributaries of the river in Kazakhstan are the Koluton, Zhabay, Tersakkan, Akkanburluk, and Babykburluk (Figure 1).

The Yesil River originates in the Karaganda region, in the Niyaz Hills. The relief of the catchment area is highly variable. The upper reaches of the basin come from the Niyaz Hills, right-bank tributaries derive from the southern slopes of the Kokshetau Upland, and discharge in the south-west of the catchment originates from the spurs of the Ulytau Mountains. Apart from the uplands, the rest of the catchment is relatively flat.

The basin of the Yesil River, in the north of the Republic of Kazakhstan, is characterized by a diverse climate. The most important climate-forming factors of the territory are solar radiation (seasonal temperature fluctuations) and atmospheric circulation (storm tracks). The main features of the continental climate of the region are the large amplitude of fluctuations in air temperature, and a small amount of precipitation carried by the dry air (Burlibaev, et al. 2017). Despite the aridity of the studied area in the list of natural disasters, floods play an im-

portant role here. The discharge regimes of the rivers in the Yesil basin are dominated by melting snow that produces a pronounced spring flood. The peak flood is generally followed by a prolonged period of low flows, with a complete drying out of small, and often also relatively large, watercourses.

As the peak discharges of the Yesil river and its tributaries are dominated by snowmelt, climate change should be considered as a source of increased flood risk (Galperin et al., 2012), especially for highly populated areas such as the national capital of Astana. In this study, we analyzed available information for floods of the past in the Yesil basin. The resulting flood chronology was used to assess changes in flood frequency, severity, and to identify the main causes of flooding.

Data and research methods

The Flood Chronology

Information and data on floods were obtained from hydrometeorological periodic publications, archival data, electronic resources, scientific articles and other sources. Flood data of the Yesil River basin was divided according to their century of occurrence; the XIX, XX and XXI centuries.

During the XIX century, flooding was observed in 1824, 1841, 1854, 1856, 1860, 1886, 1889, and 1896. All floods occurred in March-April spring season, but the main reasons of flooding differd; such as the flow of a river, an abundance of precipitation, and intensive snow melting.

The floods observed in the period 1820-1850 were in the Petropavl and Akmola regions. In Petropavl city, 700 out of 800 houses were flooded. The flooding lasted three days in the Akmola region. In addition, temporary fortifications, dugouts built by soldiers of the 2nd West Siberian Line Battalion, were flooded and required extensive restoration work.

Floods are also mentioned for the Akmola and Petropavl regions between 1850 and 1860, with snowmelt as the main cause.

Compared with the aforementioned floods, the level of floods was significantly higher in 1886 and in 1896. The event of 1896 reached very high levels of flooding in Akmola and Atbasar, and featured two separate peak flood waves in April. As a result of the floods, villages were flooded, many houses were damaged, and dams and mills were destroyed. “Most of the houses in the village were flooded on a half yardstick (35-36 cm). Stoves were washed away in many houses, hedges are carried away by water, but there were no accidents with people. The village was flooded, many houses were damaged”(Akmola regional Museum of local lore).

Due to the lack of available data, the reasons for the occurrence of a flood of several years have not been identified. However, with a quick review of natural phenomena in those periods, we find information about heavy snowfall and intense snow melting. Thus, we can tentatively conclude that most of floods were caused by the melting of spring snow. According to the data “The surface water resources of the areas the development of primitive soil and fallow lands” (1958) in the Northern Kazakhstan on the Yesil River, the water level rises during high floods by 5.5-6.0 and 8.5-9.0 m respectively. Water levels and water discharge during high floods are increasing rapidly. Thus, on the medium and large rivers of the Akmola region the highest daily rise of the water level is 1.0-1.5 m, in high-water years it already reaches 2.5-3.0 and even 3.3-3.7 m.

