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MASTER THESIS

Topic: Optimizing the use of water resources of mountain rivers of the Greater Caucasus (case study on the Gudyalchay river)

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Abstract

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Optimizing the use of water resources of mountain rivers of the Greater Caucasus (case study on the Gudyalchay river)

The aim of the thesis is to study and propose effective solutions to the management of the Greater Caucasus River, in the example of the Gudyalchay river. The Greater Caucasus rivers are mainly spring-fed rivers, which come from the high mountainous areas. High water periods coincide with intense snowmelts observed mostly in early April, while low flows come in late August or early September. Water resources of the target region are mostly used for irrigation and drinking water, which is mostly required late summer months. This pattern requires effectively optimizing the water resources in the river of the Greater Caucasus.

In most cases, it is proposed to regulate the flow of the river to solve this problem. However, flow regulation in parallel leads to the loss of very valuable ecosystems. These ecosystem services include mostly cultural and regulating services, such as the provision of spawning grounds for migrating fish, as well as tourism. In this study, methods and techniques are used to determine the years in which the impact of human economic activity on river flow began. These methods are based on comparing the flow of disturbing rivers with the flow of rivers with a natural regime of precipitation in the basin. Based on observations of natural flow, the dependence of river flow on the main flow-generating factors is studied, and the analytical relationship between these factors and the flow is found. Then, due to these dependencies, the natural flow is calculated for the period of anthropogenic factors on the flow and is quantified based on the difference between the flow observed with the natural flow. Using the multiplicity correlation between precipitation and temperature, the change in flow was quantified based on possible precipitation and temperature changes. According to the given formulas, it is possible to determine the impact of climate change on both, non-seasonal and annual flows. New proposals have been made to calculate the total evaporation from the river basins. The average multi-year value of evaporation from river basins was found based on these proposals. The effect of evaporation and solubility on the river flow was determined by hydrographs. The importance of snow waters in the nutrition of Gudyalchay, Damiraparanchay, Gusarchay, Agsuchay, Balakenchay and Goychay rivers was noted. The formula for calculating the natural flow according to water balance methods is given.

Çiçək İmanova

Böyük Qafqazın dağ çaylarının su ehtiytlarından istifadənin optimallaşdırılması (Qudyalçay timsalında)

Dissertasiya işinin obyekti Böyük Qafqaz dağ çayları, xüsusilə də Qudyalçayın ümumdaxili paylanmasıdır. Dissertasiya işinin əsas məqsədi Böyük Qafqazın dağ çaylarının axımının ümumdaxili paylanmasını öyrənmək və çayların su ehtiyatlarından istifadənin optimallaşdırılmasını təsnif etməkdən ibarətdir. Böyük Qafqaz çayları əsasən yaz gürsululuğuna malik çaylardır. Bu çaylar mart ayının sonlarından başlayaraq intensiv qar ərimәsi nəticəsində daşır, yay aylarında isə əsasən az sulu olurlar. Yay aylarında su ehtiyatlarından istifadəyə ehtiyacın kəskin artması eyni zamanda çayın suyunun az olması, çay axımından istifadəni optimallaşdırılmasını tələb edir. Əksər hallarda bu problem həll etmək üçün çay axımının tənzimlənməsi təklif olunur. Lakin axımın tənzimlənməsi parallel olaraq çox qiymətli ekosistemlərin itirilməsinə səbəb olur. Bu ekosistem xidmətlərinə dekreasiya və balıq miqrasiyalarını aid etmək olar. Təqdim olunan dissertasiy işi çayların ekosistem xüsusiyyətlərini saxlamaqla onlardan istifadəni optimallaşdırmaq üçün təkliflər məqsədini daşıyır. İnsanın təsərrüfat fəaliyyətinin çayların axımına təsirinin başlandığı illərin təyin olunma üsulları və metodlardan istifadə olunur. Bu metodlar rejimi pozulmuş çayların axımının təbii rejimə malik olan çayların axımı, yaxud da hövzəyə düşən yağıntılarla müqayisəsinə əsaslanır. Təbii axım üzərindəki müşahidələrə əsasən çay axımının əsas axımyaradan amillərdən asılılığı öyrənilir və bu amillərlə axım arasında olan analitik əlaqələr tapılır. Daha sonra, həmin asılılıqlara görə antropogen amillərin mövcud olduğu dövr üçün də təbii axım heablanır. Son mərhələdə təbii axımla müşahidə olunmuş axımın fərqinə əsasən antropogen amillərin axımına təsiri ədədi baxımdan qiymətləndirilir. Yağıntı və temperatur arasında olan çoxluq korrelyasiyasından istifadə etməklə də mümkün yağıntı və temperatur dəyişmələrinə əsasən axımın dəyişməsini ədədi baxımdan qiymətləndirilmişdir. Verilmiş düsturlara əsasən həm aylıq, həç mövsümi, həm də illik axıma iqlim dəyişmələrinin təsirini müəyyən etmək olar. Ərazi çaylarının hövzələrindən gedən cəm buxarlanmanın hesablanması üçün yeni təkliflər verilmişdir. Həmin təkliflər əsasında çay hövzələrindən gedən buxarlanmanın orta çox illik qiyməti tapılmışdır. Buxarlanmaın və qarərimәsinin çayın axımına təsirini hidroqraflarla müəyyən edilmişdir. Qudylçay, Dəmiraparançay, Qusarçay, Ağsuçay, Balakənçay və Göyçay çaylarının qidalanmasında qar

sularının əhəmiyyəti qeyd edilmişdir və onların çoxillik axımına təsiri göstərilmişdir. Su balansı üsullarına görə təbii axımın hesablanma düsturu verilmişdir.

Content

Introduction

The importance of the study. As a result of intensive development of industry and agriculture, population growth, and urbanization, human demand for freshwater resources has increased. Agricultural and drinking water withdrawals from small mountain rivers pose serious concerns regarding their sustainable use of them. Excessive water withdrawals from rivers without returning lead to going rivers completely dry. This in itself leads to other problems and endangers the diversity of rivers as an element of the landscape. The water of some rivers in Azerbaijan is completely used for industrial and economic needs. The water of the rivers used for industrial purposes does not year. This, in turn, leads to serious problems, such as their loss of function as an element of the landscape. On the other hand, in most industrial enterprises, municipal sewage is discharged directly into rivers without any treatment. While many countries around the world use wastewater treatment plants in most industries, this is difficult for small industries because pollution control equipment requires large investments. These processes lead to the crisis of the ecological condition of rivers. As a result, rivers can become unusable. Pollution of the river is a threat not only to humans but also to the animals, fish and other living organisms that live there. It causes the loss of very valuable ecosystems living there. Polluted rivers destroy aquatic life and reduce production. Already polluted river is unfit for drinking, agriculture and industry. The polluted river also loses its aesthetic quality.

Purpose and objectives of the study. The main purpose of the thesis is to study and propose effective solutions to the management of the Greater Caucasus river, in the example of the Gudyalchay river. The Greater Caucasus rivers are mainly spring-fed rivers, which come from the high mountainous areas. High water periods coincide with intense snowmelts observed mostly in early April, while low flows come in late August or early September. Water resources of the target region are mostly used for irrigation and drinking water, which is mostly required late summer months. This pattern requires effectively optimizing the water resources in the river of the Greater Caucasus.

The sharp increase in the need to use water resources in the summer months, as well as the low water, requires optimizing the use of river flow. In most cases, it is proposed to regulate the flow of the river to solve this problem. However, flow regulation leads to the loss of very valuable ecosystem services including declination and fish migration. The present thesis aims to propose to optimize the use of rivers while maintaining their ecosystem characteristics.

Certain tasks have been set to achieve these goals. To determine the physical and geographical factors affecting the Greater Caucasus rivers. To determine the precipitation, air temperature, evaporation and other surface factors that affect the flow of rivers. To assess the impact of anthropogenic factors on the regime of rivers. Includes calculation of the ecological flow of rivers. To assess the impact of climate change on the flow of local rivers. It is to optimize the water resources and water use of the Greater Caucasus rivers.

Literature review. The references used in this study include published materials of international and local journals, as well as reports of international and government organizations. The main sources are scientific studies, data from the State Statistics Committee of the Republic of Azerbaijan, data of the National Hydrometeorology Department and other sources. Scientific articles published abroad and in our country were used. In addition, the National Hydrometeorology Department has collected and analyzed surface, hydrological and meteorological observations for many years.

Chapter 1. Physical and geographical factors including the flow of the Greater Caucasus rivers

Bedrock geology

All watershed ecosystems are rock-based. The nature of this rock determines the character of overlying soils and influences the ultimate movement of water draining through those soils. Rock is formed in one of three ways: igneous, sedimentary and metamorphic processes. Each type has its special physical qualities and chemistry (Mossler and Book, 1995).

Sedimentary rocks consist of either fragment of minerals and rock eroded from previously existing rocks and then deposited by natural forces, or of materials precipitated from aqueous solutions. Thus, sandstones are formed from sandy sediments, limestones and dolomites come from finer sediments with a high proportion of shell and carbonate and shales come from the finest clay sediments (Salamov et al., 2020). Sedimentary rocks are formed as a result of the precipitation of materials in salt and gypsum solution. As with igneous rocks, the chemistry of sedimentary rock becomes a significant impact on watershed soil and water chemistry. This is especially true for rocks containing high concentrations of calcium carbonate, an important buffering agent, especially in freshwater systems. Sedimentary rocks usually exhibit a layered or stratified structure, reflecting the depositional processes involved in their creation (Heathcote, 1998).

Metamorphic rocks are created when igneous or sedimentary rocks are subjected to further heat and pressure, thus modifying their crystal structure and their physical properties. Slate, for example, is the metamorphosed form of shale; marble is the metamorphosed form of limestone. Metamorphic rocks show a more pronounced alignment of crystals than is seen in igneous or sedimentary rocks, a result of the action of heat and directional pressure on preexisting crystal structures (Heathcote, 1998).

All the described structures of the Greater Caucasus anticlinorium sink sharply in the Girdiman river and close periclinal in the east on the shores of the Caspian sea. The buried continuation of Vendam anticlinorium in the area of Shamakhi-Gobustan synclinorium is considered to be the maximum gravity of Yavanidag-Sangachal. Here, between the Girdiman and Agsu rivers, there is a thick (1500 m) Cretaceous sedimentary cover on the Maykop sediments, which is called the basgal cover. In the west, much of the southern part of the Vendam anticlinorium between the Mazim and Girdiman rivers is covered with gravel (Alizadeh et al., 2016).

The Greater Caucasus mountains consist of support plates extending to the north. On the southern flank of this range, Cretaceous rocks have been pushed over Pliocene sediments. Ongoing nap formation is reflected in modern seismic activity: the hypocenters of earthquakes along the south flank of the Greater Caucasus descend to a depth of 100 km to the north (Clarke, 1993).

For a long time, mountain rivers bring rocks from their basins and collect them downstream. The rocks collected in the lower part are called inflow conus. South of the Greater Caucasus sand, gravel and clay form the basis of the rocks brought into the rivers starting from the slope. As a result, the inflows occur mainly in the inflow cones, located in the parts of the rivers flowing from the mountainous areas to the plains. Bottom of the flow of mountain rivers, such as the Goychay river importing crumb materials due to a decrease in the flow rate in the foothill plain area arises from the accumulation of sediments.

As a result of a sharp decrease in the slope of the river, the speed decreased in the plains and imports begin to collapse intensively. Sand-gravel river collected in delivery cones. It gradually strengthens the riverbed. This completely prevents future erosions in riverbeds. That's it therefore, erosion in stable riverbeds is very weak or non-existent. Bringing cones most of the time is considered the most suitable place for settlement, and urbanization in such areas is very intensive.

The inflows collected below from the delivery cones of the rivers are also valuable construction materials are considered. Intensive sand-gravel extraction in riverbeds often causes deformations, and bottom and side erosions. As a result of the extraction of sand and gravel, the stability of riverbeds is lost, and the process of erosion in various forms begins. If, as a result of excavation at the bottom of the river, there are sharp differences in elevation in different parts of the riverbeds, this bottom erosion causes. It is important to note that the river takes into account the full impact on the environment extraction of construction materials by methods that allow the ecological balance of the river to be maintained, taking into account the impact on the environment. However, this is possible in the context of a comprehensive investigation and Environmental Impact Assessment.

Natural bottom erosion is very characteristic of a mountain river. The main reason for bottom erosion is the high water level in the riverbed, the large differences in the height of the bottom in different places and the high speed. Due to the low water velocity in the plains, bottom erosion does not occur. If the flow velocity in the riverbed increases as a result of human activity, the bottom erosion intensifies (Xiong et al., 2019).

In the distance from the source of the Goychay river to its mouth, there may be depressions in the longitudinal profile, and convex areas. As a rule, the convex parts of the riverbed are washed away. The depressions are filled by riverbeds. Thus, under the influence of gravity, the river always tries to create a balance in its profile from source to source. Over time, the longitudinal profile of the river becomes smoother, the bumps and depressions decrease as a result of erosion and accumulation. The creation of artificial depths as a result of the unregulated extraction of sediments in any part of the riverbed causes the formation of both depressions and bumps in those areas. In this case, the river water collects in the same depression, and on the other hand, the convex parts are eroded. As a result, the bottom of the river gradually deepens. As can be seen from the longitudinal profile of the Goychay river, after leaving the mountainous area, there is a sharp decrease in the slope of the riverbed, where the import cone was formed. Currently, the longitudinal profile of the river is very close to the equilibrium profile.

Rainfall and snowmelt

Physical and geographical factors affecting the flow of rivers are divided into 2 groups: Climatic factors and surface factors.