During the 20th century, there were 5 floods between 1900 and 1920, according to a study of Antonchev (1997). Floods occurred in April and May. Four of them (1902, 1908, 1911, 1913) were from the spring flood of the Yesil River, and one (1912) was formed because of flooding. As consequences many peasants and Kazakh villages were flooded. For example, 30 peasant villages and 48 Kazakh villages in the Atbasar district and 1 peasant village in the Akmola region were flooded on April 5, 1912. On May 2, 1913, the tide of the Yesil River is only a part of the lower bank of the Yesil River.

Major floods did not occur during the 1930s. After that, the high water levels were recorded between 1940 and 1960 (Galperin, 1994), (Plekhanov 2003), (Shamenov, 1996); notably in 1940, 1942 and 1948. Maximum water levels were high almost everywhere in 1942, and their frequency was less frequent, in the Yesil Basin – once every 10 years. During these years, high snow reserves were the main cause of high floods. Maximum water levels (H_{max}) have increased since 1948 with 2-3%, by the alignment of the city Astana. , the excess of H danger occurs approximately once every two years, with 1-3 days of the period prevailing, but this year it was 10 days. An important role in its formation was played by liquid precipitation.

Flooding was occurred in the 1970s and 1980s, but the exact dates are unknown. This situation occurred in 1970, 1971. Due to multiple floods in Central Kazakhstan and the Yesil basin, which were in 1972, preceded by the improvement of soil quality by the beginning of autumn cementation. The significant role of precipitation during the period of snowmelt in the formation of floods in the upper Yesil, precipitation was eight times higher than the norm

in the second decade of April.

Flooding caused great damage to several settlements and areas of the Yesil River Basin, caused by rising water levels in 1980-1990. Proof of this is that 1988, which was registered as a year abundance of water. This is stated in the following source (Galperin 1994): The highest water levels are noted at the gauging station Akkanburlyk, Grigorievka, Privolnoye. As a result, populated areas of the Akmola, Karaganda, Kokshetau, Kostanay, Ural, Aktobe, and Turgai regions were flooded; most damage was caused to Akmola region: villages were flooded, roads were washed out, bridges, communication lines were washed out, and part of the dam was broken temporary storage warehouse in Zarechny of Akmola region.

At this stage, the highest water levels in the Yesil River were recorded in 1986, 1987, and the volume of water flows was 5-15%.

Approximately one time in 50-100 years on the rivers of Kazakhstan, occur catastrophic floods (MIC). According to Kazakh scientists (Plekhanov 2003) (Galperin et al. 2012) floods in the last decade of the 20th century occurred in the spring of 1993. Maximum water levels reached dangerous levels in the Yesil, Koluton, and Zhabay Rivers. The height of the flood wave was more than 8 m in Yesil within the North Kazakhstan region. Due to excessive snow reserves, sharp and significant warming with simultaneous heavy rainfall, catastrophic rainfall floods were formed on almost all lowland rivers of the republic. Flood waters of various levels for specific rivers of watercourses and the spill boundaries are not defined. According to estimates, only direct damage from floods in Kazakhstan amounted to $ 500-600 million in 1993, more than 12.5 thousand people were evacuated. This is an emergency; obviously belong to the highest category.

The water level rose above dangerous levels in 1995, on the Yesil River and its tributaries (Koluton, Zhabay, Tersakkan, Akkanburluk and others), however, did not cause serious damage due to the short duration of the flooding of the territory.

Flood of the places are often found in the Yesil, Zhabay, Kolutan, Akkanurbuk rivers in the 19th century and correspond to the April-May period. The reason of the occurrence of flooding can be explained by an increase in spring snow, precipitation and water levels.

The chronicle of the most catastrophic floods that occurred in the Yesil river basin in the 21st century as follows.

The capital of the country was renamed Astana in 1998 and due to population growth, the development of suburban settlements, land development led to the flooding of the territory. Rapid population growth, development of facilities within the water protection zones of rivers have significantly increased the risk of exposure to flooding, led to social tensions and economic damage. For example, damage from spring floods in the Akmola region in 2014 amounted to over 10 billion tenge (26 666 666 $ at the rate of 01.03.2019), 8–9 billion tenge (24 000 000 $ at the rate of 01.03.2019) in 2015, 900 million tenge (2 400 000 $ at the rate of 01.03.2019) in 2017 was provided for flood control, and the damage amounted to 24 million tenge (64 000 $ at the rate of 01.03.2019) (Interfax Kazakhstan: 2014, Dixinews: 2014).