Climatic factors are also called meteorological factors. These factors are the main meteorological factors involved in the slope of the stream, which determine the income and expenditure of the water balance of the area (Webb and Nobilis, 2007). These factors determine the nutritional characteristics of rivers, their distribution throughout the year, ecological flow and quantitive measures of the flow. These factors are divided into 2 parts: Direct and indirect. Indirect is also called the factors involved in the formation of the flow. Factors that directly or indirectly generate flow include the factors that make up the bulk of the rivers' water balance. These factors include solid and liquid precipitation falling into the river at different times of the year. The amount of precipitation in the river is involved in the feeding of the river in a short time. (Arnell, 1992). Groundwater, one of the other sources, is present when precipitation begins to decrease. When rainfall is low, groundwater reserves are depleted. The river begins to dry up. As a result, atmospheric precipitation is the only source of groundwater and a source of groundwater, is one of the main sources of income for the river's water balance (Schaller and Fan, 2009). The role of precipitation in the formation of different characteristics of river flow is not the same. Their strongest effect is felt in the formation of the maximum flow. Rain and snow play an extremely important role in the formation of the maximum flow of mountain rivers. The occurrence of floods and their maximum consumption depends on the amount and intensity of the precipitation. In rivers with an absolute majority of rainwater in their feeding, the impact of source factors on the formation of floods, especially their maximum consumption is weak. In rivers fed by rain-snow water, the cost of maximum consumption in some years increases due to rainwater (Israfilov, 2002).

All the water in the basin comes from rain, snow and dew. Water vapour is always present in the atmosphere, even in the driest regions. The deposition of this moisture as precipitation depends on both local and regional or on a larger scale, complex physical events (Shahraki, 2019). The most casual observer knows that rainfall is rarely evenly distributed in a certain area: for example, in one part of the city it may rain and in another one it dries up. Like all meteorological factors, atmospheric precipitation is subject to the law of vertical zoning. The variability gradient of precipitation is very complex for the entire area (Maharramova, 2018).

The inflow of surface water and precipitation into the riverbed during the minimum flow is not interrupted in many basins. At the same time, groundwater, which plays a key role in the formation of minimal flow, is also fed by precipitation. Precipitation in the river reservoir has a significant effect on the formation of both annual flows. In this regard, the increase in the annual precipitation layer also affects the increase in the minimum flow (Raymondi et al., 2013). In plain rivers and the lower zones of mountain rivers, the water in the riverbed is hydraulically in contact with groundwater. During periods of flooding and prolonged floods, groundwater supply in such rivers is cut off and part of the water in the riverbed is used to increase groundwater reserves. Groundwater recharge in such rivers is maximized after the end of the multiplication of rivers, however, due to the lack of hydraulic contact with groundwater, the period of feeding coincides with the period of abundance (Balke and Zhu, 2008). Climatic factors that make up the water balance include evaporation and lack of humidity. Intense evaporation occurs mainly in hot seasons. In this case, a large amount of water evaporates from the river basin. The evaporation process takes place both from the dry surface and from lakes and reservoirs in the rivers, as well as from plants, especially in forested areas.

In the mountains, precipitation increases to a certain height and then begins to decrease. On the southern slopes of the Greater Caucasus, their number is estimated at an altitude of about 2400-2600 m. After these heights, the amount of precipitation decreases. The region with the highest number of rainy days with a daily amount of more than 20 mm is observed on the southern slope of the Greater Caucasus (Makhmudov, 2016). The maximum annual rainfall is 800-900 mm on the north-eastern slope of the Greater Caucasus. On the southern slope of the Greater Caucasus, the maximum annual precipitation is 1400-1600 mm (Forte et al., 2022).

The amount of precipitation is repeated from the plains to the mountains. On the southern slope of the Greater Caucasus, this period is 160 days and in the middle mountainous part of the southern slope, it reaches 170 days (Eldarov et al., 2015). On the south-eastern slope of the Greater Caucasus, this period lasts 120 days. The largest daily maximum precipitation was 148 mm in Alibey on the southern slope of the Greater Caucasus (Mirmousavi et al., 2022).

Table 1

Monthly precipitation in the Goychay region (2019)

Meteorological indicators	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Monthly precipitation mm	35	3,2	37,3	66,3	48,1	37,1	1,1	18,1	22,1	46,4	4,1	65,4
Maximum monthly precipitation mm	20	2	12,8	16,7	10,8	28,5	0,7	8,8	20,4	38,7	3,1	15,3
Continuation of rainless days	21	22	10	9	5	8	1	10	12	11	12	10

Table 2

The average perennial flow of the Greater Caucasus rivers in 1961-2010

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Goychay-Buynuz	5.8	5.3	6	10.9	13.4	13.7	9.6	7.7	7.8	9	8.2	6.7
Qusarçay-Quzun	1.84	2	3.04	5.75	7.51	8.30	8.68	5.03	4.4	3.8	2.93	1.9
Qudyalçay-Kupçal	3.40	3.56	4.75	7.34	10.01	13.27	10.52	6.45	6.39	6.21	5.46	4.20
Agsuchay-Agsu	1.38	1.56	2.17	2.83	3.17	1.83	0.99	0.64	0.91	1.32	1.7	1.44
Demiraparanchay-Qutqashin	1.63	1.53	1.71	3.37	6.43	9.38	6.38	4.12	3.61	3.50	2.71	2.09

Figure 1

The average annual water flow of rivers in 1961-2010

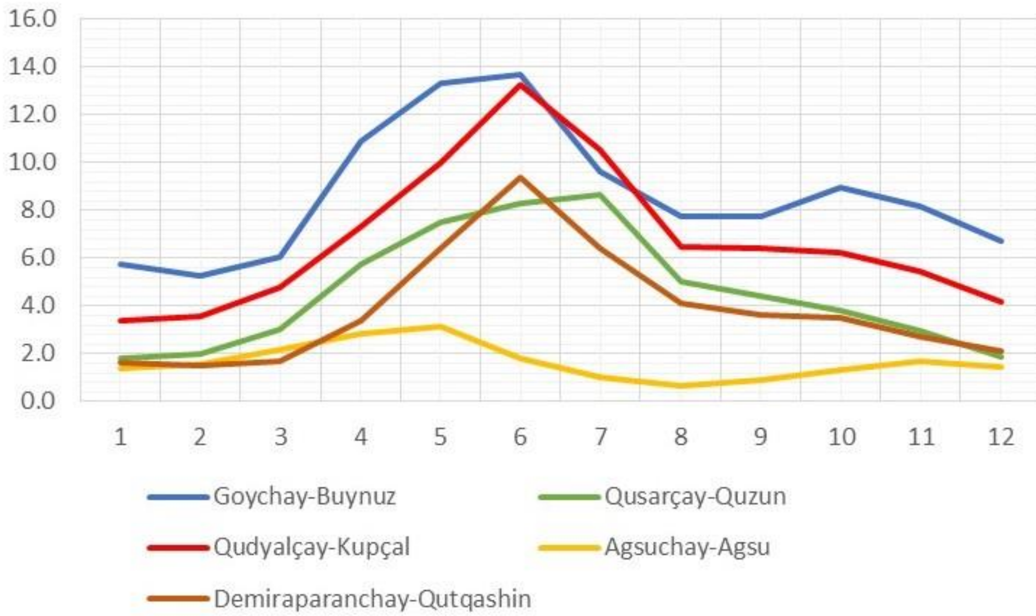


Figure 2

Average perennial flow in the Goychay-Buynuz river

Figure 3

Average perennial flow in Gusarchay-Guzun river

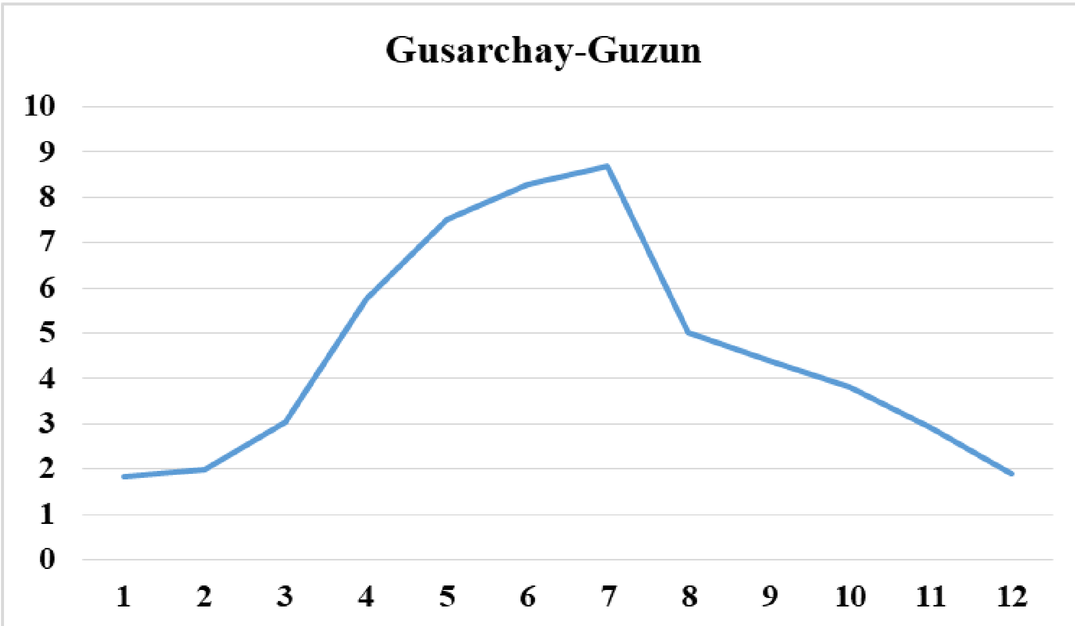


Figure 4

Average perennial flow in Gudyalchay-Kupchal river

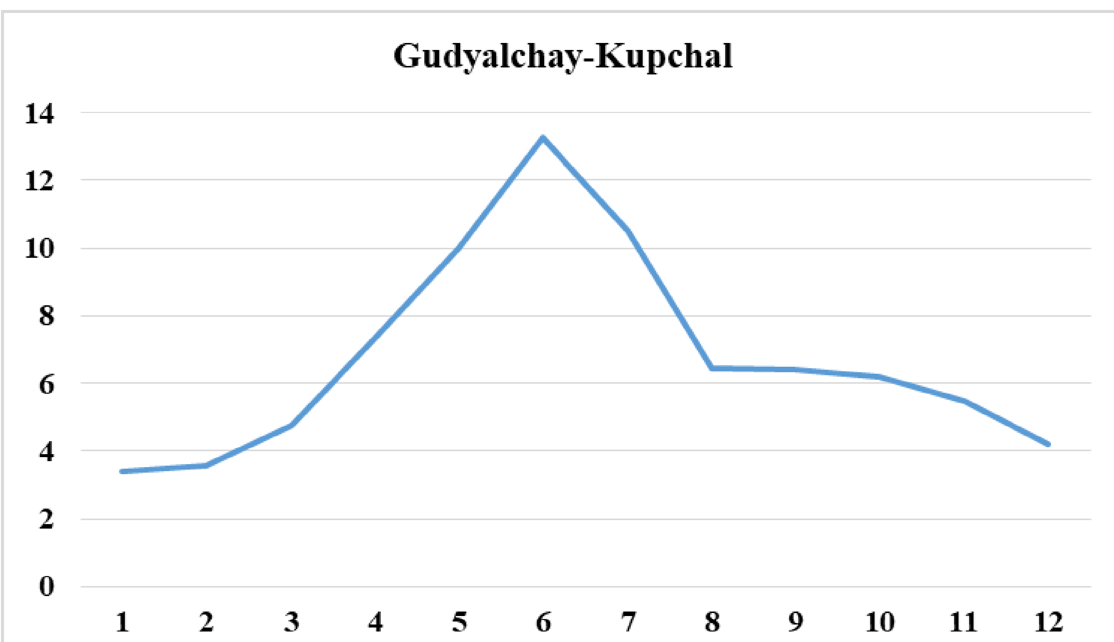
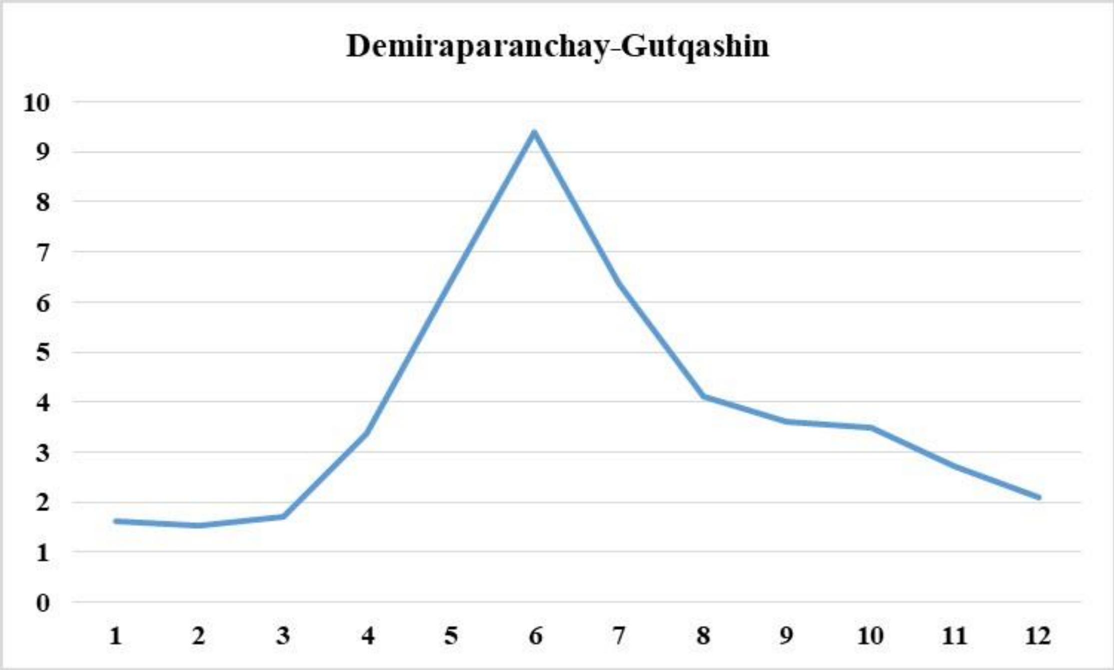


Figure 5

Average perennial flow in Demiraparanchay-Gutqashin river



Rivers may have different sources of nutrition at different times of the year and in different parts of the year. The fivers of the Greater Caucasus are fed mainly as a result. Much of the river flow is due to the melting of snow and ice. In snowy and cold areas, the natural river regime has a downward flow when snow accumulates and a peak flow when snowmelts (Arheimer et al., 2017). Rapid snowmelt can cause landslides and floods. The amount of frost cover in the area affects the scale of landslides and floods.