In this century, the availability of data about floodwaters comparing to the past century allowed us to analyze a dangerous hydrological phenomenon. Flood data analysis was reviewed using data (Sharipkhanov et al. 2015) (MIC).

Catastrophic floods since 2000 have been observed 9 times. Floods occurred in April and May spring. In addition, there are several cases of flooding during the year. It was found that most of the floods occurred due to rising water levels to dangerous levels in the rivers Koluton, Zhaybay and Yesil. This was in 2007, 2009, 2014, 2016 (April 17-25) (Sazanova et al., 2012). One of them, rarely recurring, led to huge material damage took place in 2014.

The water level in the Koluton River reached 690 cm, and the water level in the Zhabay River reached 808 cm in April 2007. As a result, the village of Koluton and the city of Atbasar and the farms located on the banks of the river were flooded. Due to the reached water hazard levels, local areas were flooded in the city of Petropavl on the Ishim River (Babakhanova et al., 2009). There was no significant damage to the city of Petropavl in 2009, since the floods were lower than the elevated water level (Sazanova et al., 2011).

The floods that occurred on April 12–13, 2011 and April 7–9, 2016, were caused by a sharp rise in water level during the destruction of dams (Shmidt et al., 2017). Due to the destruction of the Aydabul dam of the Zhabai River in 2011, as a result of flooding 70 houses in Akmola region and houses in the suburb of Balkhashino in Atbasar were flooded. The second flood was recorded in the Zhabay River in the Atbasar region and on the Koluto Rivers in the Koluton region. Village roads and houses, some houses in the city were flooded, and people moved to safe places (Sazanova et al., 2012).

The flood, which was in 2014 unforgettable,

since, the flood from April to May (8, 9, 11, 28 April, 4 May) was observed in several river basins that led to flooding of settlements and people had to move to safe places. In 2014, the height of the flood wave on the Yesil River was 3.4 ... 7.3 m, of the Akmola region, in the North Kazakhstan Region – 9-11 m, on the Kalkutan Rivers, Silety – 4.1-4.7 m, on the river Zhabay – 5.1.1.6.2 m (Sharipkhanov et al., 2015).

The occurrence of floods is primarily due to the 1.5 times increase in soil moisture content in the rivers Zhabay, Koluton, Silety, Shagalaly and snow reserves by 15-20%, as well as high temperatures in all regions of Kazakhstan, and due to intense precipitation in April in Akmola and North Kazakhstan regions. For example, the flooding in Atbasar on April 8, 2014 (Fig. 2) was caused by an increase in air temperature, and in such a case most of the flow was formed from melting snow, and water canals do not have time to reduce the water routes. Consequences: 103 houses on the following streets were flooded: Elektrostantsionnaya, Dzhambul, Transportnaya, Sary – Arka, March 8, Stepnaya, Dostyk, Kazakhstan. In total, 79 people were evacuated, including 9 children.

Flooding occurred on May 9, 11, 28 and 4 due to the above factor, as a result of rising water levels in the village of Zarechnoye, on the Zhabay River, in the western part of Atbasar and Petropavl. The highest water level was reached 1094 cm on May 4 of this year in Petropavl. However, due to increase in water discharge to 1540 m3 / s from the Sergeevsky reservoir to the Yesil River at the end of April of this year, highway of the Chelyabinsk-Novosibirsk to 528 km and recreation areas were flooded near the villages of Pokrovka, Dolmatova, Novonikolskoye (Sazanova et al., 2015). This catastrophic hydrological phenomenon led to huge economic losses.