As can be seen in the given hydrograph, the times when the rivers flow the most are the spring and summer months. During these months, the temperature rises and decision-making process accelerates. In Gudyalchay, Goychay, Gusarchay and Damiraparanchay the flow increases mainly in spring and summer (Figure 1).

Air temperature and evaporation

One of the climatic factors actively involved in the formation of the flow is the air temperature. The annual course of temperature significantly affects the formation of the flow and its distribution during the year. Daily, monthly and annual temperature fluctuations occur depending on atmospheric events. The intensity of snow accumulation and melting varies depending on the annual temperature course in the river basin (Overland et al., 2015). The duration of fertility is determined by the temperature in the basin. The warm period of the rainy season causes most of the snow and water resources in the river to pass in a short period. In most cases, the area's rivers exceed half of their annual water supply in a short period. The weak course of temperature during the flood period has a great impact on the flow of rivers in the area. In this case, the period of flooding is prolonged, and in some cases, the snow reserves in the basin remain with each other without melting for a year (Arismendi et al., 2014). Although the melting time of snow reserves does not significantly affect the annual flow, it has a strong effect on the formation of maximum and minimum flow. Prolonging the melting time of snow increases the cost of the minimum summer flow while decreasing it reduces it (Fountain and Tangborn, 1985).

The effect of temperature flux on the flow, as a rule, weakens after the depletion of snow in the basin, and only affects the evaporation from the basin. Surface factors have been assessed as factors influencing the formation of currents (Delpla et al., 2009). However, the river basin is an open system in which the components are in close contact and interact with each other. The change of one of these components affects the change of the other, and here almost all factors are interdependent (Meehl et al., 2004). Therefore, the climatic factors, which are the main components of the river flow, themselves depend on the surface factors, and here it is impossible to completely separate from each other. It is very difficult for the annual temperature to change depending on the height of the basin. As the altitude increases, the temperature decrease (Yang et al., 2021).

In the Greater Caucasus, there is no significant difference distribution of the average multiyear temperature. In areas with the same altitude, the difference in the average multiplicity of air value is small. This is primarily because the whole is long the same climate zone. Towards the mountains, the air temperature decreases to 4-5° C at an altitude of 2000 m. At an altitude of 3000 m, 1-2° C is observed. The average monthly temperature in the mountains is 8-9° C at an altitude of 3000 m.

Table 3

Average annual temperature indicators of the Goychay region (2010)

Meteorological indicators	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	annual
average monthly temperature	3,5	7,0	10,9	12,3	17,4	23,9	28,9	26,9	24,6	18,3	11,1	0,1	15,4
monthly minimum t	-2,9	2,9	5,9	9,3	12,9	19,5	23,6	19,6	19,1	12	6,8	-4	-4
monthly maximum t	8,5	12,4	16,4	16	25,4	27,9	31,9	30,8	26,7	20,6	14,3	6,3	31,9

Flow-generating factors include atmospheric precipitation and groundwater. Groundwater, in turn, is the former mountain the influence of atmospheric precipitation and groundwater are subject to the law of geographical zoning. Indirect factors include groundwater supply temperature, evaporation, relief, and hydrological basin belongs to. Surface factors are not subject to any zoning local characteristics. The group of conditional factors includes the area of the basin, the average height of the reservoir, the slope, the depth of the erosion section, the density of the river abundance the coefficient of natural regulation of groundwater flow. They are in close contact with each other, one can influence the other and change it. The formation of minimal flow in mountain rivers is different from that in plain rivers, depending on the vertical zoning. The vertical zoning of climatic, geomorphological, hydrogeological, soil-vegetation factors and the change of these factors even at short distances is reflected in the formation of minimal flow. The influence of physical-geographical factors on the minimum flow of territorial rivers was first analyzed by Imanov.F.A (Imanov, 1979). The effect of atmospheric precipitation on the minimum flow of local rivers is unclear. As the rate cost of precipitation increases, so does the cost of minimum flow. The increase in the cost of the flow is somewhat slow, depending on the precipitation, both in the warm period of the Caucasus year and in the cold period. That is, at low values of the annual precipitation increases, there is an increase in the minimum flow (Mamedov and Shabanov, 2017).

Evaporation is the conversion of water from the liquid to a vapour form. It occurs over the surface of open water bodies as water molecules escape from the liquid into the air. Evaporation is said to occur when the transition from liquid to air exceeds the transfer from air to liquid; when the opposite is true, it is said that precipitation has occurred (Lorenz et al., 2021).

The effect of evaporation on the flow passes easily from one year to another. Excessive evaporation from the river in any year can significantly reduce the flow the following year. Accurate assessment extending from the basins of Azerbaijan rivers remains a problem to this day. The temperature of the air and the surface of the soil determines the distribution of the flow throughout the year. The melting of glaciers, is the beginning of the period of turbulence, the duration of which occurs under the influence of temperature (Peel and McMahon, 2014).

Evaporation also occurs from dry surfaces. Where soils are saturated and the water levels are high, evaporation rates may approach those from free-water surfaces. As factors increases, the evaporation rate will decrease rapidly. Artificial coverings or a natural cover on a soil surface further limit evaporation from the soil (Monteith, 1965).

Transpiration is the transfer of water molecules into the air through the tissues of living plants. Thus, evaporation and sweating can occur simultaneously in an area such as a rice. Transpiration rates are usually measured in the area where the is a complex process that can involve "bagging" plants or trees to capture all moisture. Such experimental data are sometimes criticized because the process of covering a growing plant with plastic or another film can change the temperature of the tissue and thus affect the rate of natural processes (Song et al., 2018).

Evaporation and transpiration rates are often combined into a single "evapotranspiration" rate, that can be determined from field measurements using controlled evaporation techniques and mass balance approaches (Feyzi and Rezaei, 2022).

The maximum value of evaporation from the surface of local rivers is in the middle mountainous areas with high heat and humidity. Low evaporation rates in the lowlands and highlands, low humidity in the lowlands, and low temperatures and low humidity in the highlands (Weingartner et al., 2007).

Certain principles are taken into account when deriving dependencies for the calculation of evaporation. Since the precipitation in the plains where the flow does not occur is completely spent on evaporation, the cost of evaporation in those areas is equal to the cost of precipitation. The cost of precipitation in high mountain areas is higher than possible evaporation. Therefore, evaporation from these areas can be considered equal to evaporation from the water surface (Lam et al., 2011).

One of the main factors influencing evaporation is wind. However, it is difficult to determine the relationship between wind speed and surface factors. Therefore, averaged values of stations in different altitude ranges were used.

Chapter 2. Influence of anthropogenic factors on the flow of the Greater Caucasus Mountain rivers.

Land use and overgrazing

Overstocking means a condition where an area is intensively pastured with more animals than it can resist for a grazing season. During the summer, many mountain pastures in Greater Caucasus are leased to temporary pasture tenants. Tenants usually come from other areas and are not residents of the mountain territories. According to the law, no more than 8 sheep per hectare can be kept in pastures. However, this rule is not followed, on the contrary, it becomes more intensive. Municipal officials and community members do not control the number of sheep and cattle (Hao et al., 2018). They do not have the financial means to control. On the contrary, they graze more animals and cause soil erosion and degradation. Overgrazing causes serious damage to the flora of the area. Reduces the value of soil humus. At the same time, the land is being trampled so much that landslides can occur in that area. This endangers the lives of the living there. In our country, lands in Yerfi village of Guba region are subject to overgrazing. Lands in this area are not controlled. Soils are gradually eroded and degraded. Landslides and floods are also increasing. The rivers in that area, such as the Gudyalchay are turbid and polluted. Land degradation leads to many problems. These include socio-economic problems and it also reduces biodiversity there (Abbasov, 2019).

The arid climate of Azerbaijan, the unequal and limited distribution of water resources in the region, population growth and rapid economic development in recent decades are increasing the country's demand for water. The increasing amount of water taken from water sources, mainly from rivers, has led to significant changes in the regime of major rivers in the country, the flow of most rivers has decreased, and the natural distribution patterns of the flow have been violated the year (Mamedov and Ibadzade 1988).

The intensive impact of economic activity on the flow of the Azerbaijani rivers dates back to the 1930s. Water intake for irrigation and domestic needs are the main anthropogenic factors affecting the flow of rivers, which are the main sources of water in the country. Currently, the impact of economic activities on the flow of rivers in the country is mainly in the following areas (Cheng and Li, 2018):

- Withdrawal of water from riverbeds and basins for economic and household purposes

- Regulation of river flow
- Disposal of used water into riverbeds
- Transfer of water resources from one basin to another

The main reason for taking water from rivers for economic and household purposes in Azerbaijan is irrigation and providing the population with drinking water. For this purpose, the implementation of large-scale water management projects began in the 1930s, and as a result of these measures, the area of irrigated lands in the country has significantly expanded. Samur-Davachi plain is considered to be the main irrigated area of the country.

Comparative analyzes based on statistical methods are used to determine the initial years of the impact of economic activity on river regimes. These methods are based on comparing the flow of disturbed rivers with the flow of rivers with a natural regime or precipitation in the basin (Shiklomanov, 1989; Imanov, 2000 and Fatullayev, 2002). For example, according to the most common methods, the initial year of the impact of economic activities is found by the following relationship:

$$\sum_{1}^{n} Y_{qap} = f(T) \tag{1}$$

$$\sum_{1}^{n} Y_{qap} = f\left(\sum Y_{an}\right) \tag{2}$$

$$\sum_{1}^{n} Y_{qap} = f\left(\sum Y_{qol}\right) \tag{3}$$

$$\alpha = f(T) \tag{4}$$

$$\sum_{1}^{n} Y_{qap} = f(X) \tag{5}$$

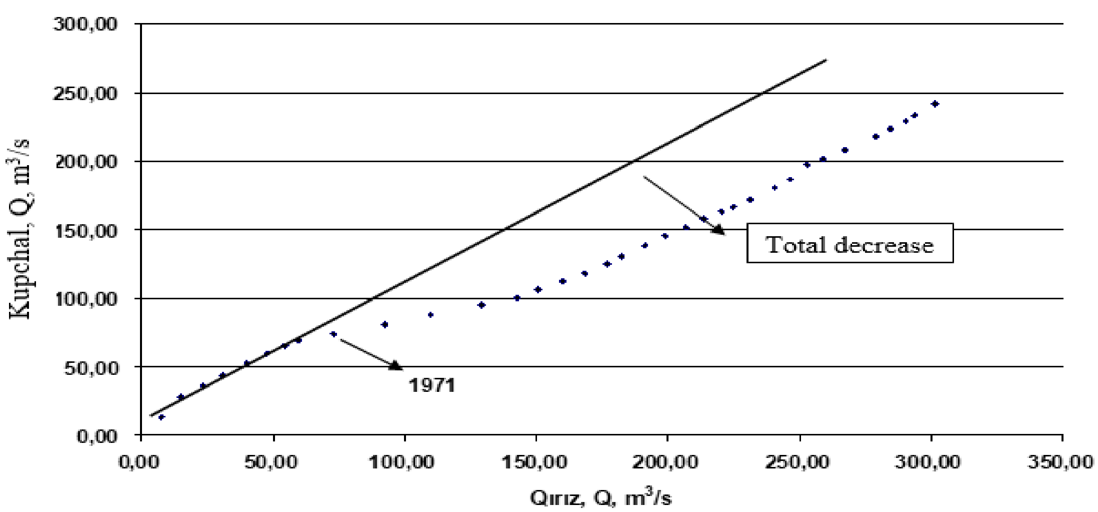
Here, $\sum_{1}^{n} Y_{qap}$ is the consecutive sum of the unit values of the river flow, which should be determined by the starting year of the anthropogenic economic activities; T - years; $\sum Y_{an}$ - the consecutive sum of unit prices of similar river flow with a natural regime; $\sum Y_{qol}$ - the sum of the unit values of the flow of tributaries n the river; α - the ratio of the total flow from the tributaries to the flow observed at the closing point; X - is the sum of unit values of atmospheric precipitation in the river basin.

Based on the above relationship, it is possible to determine the year in which the impact of economic activities on the minimum, seasonal and annual flows began. Minimal flow values should be used when determining the impact on the annual flow (Imanov and Orlov, 1993). It should be noted that years when the impact of economic activity on both the annual flow and the minimum flow often coincide.

According to the methods listed above, the most difficult step in determining the starting year of economic activities is to find a hydrological similar river. A similar hydrological river should be located in the area adjacent to the studied river in terms of physical-geographical, hydrological, and morphometric characteristics. In addition, a similar site should have a natural regime and adequate information that there is no impact of economic activities on that site. Usually, it is more expedient to take two similar points on the same river and give good results. This is because the requirements for a similar hydrological station can often apply to sites located on the same riverbed. In this case, it is necessary to take the higher point, similar to the lower point. This is because it is easier to find a point with a natural regime in areas with higher altitudes. For example, in Figure 6, to determine the impact of economic activities on the annual flow of the Kupchal settlement of the Gudyalchay, the settlement above and that river was taken as similar. According to this picture, the impact of economic activities in the Kupchal settlement has been felt since 1971.