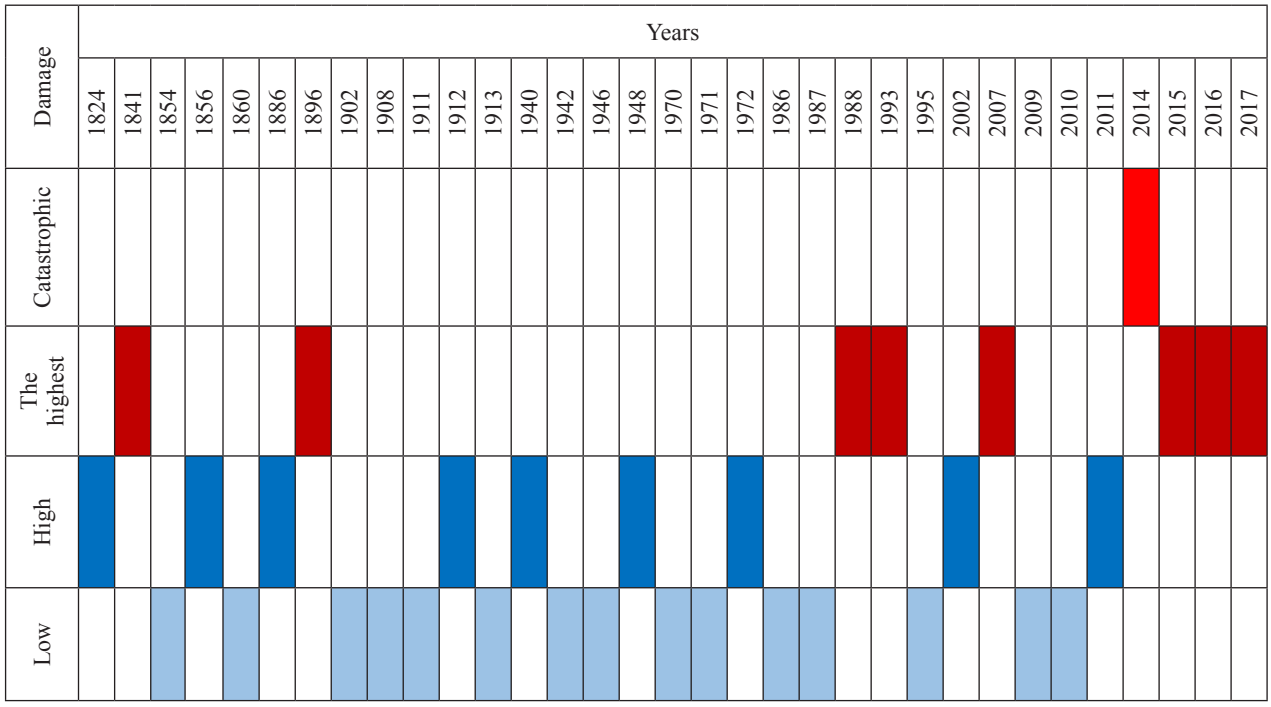
Figure 2 – Consequences of flooding in the Yesil river basin
a) Atbasar city 2014; b) Atbasar city 2014; c) Atbasar city2017 d) Petropavl city 2017

Note: photo source: a)https://docplayer.ru/73305239
b) https://www.kazpravda.kz/uploads/redactors/images/5abb2074322471522212980.jpg
c) http://today.kz/news/kazahstan/2018-03-05/761484-zhitelej-atbasara-predlozhili-pereselit-iz-za-navodneniya/#lg=1&slide=0
d) https://www.youtube.com/watch?v=KANwwI1wIE4

Flood disaster resulting from intense snowfall was observed in 2015 and 2017 (MIC). Flooding took place in the Atbasar River, Zhabay River, in the villages of Koluton, Novonikolsk, Dolmatova and Petropavlovsk in 2015. 18 houses homestead and garden plots, as well as the highways of Che-

lyabinsk-Novosibirsk, which have national importance, were flooded (Schmidt et al., 2016). The occurrence of floods of the 20th century is higher than in previous centuries. Given the rapid rise in water levels due to melting snow, intense precipitation, the opening of rivers, and dam failures, it can be concluded that many floods can be associated with anthropogenic climate change and anthropogenic activities. Having explored the frequency and magnitude of floods during the XIX, XX and XXI centuries shows that the Yesil River basin is highly susceptible to flooding. By scale and damage, floods are divided into four groups: low, high, exceptionally high, and catastrophic (Buzin, 2008).

Table 1 – Classification of of flood damage 1824-2017.



As shown in Table 1, the proportion of 33 floods are as follows (if we count the flood in each river per year, the total is 47): about half (45%) is low, 27% is high, 24% is the highest and 3% is catastrophic floods. The amount of flood damage in the study was determined based on the scale of the flood. More specifically, the description is as follows: *Low* – less than 10% of agricultural land located in lowland areas is flooded. They cause insignificant material damage and almost do not disrupt the economy or the population, *high*-accompanied by significant flooding, cover relatively large areas, disrupt economic activity and livelihoods. Sometimes they necessitate temporary evacuation of the population. Material and psychological damage is significant, *the highest* – paralyze economic activity, cause great material and psychological damage. Very often, it is necessary to resort to mass evacuation of the population and material values, *catastrophic* – the life structure of the population changes dramatically. Material damage is huge. May cause deaths (Buzin 2008).

Results and research

Flood Types

The causes of flooding are varied. This is primarily seasonal melting of snow accumulated in the preceding season of the year on the plains, heavy rainfall, strong wind, ice and surge phenomena. The danger of flooding depends primarily on the rising water level in the river. In this case, the most important characteristic is the maximum water level, which controls the area and duration of flooding of the area (Borsch et al., 2015).

An attempt was made to define the main factors determining the causes of floods in the Yesil river basin since 1824 when records are available. Assessing the role of flood control factors has crucial for determining the extent of floods and implementing measures to prevent and minimize adverse effects,

design hydraulic structures and develop regional economic sectors.

Reviewing studies of Tyrrel and Nickey (1991), Scott and Mudelsee (2018), Koronkevich (1982) Nezhihovsky (1988) Borsch et al. (2015), Alberto and Rogger (2015), Spivak, Arkhipkin and Pankratov (2004), Spivak, Arkhipkin and Sagatdinova (2005), Akimov et al. (2009). aimed at the classification of flooding factors, it was found that many factors of its condition are affected by various climatic conditions and anthropogenic factors in flood zones.

The factors determining the occurrence of flooding were identified by Akimov (2009) in four groups: a) maximum runoff formation as a result of spring snow melting on the plains; b) maximum runoff formation as a result of melting mountain snows and glaciers; c) the maximum formation of runoff as a result of heavy rainfall; and d) maximum formation of runoff as a result of the combined effect of snowmelt and heavy precipitation.

According to the classification of John J. Tyrrel (1991), factors affecting the flood were divided into 6 groups: a) floods caused primarily by the state of the tide. These are normally either high tides or spring tides, usually containing a storm surge in addition to the water height of the river; b) Floods which are 'tide-led', but with small contribution from rainfall as well; c) floods which have their origin in both tidal and rainfall conditions in more or less equal proportions; d) floods due to rainfall predominantly, but with some contribution from tidal; f) floods which occur when rainfall is the primary cause and when there is no contribution from tidal conditions; and g) floods which are a response to conditions not covered by the previous categories. Sudden temperature changes may cause snowmelt and ice melt resulting in floods. Another flood situation occurs when there are major releases from the Inniscarra dam usually arising when the dam is at capacity and there are substantial influxes of water from the catchment.

Floods are classified into different types depending on where the water comes from and on their generating processes. Several types of floods are: flash floods, dam-break floods, ice-jam floods, glacial-lake floods, urban floods, coastal floods, and hurricane-related floods (Paolo, 2014).

Borsch considered the problem from a different point of view and divided the formation of flooding into six groups.