Figure 6

Double integral connection between Kupchal and Qiriz settlement of Gudyalchay



In practice, when a similar river is difficult to find, they often use (1) or (5) connections. However, these methods also have drawbacks. For example, the results obtained by formula (1) are not sufficiently accurate. The formula (5) also requires information on atmospheric precipitation, and it is difficult to find information on the average annual rainfall in the basin for each year. It should be noted that it such information is available, the application of formula (5) may give better results.

Statistical and water balance methods are mainly used to assess the impact of anthropogenic factors on river flow. To make statistical assessments, it is important to have observations of the various flow characteristics of the river during a period when both natural flow and anthropogenic impact are already present. Based on observation of natural flow, the dependence of river flow on the main flow generating factors is studied and the analytical relationship between these factors and the flow is found. Then, according to these dependencies, the natural flow is calculated for the period of anthropogenic factors. In the final stage, the impact of anthropogenic factors on the flow is quantified based on the difference between the flow observed with the natural flow (Delucchi, 2010).

The above can be expressed analytically as follows:

$$\Delta Y_{ant} = Y_t - Y_m \tag{6}$$

Here, ΔY_{ant} - streamflow is the result of anthropogenic factors; Y_t - numerical value of natural flow; Y_m - observed flow.

If there are no observations of the main flow factors, then the natural flow indicators of the studied river can be calculated using the flow data of the neighbouring river with a natural regime using the method of hydrological similarity. Detailed information on the hydrological similarity method is given above.

To assess the impact of economic activity on summer and summer-autumn minimum flows, Imanov proposed to establish a relationship between winter and summer minimum flows. In these relations, the minimum winter flow is conditionally taken as natural, and the impact of economic activity is calculated based on the change in these relations over a multi-year period (Imanov, 1989 and Imanov, 2000).

The main disadvantage of statistical methods is that there are often no observations on the natural flow of rivers, or these observations cover a very short period. For example, hydrological observations in most rivers in Azerbaijan began long after anthropogenic factors were present, and therefore the application of statistical methods poses certain difficulties. On the other hand, the error of the result obtained by statistical methods is usually large.

When applying the water balance method, the natural flow of the river must be calculated as in statistical methods. When calculating the natural flow, the impact of all the factors, affecting the river flow in the basin should be assessed, and accurate information should be provided on the amount of water taken from the basin for different needs.

According to water balance methods, natural flow can be calculated by the following formula:

$$Y_t = Y_m + Y_g - Y_q \pm Y_{an} \pm Y_d \tag{7}$$

Here, Y_g - the quantitative amount of water taken from the river basin for various needs; Y_q - used water returned and artificially introduced into the basin from other river basins; Y_d - is a change in flow under the influence of other anthropogenic factors (deforestation, drainage of swamps etc.).

After taking into account all the factors listed above, as in statistical methods, the effect of anthropogenic factors on the flow is calculated based on the difference between the value of the natural flow and the observed flow value (Shiklomanov, 1989).

One of the most widely used statistical methods is to analyze the total losses in the basin, calculate the difference between the average values of water resources and the closure point, and find the flow loss due to anthropogenic factors. In this case, the calculations must be performed with the following formula:

$$Y_{ant} = \sum Y_{qol} + Y_{yan} - Y_{qap} \pm \Delta Y \tag{8}$$

Here, Y_{ant} - the numerical value of the impact of anthropogenic factors on the flow; Y_{qol} -flow from the tributaries to the main riverbed; Y_{yan} - side flow to the main riverbed; Y_{qap} - flow at the closing point; ΔY - other inflows and outflows of the flow which can be attributed to evaporation and infiltration from the water mirror.

Riverbed water balance (RWB) should be calculated to determine the level of impact of anthropogenic changes in different parts of the river. When calculating the channel water, two points on the river are selected and the distance between these points (Glasson, 1999 and Bathia, 2000).

For any part of the river, the RWB can be calculated by the following formula:

$$Y_a - Y_y - Y_{ya} + Y_{sg} \pm Y_{mt} \pm Y_x = \Delta Y \quad (9)$$

Here, Y_a and Y_y - flow rate at the lower and upper points; Y_{ya} - side flow between lower and upper points; Y_{sg} - the amount of water taken from the channel; Y_{mt} - drain regulation; Y_x - calculation error; ΔY - it is the difference between the income and deduction elements of the RWB equation.

It should be noted that water balance methods are more reliable in assessing the impact of anthropogenic factors on river regimes. However, the main disadvantage of these methods is the lack of the necessary database and the low quality of the available data (Zalewski, 2000).

Under the influence of anthropogenic factors, the flow loss varies over a large range and has an increasing tendency. Flow losses include water taken by pumping stations, evaporation from the surface of reservoirs and streams, infiltration of reservoirs and streams, as well as other losses. Flow losses are usually calculated as the difference between the natural flow and the flow observed at that point.

The influence of economic activity on the North-Eastern slope of the Greater Caucasus and the flow of the Shirvan rivers was calculated by Y.M.Eyvazova. The regularities of flow change in that area are given in Table 4.

Violation of the natural regime in the area mainly affects the period after 1966-1960. Samur, Turyanchay, Goychay, Gudyalchay and Valvalachay rivers, are the main rivers of the region. As a result of the impact of economic activities on rivers, the flow has decreased by an average 0f 30-35%.

Table 4

Assessment of the impact of economic activity on the north-eastern slope of the Greater Caucasus

River-station	Number of years of observation			Flow change		
	N_{total}	$N_{natural}$	$N_{disturb}$	Starting year	Q, m^3/c	
					Q_{obz}	Q_{equal}
Samur-Akhtı	54	37	17	1964	43.6	45.4
Samur-Usukh	32	19	13	1968	59.8	74.2
Gusarchay-Guzun	63	35	28	1967	4.46	6.9
Guruchay-Susay	30	11	19	1972	0.69	0.73
Gudyalchay-Kupchal	61	42	19	1976	6.22	6.7
Garachay-Ryuk	27	9	18	1977	2.14	2.89
Valvalachay-Tangaaltı	48	31	17	1977	3.55	4.24
Turyanchay-Savalan	60	31	30	1964	17.6	17.7
Goychay-Goychay	57	23	34	1957	11.8	13.0

River pollution

As a result of modern technology, their pollution in the world's oceans, seas, rivers and lakes are inevitable. In particular, it has a negative impact on their quality and quantity. This is the case in our country, as in many countries around the world. Pollution of our water bodies is studied by various authors and has become a global situation (Aliyev & Khalilova, 2014).

Human use of water in the Greater Caucasus mountains has different purposes. The main purpose is that people use the water of mountain rivers for economic purposes and due to the need freshwater. Extensive and intensive use of water, in turn, creates various problems.

One of the causes of pollution of the Greater Caucasus mountain rivers is the pollution of enterprises and agricultural wastewater located there. In particular, the rivers flowing from the southern slope of the Greater Caucasus have been exposed to such pollution. Although Katekhchay, Balakanchay and Damiraparanchay were exposed to agricultural wastewater, hydrochemical analysis in 2018 showed that the level of pollution in these rivers has increased. According to the Water Pollution Index, it belongs to the 2nd class of clean water (Mahmudov et al., 2020).

Among the observations made in the rivers flowing from the north-eastern slope of the Greater Caucasus, it is included in the class of clean water. The role of factories in the Gudyalchay, Gusarchay, Qarachay and Valvalachay rivers is great. Many factories, plants and enterprises have been built and put into operation in Khachmaz and Guba regions. Factory, household, communal, and industrial wastewater from these regions are discharged into the rivers and increase the amount of pollution. In particular, the intensive discharge of sewage from the Guba cannery into the Gudyalchay polluted the water there. Many years of observations have also been made on the north-eastern slope of the Greater Caucasus. From these observations, it can be concluded that the rivers of the north-eastern slope of the Greater Caucasus, according to the Water Pollution Index, belong to the group of moderately polluted water. The level of pollution in the Gusarchay has dropped significantly in recent years. These rivers play an important role in feeding the Jeyranbatan reservoir. Pollution of these rivers increases our need for drinking water and if it is contaminated at its peak, then the rivers will become unusable. The water of the rivers will not be used and the life of the living there will be endangered.

Certain analyzes were taken from Shahnabat, Mahmuddera and Abildere river waters. The analysis shows that the water of these rivers was colourless and odourless. As a result of the analysis of the Water Pollution Index, these rivers are classified as class 1 is very clean water.

In the case of pollution, many experts agree that if the concentration of any contaminant found in the riverbed exceeds the Permissible Concentration Limit (YVQH), then the ecological flow cannot be ensured. In other words, to ensure ecological flow, it is necessary to accept the following inequality (Vernichenko, 1984).

$$\frac{Q}{YVQH} \leq 1 \tag{1}$$

Here, Q is the observed concentration of any pollutant and the PCL limit for that pollutant. It is clear that the value of the environmental flow cannot exceed the value of the observed flow. In other words, the following inequalities are always true (Abbasov, 2007).

$$Q_m - Q_{ec} \geq 0 \tag{2}$$

Here, Q_m - is the observed flow.

In order to reduce the concentration of pollutants and ensure the environmental flow, the cost of the environmental flow should be increased in proportion to the concentration of the pollutant (Abbasov, 2007). In this case, it is proposed to calculate the environmental flow by the following formula:

$$Q_{ec}^{*} = \frac{Q}{YVQH} Q_{ec} \tag{3}$$

Here, Q_{ec}^{*} - pollution is the cost of the ecological flow if it is observed.

If,

$$\frac{Q}{YVQH} \geq 1 \tag{4}$$

So, this time,

$$Q_{ec}^{*} \geq Q_{ec} \tag{5}$$

In other words inequality ($\frac{Q}{YVQH} \geq 1$) shows that in the case of pollution, the value of the environmental flow must always increase in proportion to $Q_{ec}^{*} = \frac{Q}{YVQH} Q_{ec}$.

If we consider the formula $Q_{ec}^{*} = \frac{Q}{YVQH} Q_{ec}$ in the inequality $Q_m - Q_{ec} \geq 0$, then the following is obtained:

$$Q_m - \frac{Q}{YVQH} Q_{ec} \geq 0 \tag{6}$$

The latter inequality indicates that the ratio between the observed flow and the environmental flow must always be greater than or at least equal to, the ratio between the concentration of the pollutant and the Permissible Concentration Limit. Otherwise, pollution leads to a lack of ecological flow (Abbasov, 2007). After determining the value of the ecological flow, it is possible to determine the permissible limit of water to be taken from the riverbed and this is calculated as follow:

$$Q_{ys} = Q_m - Q_{ec} \tag{7}$$

Here, Q_{ys} - is the numerical value of the allowable water intake.

In this case of contamination according to formula $Q_{ec}^{*} = \frac{Q}{YVQH} Q_{ec}$, the formula $Q_{ys} = Q_m - Q_{ec}$ is as follows:

$$Q_{ys} = Q_m - \frac{Q}{YVQH} Q_{ec} \tag{8}$$

It follows that it is necessary to increase the value of the polluted environmental flow and in order to increase this value, either the non-return water intake must be reduced or the source of pollution must be prevented to ensure the ecological flow at lower prices. The implementation of this or that measure should be decided in terms of economic viability (Abbasov, 2007).

Environmental flows

In modern times, it is impossible to develop human life and any sector of the economy without sufficient water. The growing water demand once again confirms that water plays n invaluable role in all areas of human activity. However, the use of the water resources often has a negative impact on the ecological condition of rivers, which are the main sources of water, disrupting the metabolism of substances and energy in river ecosystems (Poff, 2013). The main source of this problem is that the amount of water taken from water bodies, especially rivers, for various needs is not calculated correctly and as a result excessive water withdrawal, all natural processes in river ecosystems are negatively affected. Human economic activity in river basins primarily affects the abiotic properties of the river ecosystem, changing its water, thermal, radiation regimes, consumption, and flow processes. Changes in the hydrological regime of the river ultimately affect the biotic properties of the ecosystem (Dyson et al., 2003).

Ecological flow refer to a quantitive and qualitative indicator of river flow that does not cause strong quality changes in the river ecosystem during the use of water, and meets all the life needs of living things in the ecosystem (Acreman et al., 2014). The logic behind this concept is that river ecosystems have adapted to natural flow conditions, and human changes in river flow regimes, both quantitatively and qualitatively affect these ecosystems, violate their natural laws, and lead to very serious negative changes in their lives of ecosystem inhabitants. Therefore, in order to protect river ecosystems and provide water for living things, it is necessary to achieve a level of protection of river flow that is very close to natural conditions (Davies et al., 2013).

The artificial reduction of the amount of water in riverbeds and changes in the natural water regime has a serious impact on the physicochemical and biological processes occurring in rivers, endangering the existence of river ecosystems. Therefore, when taking water from rivers for any purpose, it is necessary to determine the amount of water taken in such a way taken in such a way that the water remaining in the river, and can develop hydrobionts. In addition, the chemical and biological composition of wastewater discharged into riverbeds should not change significantly and the water in the river should meet a number of environmental norms and standards. In other words, the value of the ecological flow must be ensured when any amount of sewage is discharged into the riverbed or when any amount of water is taken from the riverbed (Vladimirov and Imanov, 1994).

There are many calculation methods proposed in the research on environmental flow calculation and their number is increasing over time. These methods include individual approaches, taking into account regional differences, economic goals features are reflected.

A broad classification of the methods used to calculate ecological flow has been provided by Tharme (Tharme, 2003). In its classification, Tharme notes that there are 207 methods in different regions of the world. According to Tharmen's classification, ecological flow methods are divided into four groups – hydrological, habitat, modelling, hydraulic assessment and holistic methods. However, Tharmen's review does not cover methods developed in the Soviet Union. The methods developed in that area were studied in more detailed by Imanov (Imanov, 2000).