The complexity of the flood situation and the diversity of opinions led to the separation of floods into different types of floods that define this natural phenomenon. The above classification cannot be clearly defined for the Yesil river basin. Thus, the main factors contributing to the formation of floods were identified (Fig. 3).

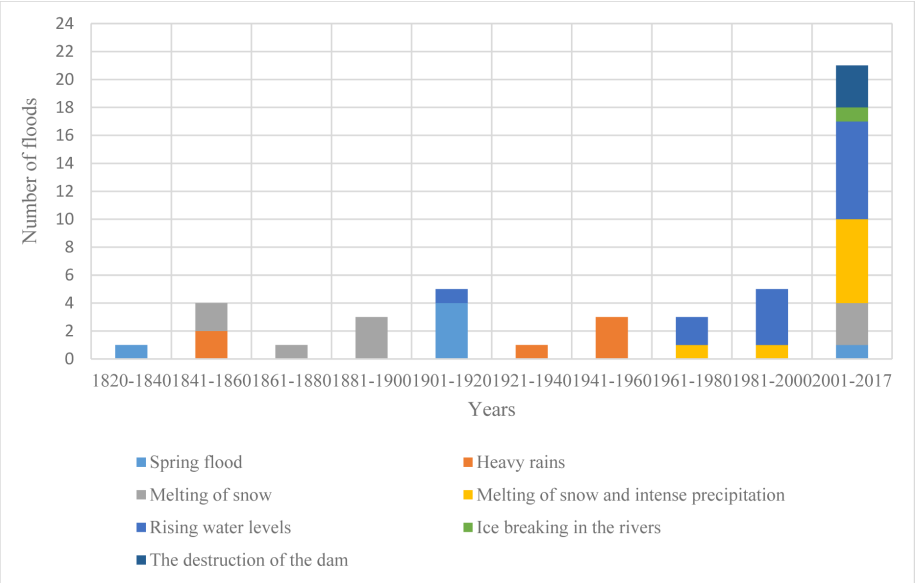


Figure 3 – Causes of flooding in the basin of Essyl river 1824-2017

As shown in Figure 2, the factors that contribute to the formation of flood waters were combined into 7 main groups. It can be seen that floods often occur as a result of snow melting and intense rainfall, as

well as rising water levels. These type of floods occurred between 1901-1920, 1961-1980, and 1981 and 2017. The impact of intense precipitation was the main cause of floods in 1841-1860 and 1921-1960 with floods resulting from snow melt being more common between 1841-1900. Floods since 2000, almost all of these factors have contributed to flooding.

Table 2 – Different various conditions of floods and their scales in the Yesil river basin

Cause of flood / Frequency	Snowmelt	Melting of snow and intense rainfall	Rising water levels	Dam failure	Ice jams	Spring floods	Intense rainfall
Once every 5–10 years							
Once every 20–25 years							
Once every 50-100 years							
Once every 100–200 years							

– catastrophic – exceptional – high – small

An analysis (Table 2) of flooding in the catchment showed that the frequency of relapses during runoff and the opening of the river was observed once every 5–10 years is the low flood; Intensive precipitation and destruction of dam observed once every 20–25 years is high flood; as well as the highest is that occurring once every 50-100 years due to intensive dissolution of snow and elevated water levels.

The frequency of repetitive, which occurred once every 100–200 years, was the most danger flood, mainly dependent on the melting of snow and intense precipitation in the Yesil River Basin.

Conclusion

1. The Yesil River is highly susceptible to flooding according to the Nezhihovsky (1988) classification. 2. Causes of floods in the Yesil catchment are: snow melt, heavy rains, spring floods, a combination of snow melt and intense rainfall , rising water levels, ice jams, and dam failures. 3. The frequency of floods in the 21st century is higher than of both the 19th and 20th centuries and would appear to be a consequence of anthropogenic climate change, floodplain encroachment and dam failures. Water management specialists can use the results of the study for practical purposes, for emergencies in the future, when developing projects for hydraulic structures.

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