As mentioned above, according to the classification of Tharmen and other authors, ecological flow methods can be divided into four groups. At the same time, these methods differ from the regional point of view, and there may be some difficulties in applying the method developed for one region to another. We need to look at some of these methods, taking into account the emergence of different approaches, depending on the main objectives. The proposed methods can be conditionally grouped as follows:

1. Methods based on hydrological or statistical estimates. During the application of these methods, the multi-year observation data observed at the hydrological water metering stations operating on the river are used. These methods are considered the most common methods. The proposed calculation methods, as a rule, involve the use of the lowest values observed when the river regime is not affected by anthropogenic factors. One of the methods based on statistical estimations was proposed by R.Abbasov and V.Smakhtin and detailed information about this method is given below (Smakthin, 2006).

2. Habitat modelling method. Habitat modelling methods are the most widespread and widely used methods after hydrological methods. The main feature of these methods is to find the relationship between the distribution characteristics of the flow over many years and lifestyle of aquatic life and to take into account these relationships when calculating the values of ecological flow. In the modelling of habitats, the aquatic ecosystem itself is taken as the main user of water, and changes in the distribution of flow over time are assumed to be the main cause of all processes occurring in the ecosystem. However, the main disadvantage of these methods is that assumption is not entirely correct. In other words, the time distribution of the flow does not determine all the processes in the

river ecosystem. Some authors include hydrological and habitat modelling methods in the same group (Gordon, 1992 and Loperfide, 2014).

3. Hydraulic evaluation methods. These methods are based on maintaining a certain level of velocity and depth of water in the channel. In other words, the depth and velocity of the water in the riverbed must be such that the metabolism in the ecosystem is fully ensured and there are no significant changes in the geomorphological features of the riverbed. The method described above is the most widely used to these methods. As a rule, the main disadvantage of these methods is the excessive demand for information on river ecosystems and hydrological characteristics, which makes it difficult to apply these methods in Azerbaijan type countries. According to the author, the depth and speed of the river should be at a level that will allow the movement of tourist boats (Hyra, 1978). One of the methods based on water velocity and riverbed size was proposed by I.S.Shahov. According to this method, the cost of an ecological stream is calculated based on the specific energy of the stream. In this case, the capacity and speed of the flow of solid materials are taken into account.

4. Holistic methods that take into account the ecological characteristics of the basin. These methods are also known in the hydrological literature as holistic methods. These methods are mainly developed by hydro-ecologists and are based on the application of the ecosystem approach (Ward and Stanford, 1987). An ecosystem approach refers to the lifestyle of aquatic organisms and the metabolism and energy flow in the ecosystem. The application of these methods has, in a sense, reduced the use of habitat modelling methods.

It should be noted that each of the proposed methods has its own characteristics and advantages. The main shortage is that sometimes it is difficult to obtain the necessary information about the basin, flow velocity, hydroecological and other features of the Greater Caucasus mountain rivers during calculations. On other hand, the larger number of methods proposed suggest that different researchers may not be able to come to a consensus and that there are difficulties in solving the problem.

The proposed method for calculating the ecological flow of small mountain rivers is based on the statistical series generated during the observation period. This method is more appropriate in countries where there are no permanent observations of river ecosystems. It should be noted that although there are many methods based on the values of the natural observation period (Tennant, 1975), many of these methods are not well scientifically substantiated and this regard, Imanov's method is an exception. At the same time, this method is the first in the former Soviet Union to be developed similarly, but also allows to take into account the ecological characteristics of the basin. Therefore, Imanov's method can be applied to both hydrological methods and methods of habitat modelling (Imanova and Abbasov, 2007).

The prerequisites for the application of the method are:

1. The value of the ecological flow should allow the mountain rivers of the Greater Caucasus to be protected as an element of the landscape and to provide a habitat for aquatic organisms.

2. The ecological flow should be equal to the price at which the river ecosystem is already operating under natural conditions.

3. Ecological stream cannot be the same for the whole year and must be different for each calendar month.

Within the accepted conditions, the author proposed a method for calculating the ecological flow. The application of the method is carried out in the following sequence:

1. From the average monthly water consumption covering the entire observation period, a multi-year observation sequence complies for each calendar month.

2. The initial year of the impact of anthropogenic factors on the natural regime of the river is determined. Observations are divided into two periods that reflect the medical regime and are influenced by anthropogenic factors.

3. From the series of observations reflecting the natural regime, the lowest water consumption ($Q_{\min}$) observed for each calendar month is found and initially accepted as ecological flow (Q^*_{ek}):

$$Q^*_{ek} = Q_{\min} \quad (1)$$

4. The initial value of the ecological flow is compared with the average the average monthly water consumption ($Q_{mş}$) of the observation period when the impact of anthropogenic factors exists.

$$Q_{mş} \geq Q^*_{ek} \quad (2)$$

If, conditionally paid, the ecological condition of the river is considered satisfactory, if not paid, it is considered unsatisfactory.

5. The cost of possible water intake (Q_{ms}) for each reporting month is found for the difference between the naturally observed water consumption (Q_{tb}) and the ecological flow:

$$Q_{ms} = Q_{tb} - Q^{*}_{ek} \tag{3}$$

As noted above, in the initial approach, the lowest value observed in the natural regime for the period when there is no anthropogenic impact is taken as the ecological flow:

$$Q^{*}_{ek} = Q_{\min} \tag{4}$$

However, any hesitations that may occur in the future in the river flow must be taken into account. That is, for the natural regime, such a water consumption could be observed that its value is less than the value of the quantity ($Q_{\min}$). Therefore, the value of the quantity (Q^{*}_{ek}) must be reduced to any quantity (ΔQ_1). At the same time, the rate of water consumption observed on certain days of the reporting month (Q^{*}_{ek}) could be smaller than the value of the quantity (Q^{*}_{ek}) must be increased by any quantity (ΔQ_2).

Taking into account the above, the following formula is used to calculate the ecological flow:

$$Q_{ek} = Q_{\min} - \Delta Q_1 + \Delta Q_2 \tag{5}$$

Here, Q_{ek} - ecological flow, $Q_{\min}$ - the lowest price among the observation, consisting of the average monthly water consumption with a natural regime, ΔQ_1 - possible natural reduction of the lowest rate in the line of observation, ΔQ_2 - possible reductions in daily consumption in the reporting month, which is less than the average monthly rate $Q_{\min}$.

The value of the quantity is determined by applying the transition coefficients of the ratio the observed minimum value of the minimum value expected during the intended operation of the hydraulic structure. The transition factor was proposed by Kryukov:

$$K_1 = \frac{Q_{n+N}}{Q_n} = f(n, N, \beta) \tag{6}$$

Here, n-number of year of observation, N -intended service life of the hydraulic structure, β -level of probability of reliability, Q_n - n the lowest rate among the observations with, Q_{n+N} - $n+N$ the lowest rate among the observations with, K_1 - transition coefficient.

The calculated values of the coefficient K_1 can be used to estimate the quantity (ΔQ_1). (ΔQ_1) is the probable minimum value of the minimum current during future observations and is calculated by the following formula.

$$\Delta Q_1 = (1 - K_1) Q_{\min} \tag{7}$$

The value of the quantity that characterizes the water shortage is calculated by the following formula:

$$\Delta Q_2 = Q_{\min} - Q_{qd} = (1 - K_2) Q_{\min} \tag{8}$$

Here, Q_{qd} - the average value of water consumption observed during the scarcity period, K_2 -the scarcity period is the modular coefficient of the flow and is calculated by the following formula:

$$K_2 = \frac{Q_{qd}}{Q_{\min}} \tag{9}$$

Substituting the values of ΔQ_1 and from formulas $Q_{ms} = Q_{tb} - Q^*_{ek}$ into the formula $Q^*_{ek} = Q_{\min}$, we obtain the following formula to calculate the ecological flow:

$$Q_{ek} = Q_{\min} - (1 - K_1) Q_{\min} + (1 - K_2) Q_{\min} \tag{10}$$

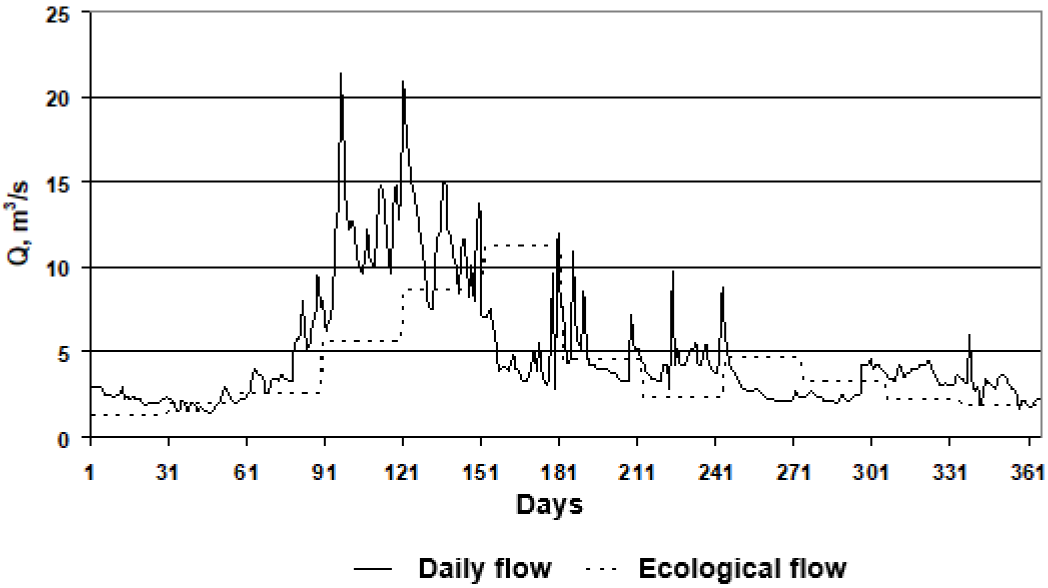
Or:

$$Q_{ek} = (1 + K_1 - K_2) Q_{\min} \tag{11}$$

According to the proposed method, the following changes in the monthly flow of ecological flow and observed water consumption for the Kupchal settlement of Gudyalchay are given. As can be seen, the amount of water in the river in most months is less than the amount of water required for the normal functioning of the river ecosystem, the ecological flow and the amount of water required to prevent the crisis. Otherwise, the river ecosystem cannot function as an element of the environment.

Figure 7

Comparison of monthly ecological flow and daily observed water consumption in Kupchal settlement of Gudyalchay (2012)



Ecological processes in riverbeds play an important role in the preservation of rivers as an element of the landscape. The river and the water body from which it flows are components of a single ecosystem and the maintenance of a complete and comprehensive ecological balance is more than the free water exchange between these two water bodies. This exchange takes place continuously through the body of water entering the river's ecosystem from the river continuously, then it is impossible to talk about any ecological balance. Adequate water at the mouth of the Greater Caucasus river facilitates the migration of temporary fish and other aquatic organisms to the river (Forte et al., 2022).

Continuously integrated into the estuary system from the river, the estuary provides the following processes:

A) The transition of organisms living in an estuary ecosystem to a river ecosystem at any time is facilitated. This position is very important for the survival and survival of organisms living in the ecosystem. For example, most sturgeons in the Caspian Sea are spawning and semi-transient, so they spawn in rivers. At this time, sturgeons leave the Caspian Sea, enter the rivers in large groups and spawn (Kajiwara et al., 2003).

B) Water, which is continuously entering the estuary ecosystem from rivers, is the main income part of the water balance of the estuary system and if this income is not part of it, the processes of drying and salinization can occur in the estuary ecosystem. The last incident was observed in the Aral Sea (Mehriban et al., 2022).

To ensure that the ecological balance in river ecosystems is fully maintained, the ecological flow should be assessed for riverbeds. Water monitoring points, where continuous observations are often located far from riverbeds (Abbasov, 2000 and Eyvazova, 2005). The main reason for this is that in most rivers the flow process is located far from the estuary and the shut-off points operate in the places where the flow is fully formed. This is especially the case for the mountain river of the Greater Caucasus region. For this reason, it is not enough to calculate the ecological flow only for observation points and in any case the ecological flow should be calculated for the river mouths.

As it is not possible to establish stationary points in all mountain rivers the calculation of ecological flow should be done indirectly for points without observation data. Such indirect methods are mainly based on the relationship between the geographical features of the basin and the ecological flow. For example, based on the relationship between the catchment area and the ecological flow, Abbasov R.H assessed the ecological flow for the river mouth (Abbasov, 2000). In this case, the author used the following sequence:

1. It is an ecological stream for all observation points in any region.

2. Relationships are established between these observation points and water catchment areas.

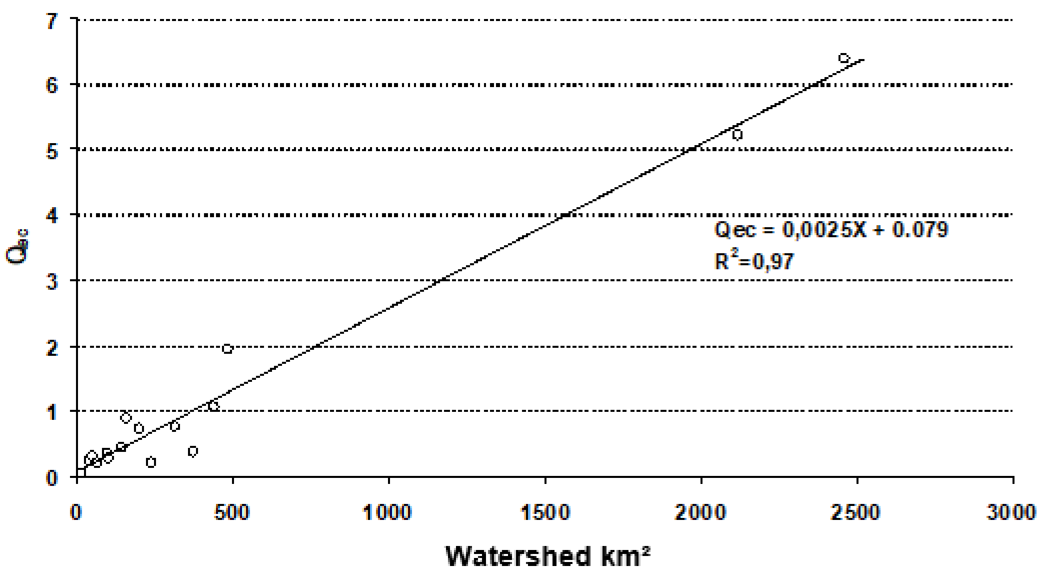
3. From these relations, the value of the ecological flow for tributaries is found in accordance with the catchment areas of the rivers.

Figure 7 shows the dependence of the January ecological flow for the north-eastern slope of the Greater Caucasus on the basin area according to the above sequence. This dependence is quite accurate and it is possible to calculate the value of the ecological flow for January according to the area of the basin according to the formula expressing the dependence. Based on this relationship, it is possible to calculate the value of the ecological

Figure 7 shows the dependence of the January ecological flow for the North-Eastern slope of the Greater Caucasus on the basin area according to the above sequence. This dependence is quite accurate and it is possible to calculate the value of the ecological flow for January according to the area of the basin according to the formula expressing the dependence. Based on this relationship, it is possible to calculate the value of the ecological flow for the estuary of any river located in the area. This relationship can also be used when calculating the cost of the ecological flow for rivers for which no regular observations have been made.

Figure 8

Dependence of the ecological flow of January for the North-Eastern slope of the Greater Caucasus on the area of the basin



As noted above, regional dependencies and flow maps can be used to estimate different flow characteristics in the absence of observational data. The theoretical basis or hydrological maps is the stability of the average humidity level of the area during a certain historical period and the change of the hydrological regime of rivers in accordance with the law of geographical zoning. This is primarily due to the fact that river flow depends on climatic factors. Flow isolation maps are complied based on flow data from zonal rivers, as they the zonal river, as they reflect the zonal variation of characteristics over the area. Variation of these factors over the territory occurs gradually, but at different intensities. This is due to the multiplicity of climatic processes and the surface characteristics of the basin. Therefore, flow isolation maps do not reflect changes in the flow of small rivers that may differ sharply from the zonal regime. The flow characteristics of polysonal rivers, which are formed in different natural zones and climatic conditions, can be sharply less or more than the zonal flow. The river flow recorded at the hydrometric position on the river is an integral indicator of the flow formed in the basin above the position. Therefore, when compiling flow maps, the amount of flow is related to the center of gravity of the catchment area. The flow is expressed in modules or layers. Flow isolates for plain rivers are carried out by linear interpolation between the centres of gravity of neighbouring river basins. In mountainous areas, the low depends on the height of the basin. For this purpose, a graph of the dependence of the flow module on the average height of the reservoir is constructed and the flow change with height is determined (Nuriyev, 2007).

Chapter 3. Integrated water management options in the Greater Caucasus

Water resources

Among the countries of the South Caucasus, Azerbaijan's water resources are more limited, accounting for only 15% of the total water resources of the South Caucasus (Imanov, 2011). Territorial and per capita water resources are 7.7 and 8.3 times less than in Georgia and 2.2 and 1.7 times less than in Armenia. In terms of water supply, our republic is one of the poorest regions in the world and has about 100,000 m³ of water per capita per year. The total water resources of the republic vary between 28.5-30.5 km³, and in temperature and dry years the water resources decrease further to 27 and 22.6 km³, respectively. Water resources in the country are unevenly distributed. If there is no such problem in Sheki, Zagatala, Khachmaz, and Kalbajar, there is a shortage of water, especially in the Kur-Araz lowland where irrigated agriculture is developing. Total water resources consist of surface and groundwater resources, and the sources of surface water resources are rivers, lakes, reservoirs and glaciers (Hajiyeva and Jafarova, 2021).

67-70% of the main river water resources of the republic and 9.5-10 km³ of the transit rivers are formed mainly due to the internal river flow of the republic. The main issues related to water management in Azerbaijan are as follows: a shortage of water resources during the vegetation period, problems related to access to clean drinking water, climate changes, salinization and regular droughts.

The highest water demands exist for irrigation water with the timing of the demand overlapping, but not sufficiently being covered by the high river flow season as the high water season ends in early July. Further high demand is for hydropower water year round need for discharge to drive the turbines. Due to the variable nature of the runoff, conflicts may arise not only between hydropower demand and irrigation demand as direct large competitors over the water resource but also between irrigation and other water users. For example, in years of flow Azerenergy may be concerned of insufficient reservoir filling if water is diverted for irrigation. A constant conflict further arises between the hydropower demand for filled reservoirs and the flood protection demand for empty reservoirs and respective space for flood water retention.

The main glaciers in Azerbaijan are located in the Gusarchay basin in the Greater Caucasus. There is a total area of 3.24 km² of glaciers. The water reserve of glaciers is 0.08 km³ (Mahmudov, 2003).

Recently, the increase in demand for water used for various purposes in the countries of the region has reduced the inflows to the country (4-6 km^3), and in the future, this rate may reach 6-8 km^3. This requires a more optimal solution to water use issues by increasing the demand for water in Azerbaijan. If at the end of the twentieth century the total demand for water in our republic was 14 km^3, now this rate has reached 19-20 km^3. Groundwater accounts for 58% (6 km^3) of source runoff and 48% (4.3 km^3) of source runoff within the country. The average annual flow module is 3.8-4 $l/s.km^2$ in the country (Rustamov and Kashkay, 1989).

The sources of the republic's water resources are surface and groundwater, which are very unevenly distributed over the territory. Due to local water resources, the largest water supply is in the Greater Caucasus (53%), especially in its southern slope zone.

Due to its water content, the Greater Caucasus is divided into three parts: the southern slope, the north-eastern slope, and the territory of Gobustan. In the high mountainous areas of the southern slope, the average annual flow module is 45 $l/s.km^2$ (1500 mm), while in the Ganykh-Ayrichay valley the average annual flow modules is 5.9 $l/s.km^2$ (177 mm). The annual flow of rivers flowing through the southern slope of the Greater Caucasus is 3.94 km^3 or 125 m^3/s. The average annual flow module is 6.14 $l/s.km^2$ or 194 mm. This flow is 38.2% of the total local flow formed in the territory of the republic. In this case, only 2.2 km^3 of flow volume (69.3 $l/s.km^2$) or 14.3 $l/s.km^2$ (450 mm) flow module falls on the share of the Ganykh river.

Despite the good water supply in the Greater Caucasus, it is found in low income regions. Examples, Gobustan and the nearby Absheron Peninsula (4% supply), the Ajinohur-Ceyranchol massive (2%) and the Ayrichay basin (7%).

Table 5

Flow patterns according to the distribution of water resources of the Greater Caucasus rivers

Territories	Area, km^2	Flow volume km^3	Water consumption m^3/s	Flow mode $l/s.km^2$	Flow layer, mm
Ajınohur -Ceyranchol	6910	0.15	4.85	0.70	22
Qanıkh basin	4857	2.19	69.3	14.3	451
Shirvan rivers	8569	1.60	50.7	5.92	187
Total	20336	3.94	125	20.9	660

Table 5 shows the estimates of average multi-year water consumption of the Greater Caucasus rivers, taking into account the last years of observation, maximum and minimum water consumption observed in all periods. These quantities can be taken into account in the use of river and water resources in the current situation.

Table 6

Estimated average multi-year and observed maximum water consumption values of the Greater Caucasus rivers (1990-2020)

River-station	Average annual water consumption m^3/s	Q_{max}, m^3/s	Q_{min}, m^3/s
Gudyalchay-Gırız	6,85	37,3	1,57
Agchay-Cek	2,12	14,8	0,51
Garachay-Ryuk	2,52	7,98	0,38
Gusarchay-Kuzun	4,52	22,9	0,72
Gudyalchay-Khınalıq	3,22	21,5	0,77
Gudyalchay-Kupchal	6,92	38,5	1,51
Agchay-Sukhtagalagıshlag	0,33	2,18	0,01
Khinalıgchay-Khınalıq	0,43	3,84	0,07
Valvalachay-Nokhurduzu	2,49	11,5	0,43

Climate changes impact

In the modern world, the hydrological regime of oceans, seas, rivers and other aquatic resources changes over time, leading to various problems (Oki & Kanae 2004). The rapid growth of the population, in turn, creates problems. Demand for water resources is growing (Shiklomanov, 2000). The development of growing industries and plants, greenhouse gases emitted into the atmosphere, sewage and plastics released into the oceans, in turn, lead to global climate change. They have been strong changes in the annual flow (Mahmudov, 1998).

For estimations of the influence of regional climatic changes over the temperature characteristics in the territory of Azerbaijan data of the meteorological and hydrological sites for the period of 1961-2005 is used. These periods are accepted as a representative period by WMO for estimating global climate changes to local conditions. As a result of long-term investigations became obvious that after 1980 both meteorological and hydrological characteristics were changed (Erler et al., 2019).

For evaluation of the climatic changes and estimating of possible impact for the territory of Azerbaijan comparative analyses of climatic rates for the period of 1961 -1990 and 1991-2005 have been made. These analysis data of meteorological sites that are located in different heights (Table 8) were used. As a result of this analysis became obvious that in all seasons, except spring an increase of the temperature states is observed. Analyses confirm that only in 2006 temperature rates 0.80 C degrees more than for the period 1961-1990 (Table 8).

Table 7

Temperature rates in 2006 for various heights and their-long term norms for the period of 1961-1990

Height, m	≤ 0	0 - 200	201-500	501-1000	>1000	For the territory of Azerbaijan
Average annual, ^{0}C	15.4	15.1	13.9	12.6	8.7	13.2
Norm, ^{0}C 1961- 1990	14.6	14.3	13.3	11.9	7.8	12.4
Difference	+ 0.8	+ 0.8	+ 0.6	+ 0.7	+ 0.9	+ 0.8

A similar analysis for the precipitation has been made. Comparative analysis verifies that there are no serious trends for precipitation data over long-term periods. However, a few reductions have been observed for the altitudes around 1000 m (Israfilov et al., 2016).

Table 8

Allocation of precipitation for various attitudes and their long-term rates (1961-1990)

Height, m	≤ 0	0 – 200	201-500	501-1000	>1000
Average annual, mm	390	322	437	592	570
Norm, mm 1961- 1990	335	327	478	534	639
Difference	55	- 5	- 41	58	- 69

Figure 9

Distribution of the yearly average temperatures (2006) and long-term temperature rates (1961-1990) on various heights

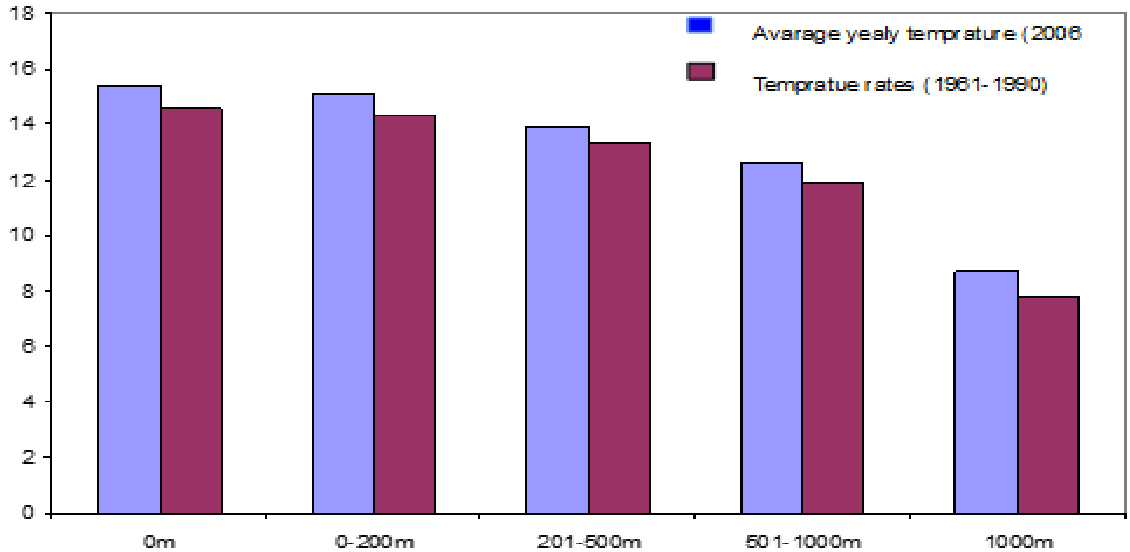
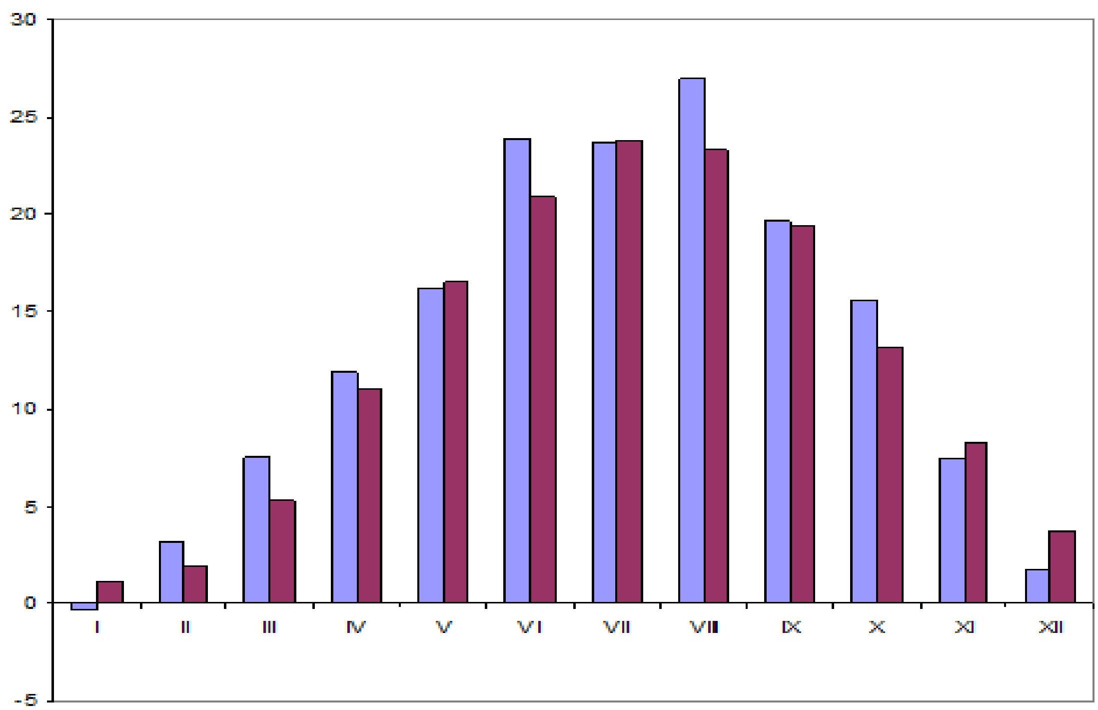


Figure 10

Allocation of yearly (2006) and long-term temperature rates in the territory of Azerbaijan



The problems of confirmation of climate change by scientific methods and numerical assessment of the indicators related to the impact of climatic factors, including changes in the flow of water resources, oceans and rivers, have long been discussed by researchers (Cook, 2022). Thus, the identification of components and equipment needed to create models based on deterministic methods that can be used as a whole to assess the impact of climate change on river flow and water resources has created a number of difficulties (Cook, 2018). Although a number of authors have considered it sufficient to study temperature, evaporation and precipitation, the main climatic elements, other researchers have proposed modelling all the events associated with atmospheric processes (Malhi et al., 2020). There are various methods currently available to study the impact of climate change on river flow, and they are divided into two groups.

1. Deterministic methods
2. Statistical methods

Statistical methods

One of the methods of studying the impact of climate change on river flow is statistical methods. The assessment of climate change according to statistical methods is based on the logic that precipitation, temperature and evaporation are the main climatic factors. The study of the tendencies of change of these climatic factors over many years also allows the flow to change over many years (Naveau et al., 2005). Statistical methods are mainly based on the analysis of trends in the increase and decrease of current generating factors over a long period and from them the main directions of natural trends of rivers are determined. As a result, changes in the flow provide a basis for determining trends. In some cases, it is possible to study the main flow changes by evaluating the changes in the relationship between these two factors based on precipitation and flow models (Browning, 1986). In addition, a number of researchers have used the quantitative correlation between flow and precipitation and temperature to quantify the flow variation based on possible precipitation and temperature changes. There are basic estimates based on statistical methods and they involve the application of a dependencies:

$$Y = f(T) \quad (1)$$

$$Y = f(X) \quad (2)$$

$$Y = f(X, t) \quad (3)$$

$$Y = f(X, Z) \quad (4)$$

$$Y = f(X - Z) \quad (5)$$

Here,

Y - river flow;

T - unit of time (years in case of consideration);

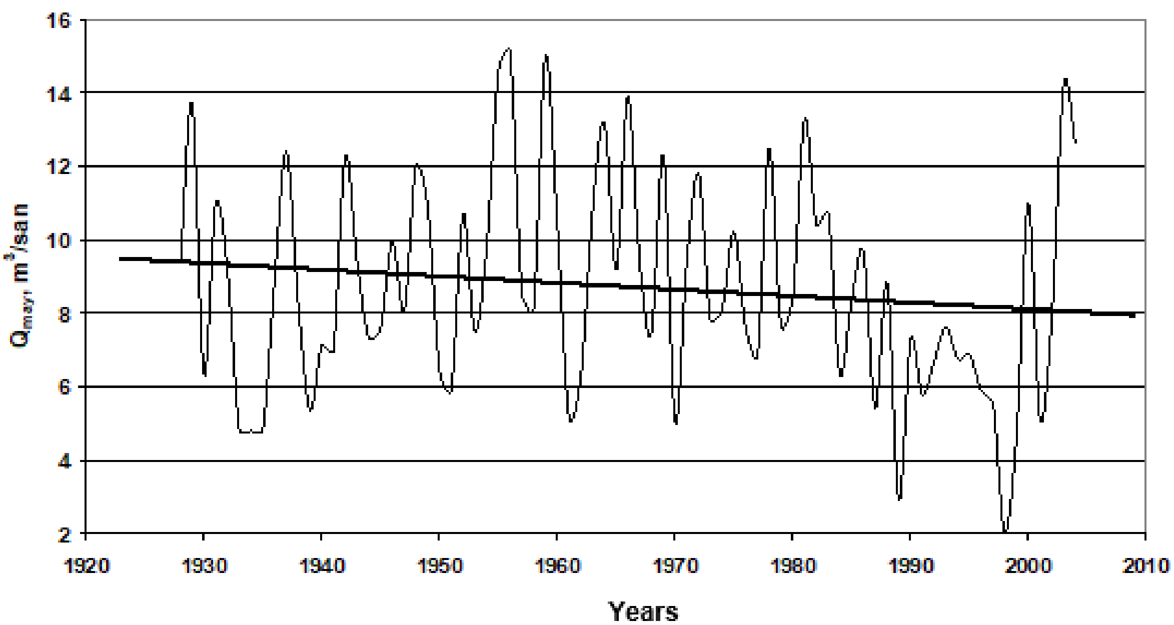
X - atmospheric precipitation falling into the river basin;

Z - total evaporation in the river basin;

t - is the air temperature in the river basin.

Figure 11

Changes in the flow of May in the Gudyalchay in time



For example, depending on the dependence in the figure above, the flow sequence observed in the Gudyalchay in May tends to change over a long period. Because the observations on this river are long enough, it is easier to observe any trend of change due to climate change. As can be seen from the figure, May flow tends decrease during 1928-2004. Thus, if in 1928-1974 the flow rate was 9.26 m^3/s, in 1974-2004 the flow rate in May decreased to 7.97 m^3/s. Of course, it is difficult to say that this change will take place only under the influence of climate change. This is because other factors, mainly anthropogenic, can affect the flow during that period. Therefore, as an auxiliary method to clarify the obtained result, it is necessary to study the trends of multi-variation atmospheric precipitation, which is the main income part of the water balance. If there are similarities in atmospheric precipitation and flow fluctuations, then it is possible to say that the flow decreases as a result of changes in climatic fluctuations.

$Y = f(X,T)$ - the assessment of the impact of climate fluctuations on the flow is based on the logic that the main climatic factors that shape the flow are precipitation and temperature and the study of the impact of these allows us to study the impact of climate change on the flow.

a. Flow-temperature model. This method is applied in two stages. In the first stage, the relationship between flow and altitude, altitude with precipitation and temperature is established. Then, according to these connections, a connection is found between the flow and the temperature. This method is mathematically expressed as follows:

$$\begin{cases} Y = f(H) \\ T = f(H) \end{cases} \Rightarrow Y = f(T) \qquad (6)$$

Here, H - is the average height of the area (or river basin). The flow values are then calculated for different temperature scenarios according to the relationship between flow and temperature.

b. Flow-precipitation-temperature model. The application of this method is based on a simpler scheme, using the total correlation relationships to find the relationships between temperature, precipitation and river flow and then to calculate the fluctuations of the flow for any value of temperature and precipitation based on these relationships.

In addition to all the positive features, statistical methods also have a number of shortcomings. Thus, when applying these methods, long-term observations with a natural regime are often required. Although the International Meteorological Organization considers 1961-1990 as the main reporting period for the assessments, there is a decrease in the flow in the territory of Azerbaijan due to the influence of anthropogenic factors, which often do not allow for to determine of the causes of the decrease. On the other hand, statistical methods are often difficult to apply due to a lack of information about evaporation and the elements that affect it.

Taking into account all the above features, it can be concluded that the application of statistical methods is possible only for rivers with a natural regime, and the application of these methods in rivers exposed to anthropogenic factors may lead to incorrect results.

The semi-empirical method is based on the water balance equation developed by Abbasov (Abbasov, 2000). The method is based on the logic that climate change does not directly affect the flow, but precipitation and evaporation, which are the main water balance quantities, and as a result, the moisture cycle in the river basin changes. Therefore, the application of the method uses a two way relationship between temperature, precipitation and evaporation, which is key indicator of climate change. In this case, as in statistical methods, empirical observational data are used. The application of the method requires more observational data than statistical methods. It should be noted that this method can give more accurate results than statistical methods (Sneyers, 1992).

The method is implemented in the following sequence:

1. Based on multiple observations of air temperature and precipitation for a specific area, the equations of dependence of these quantities on the height of the area are obtained (the correlation coefficients of these equations should be high).

2. Then, according to these connections, the relationship between air temperature and atmospheric precipitation is found.

3. Precipitation variation is calculated for different altitudes in different temperature scenarios.

4. These operations are performed in the same sequence for evaporation. In the absence of empirical observational data for evaporation, evaporation rates are calculated indirectly. Evaporation variation is calculated for different temperature scenarios based on the temperature dependence of evaporation.

5. The effect of temperature changes on the flow is estimated based on the difference between precipitation and evaporation.

Deterministic method

Another method available to assess climate change is the deterministic method. The deterministic method has been developed mainly by the world's leading institutions. It is mainly based on the modelling of the ocean, the atmosphere, the land, and the great water cycle in the direction of the (Paxton et al., 2022).

One of the most widely used and used of these methods is the GISS model. The main purpose of the GISS model is to predict atmospheric and climate changes in modern times. This model uses combined data from global climate data, land surface, water resources and ocean processes, as well as satellite information (Somerville et al., 1974). The study of climate change on Earth in the past allows us to make additional clarifications. The main disadvantage of this model is its weak application at the regional level. Another disadvantage of this method is that it often leads to unrealistic results. The main reason for this shortcoming is that it is very difficult to model climate processes on a global scale. In most cases, not enough information is available on all the quantities included in the global climate equations, which leads to some errors (Del Genio et all., 2007).

GFDL was developed by the US organisation NOAA. The main purpose of this model is to develop and expand existing knowledge about the processes in the ocean and atmosphere by studying them (Horowitz et al., 2020). It is possible to model these processes mathematically and the knowledge learned can be simulated on a computer. There are a number of shortcomings of the model. The main drawback is that the information needed to the model ocean and atmospheric processes is insufficient. This leads to many errors (Anderson et al., 2005).

GFDL studies consider the following factors:

- Global and regional weather forecast
- Includes research on global, regional climate, variability, stability and predictability
- Study of spatial and temporal changes, structure and sensitivity of ocean processes
- Study the integration and interaction of atmospheric and ocean processes.

The atmosphere general circulation model method is similar to the weather forecast model. It was created as a result of modelling local and global events between the Earth's surface and the atmosphere. When applying the AGCM method, first of all, air and ocean surface temperature, and ocean ice cover factors are used. The disadvantage of this method are that it is not suitable for the long term. Because it is similar to the weather forecast model, and this model gives favourable results in a short time. The AGCM method is one of the most convenient methods for a close and detailed understanding of atmospheric processes (Kumar and Hoerling, 1995).

Many deterministic methods are used on a regional scale. These methods allow for the assessment of climate variability and their impact on surface waters, and are also intended to assess the impact of regional differences. It is very difficult to take into account the impact of mountains on global models. These effects can only be considered through regional models (Amini et al., 2019). Therefore, in some cases, the application of regional-scale models provides a better opportunity to assess climate change and its impact on surface water. Regional models have several shortcomings. Regional models allow us to assess climate change in relatively limited areas, as well as for short periods. Given that it is both inefficient and impossible to assess the changing trends of water resources for such areas, it is understandable how useful the application of regional models can be (Jeon et al., 2018).

The impact of climate change on Azerbaijan's water resources was first assessed by R.N.Mahmudov. The author analyzes and identifies changes in the number of rivers in different physical and geographical conditions and with different hydrological characteristics, as well as changes in the time series during the year (Mahmudov, 1998). It was found that the winter flows of the Gudyalchay increase, summer, and rainy periods decrease (Table 10).

The relationship between the water consumption of winter flows of the Gudyalchay and the water consumption of spring flows shows that the increase in winter flows has a negative impact on the growth of spring flows against the background of a decrease in annual flow (Mammadov and Abdullayeva, 2009). This is also determined primarily by changes in the annual distribution of the decision process. When the temperature is high, the snow begins to melt in that area. As the settlement process accelerates, it leads to an increase in river flow. For example, the table shows that the winter flow in the Gudyalchay-Kupchal settlement in 1987-1996 increased by 0.25 m^3/s compared to 1963-1986. In the remaining seasons and finally, in the annual rate, we observe a decrease in the flow in that area.

Table 9

Comparison of average seasonal water consumption over many years

Stream by seasons, m^3/s	Observation periods			±Δ	
	1963-1995	1963-1986	1987-1995	m^3/s	10^6m^3
	Qudyalchay-Kupchal				
Spring	2.97	2.89	3.17	+0.28	+8.82
Summer	7.04	71.8	6.67	-0.51	-1.61
Autumn	11.1	11.2	10.5	-0.30	-2.84

Winter	4.80	4.73	4.98	+0.25	+7.88
Year	6.51	6.49	6.33	-0.16	-5.04

The impact of climate change on the water content of the Greater Caucasus rivers was assessed by R.N.Mahmudov (Mahmudov, 2006). For this purpose, the author used the average multi-values of temperature, precipitation and annual flow, and pair and sum correlation relations were established between the mentioned indicators.

Surveys were conducted in this area for three districts:

1. North-eastern of the Greater Caucasus

2. Southeastern slope of the Greater Caucasus

3. South-western slope of the Greater Caucasus

The dependence of river flow on atmospheric precipitation and average air temperature has been established in the separated regions. The relationships are quite close, and the values of the correlation coefficients present in the regression equations are greater than 0.7 in all cases.

This connection is expressed for the north-eastern slope of the Greater Caucasus:

$$q = 0.26X - 6.9t + 62(R^2 = 0.79) \quad (7)$$

Here, q - is the mean multiplicity flow modulus.

4. The equations for the remaining second (south-eastern slope of the Greater Caucasus) and third (south-western slope of the Greater Caucasus) equations are expressed as follows:

$$q = 0.19X - 16.7t + 57(R^2 = 0.79) \quad (8)$$

$$q = 0.31X - 14.1t + 33(R^2 = 0.79) \quad (9)$$

These equations allow us to calculate the average multiplicity modulus of the flow according to the average multiplicity values of temperature and atmospheric precipitation for the Greater Caucasus. It should be noted that the accuracy of the calculations depends on the length of the observation periods. Studies have shown that various increases in temperature will in all cases lead to a decrease in river flow. At the same time, the reaction to temperature rise varies depending on the physical and geographical position of the area and climatic characteristics. For example, in the southern part of Turyanchay, the reaction to 10 temperature increases maybe 3-5% higher than on the north-eastern slope of Gudyalchay, which may depend on the climate of the area. This difference also increases for subsequent scenarios (20 and 30) and increases to 5-10%.

As can be seen from table 11 with an increase in temperature of 10, 20, 30, an average 10-15% decrease in river flow can be observed in the Greater Caucasus region (Table 11).

Table 10

Changes in the average multi-flow modulus of territorial rivers according to their relationship in different temperature scenarios (Kazimova, 2006)

River-station	Q, l/s km^2	$\Delta T=+1^0$	$\Delta T=+2^0$	$\Delta T=+3^0$
Kharmidorchay-Khaltan	7.18	6.91	5.51	4.91
Gusarchay-Guzun	18.8	17.6	16.3	15.1
Gudyalchay-Gırız	17.5	15.6	14.2	13.3
Gudyalchay-Kupchal	13.2	12.1	10.9	9.5
Gudyalchay-Khınalıq	32.1	30.9	28.4	27.5
Guruchay-Susay	22.4	21.1	19.5	18.4
Agchay-Sukhtaqalaqıshlaq	22.3	21.0	20.5	19.3
Agchay-Cek	2.88	1.9	0.98	0.21
Velvevelechay-Nohurduzu	12.4	10.9	9.81	8.72
Velvevelechay-Tengealtı	8.78	7.35	6.41	5.25
Khınalıqchay-Khınalıq	15.1	14.0	13.8	12.3
Derkchay-Derk	9.64	8.2	7.5	6.8
Chikacukchay-Rustov	11.1	9.3	8.3	7.1
Ayrichay-Bash Dashagıl	31.3	29.1	28.2	27.2

Ayrichay- source	7.51	5.9	4.31	3.25
Alazan- Ayrichay	9.16	8.1	7.11	6.09
Balakanchay-Balakan	24	22.8	21.9	20.8
Damarchik-source	39.2	38.1	37.2	36.1
Gaynar- source	13.5	12.2	11.3	10.3
Chkodurmaz- source	15.5	14.2	13.2	12.8
Khurmukhchay-Sarıbash	24.8	23.3	22.4	21.5
Khurmukhchay-Ilisu	30.8	29.1	28.0	27.3

Water use

Integrated water management is an indefinite and somewhat vague concept that evokes both the properties of water as a multiuse resource and the fact that many different groups of stakeholders are involved in any attempt at strategic planning water resource management. Water management has been compartmentalized and fragmented because of the elusive manifestation of water at points of use that appear disjoint from its sources (Bauwer, 2000). For example, rights to water use have been attributed to owners of land near rivers, or other land localized sources such as springs, water holes, streams, lakes and so on. On the other hand, the public good nature of water has also been traditionally asserted through the right of communities, and local or central governments to capture water at the source and channel it to final agricultural, urban and industrial users (Bauwer, 2022).

This fragmented approach to water management, however, is not sustainable for several reasons. First, since water is a common, renewable resource, its usage for consumptive and productive purposes is subject to the tragedy of the commons, through a continuous pressure to over-usage on the part of the individuals (Lenton and Muller, 2012). Because, there is seldom a mechanism of rationing linked to its marginal costs, individuals capture the full marginal benefits from any additional consumption of water, but only pay a small share of the environmental costs that are instead distributed among all active and potential users. Second, typically only some of the use-values of water are considered in its management, while some use and virtually all no use values, including existence and option values, are neglected. Thus, for example, the recreational value of water sources such as rivers, streams, waterfalls, and lakes is often neglected by planners unless a specific form of exploitation, such as a park or a more specialized recreational facility is involved. The need to manage the aspects of water that are related to its future availability, under conditions of increasing uncertainty is also typically not considered in management plans. Third, the plurality of stakeholders having claims or legitimate interests over water uses makes any partitioned plan intrinsically inconsistent and a likely source of conflicts, that will ultimately make at least some of the different plans ineffective and damage the correspondent stakeholders (Biswas, 2004).

In the Greater Caucasus region, integrated water management assumes a special significance for three orders of reasons. First, the availability and management of water resources are critical because of natural conditions. Second, demographic pressure is especially high due to explosive urban growth, but also to the continuing importance of agricultural and industrial activities, all heavy users of water and all to a large extent responsible for increasing pollution. Third, water resources have been mainly developed in the past to accommodate the increasing population and economic activity, with little attention to environmental damage and recreational uses of water.

Water consumption in the Greater Caucasus region mainly includes industrial, agricultural, commercial and irrigation uses. Using the bills, the average per capita water use is then estimated using this formula:

$$PWU=1000\ (I_1+I_2+I_3+...+I_N/0.3)/30*P_t \quad (1)$$

Where, PWU is a per capita daily water use in litres, I_1, I_2, I_3, I_N – the amount of bills in AZN manat, 0.3 is the current price for one m³ of water, P_t - the total number of persons in households.

Many factors impact water use, the most important being daily air temperature which directly affects the total amount of water consumption by households. Using this information, it is possible to estimate future climate change impacts on water use as well. The amount of water loss from a system can be determined by constructing a water balance. This is based on the measurement or estimation as to the amount of water produced (taking account of any water imported and exported), consumed and lost. In its simplest form the water balance is:

Losses = Distribution System Input – Consumption

Water loss management and reduction are seen by some as the most cost effective source of water available to water utilities, yet many planners and utilities fail to include this potentially cheap supply in their integrated water strategy (Mutikanga, 2010). Ideally, most water utilities would like to operate a perfect system with zero leakage but, of course this is not possible as the majority of pipe work is buried under the ground and out of sight of the operators. There are many causes of leaks and bursts and in any water distribution system a certain level of loss will always be present and will have to be managed.

The increasing scarcity of water resources in arid regions is an important obstacle to regional economic development. Natural water sources of these regions have a high perceptibility to water-related human activities and global climate changes (Garrote, 2017). It has been widely accepted that high temperatures and reduced precipitations will affect streamflow and their inter-annual characteristics, largely decreasing the quality and quantity of water resources, both in time and space. Due to growth in population and the development of water-related human activities, demand for water resources will increase, which will be accompanied by decreasing natural supply. Climate change will also affect water needs (Askew, 1987). Warmer temperatures will likely increase evaporation rates and extend dry seasons, thereby increasing the amount of water that is needed for the irrigation of many crops, urban landscaping and environmental water needs. Rising temperatures will also affect household water use, considerably increasing the demand for potable water (Meireles et al., 2022).

Integrated regional water management planning offers a framework for water managers to address water-related challenges and provide for future needs. Formally, IRWM is a comprehensive approach for determining the appropriate mix of water demand and supply management options and water quality actions. This approach provides reliable water supplies at the lowest reasonable cost and with the highest benefits for economic development, environmental quality and other societal objectives. As it has been noted, the most important source of water in the future may be desalinated waters, even though the costs for that will be much higher than other options (Agarwal et al., 2000).

Combined with urbanization, climate change will further stress the region's agricultural products, making them more vulnerable to pests, disease and changes in species composition. Along with drier soils, the land will experience more frequent and intense fires, resulting in subsequent changes in vegetation, and eventually a reduction in the water supply (Chapman, 2017).

Several stakeholders can be identified for water use in the Greater Caucasus mountain rivers, with various types of needs and requirements. They may be ranked according to the importance and needs, quality and quantity of water supply: Urban residential water users include households and the enterprises of industry, where water is required for drinking and washing purposes. Public health closely depends on water used by these types of consumers. Advanced international experience shows that for these purposes high quality water is required. Almost in all the developed societies water for drinking and washing needs high quality. Suppliers are required to maintain consumers with the highest quality of water that meet international health standards and without interruption. The growing economy of Azerbaijan requires increasing amounts of industrial water, mainly for cooling and washing. While industrial water need not be of high quality, some technical standards should be met. Recreational resource users in the Guba, Gusar and Khachmaz regions include individuals, hotels, resorts, sanatoriums, and rest homes. Agricultural water users are mostly suburban farmers and are one of the most important categories of water stakeholders in the

Greater Caucasus. No recent data regarding agricultural water use in Greater Caucasus are available. For all these uses, treated wastewater may become the main source of water.

Water scarcity is the main driver of conflicts over water rights. In urbanized regions, conflicts among agricultural, industrial and residential water use are growing as cities expand in size and political influence. While in Greater Caucasus at present there appear to be no openly discussed conflicts among stakeholders, problems of water shortage and competition for water sources are emerging in the suburban areas. Most of these illegal houses have gardens and small agricultural activities, with no adequate management of water and no incentive to conserve water (Seckler et al., 1999).

Integrated Water Resources Management is a strategy that brings together all facets of the water cycle – water supply, sewage management, water treatment and stormwater management – to achieve strong triple bottom line benefits. In a water supply, it is very essential to investigate and evaluate all the water sources (Candido et al., 2022). Due to climate change and expected droughts in the region, alternative water resources and alternative water management approaches are needed. It is essential to evaluate all the alternative sources, even if they have low quality. Local studies have determined that, under natural conditions, the groundwater within the piedmont plains is generally unprotected from the surface. Leaking sewage pipelines have further degraded the water quality in the surface aquifer, while agricultural production has contributed to nitrate and pesticide pollution (Pereira et al., 2002).

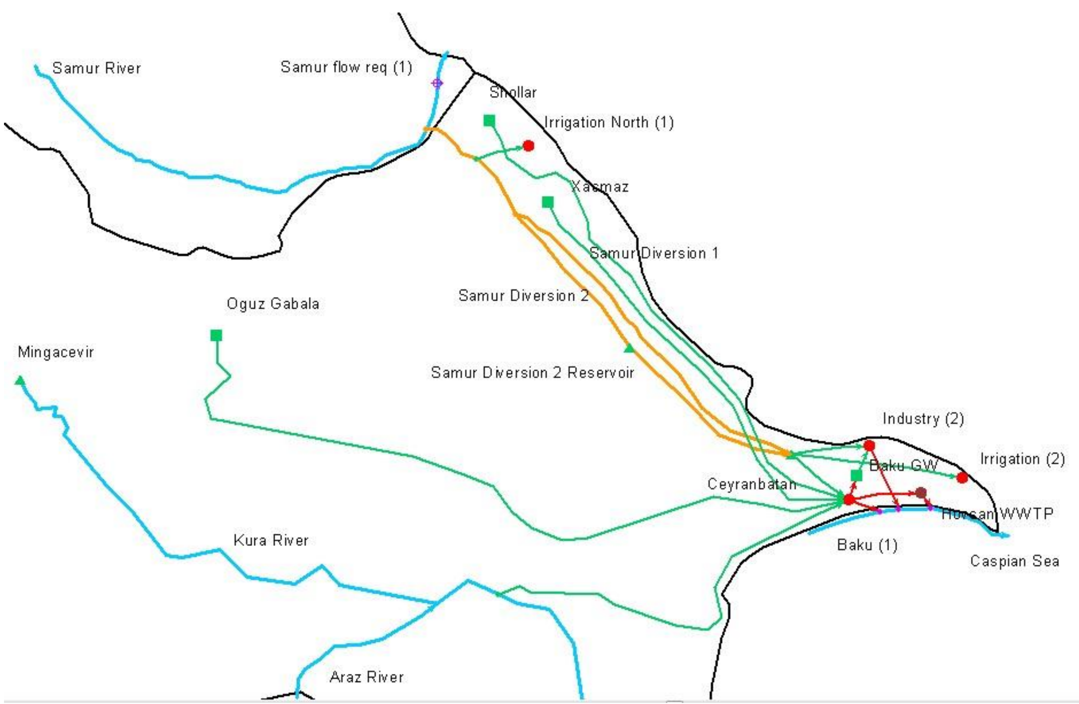
Desalination costs are highly affected by the type of facility, location, feed water, labour, energy, financing, and concentrate disposal. Desalination stills now control pressure, temperature and brine concentrations to optimize efficiency. Due to high costs, desalination may be applied only in areas where other sources of water do not exist, the near Caspian Sea that have great touristic potential (Burn et al., 2015).

An important source of value for water lies in its potential for future uses and for creating capabilities in the individuals and communities concerned. These sources of value, under dynamic uncertainly, are the so-called "real options" and are linked to the status of water as a contingent asset, that is as a stock of resources, whose growing scarcity is apparent and whose availability for future needs is uncertain. Despite their growing importance in the framework of adaptation to climate change, water option values are typically neglected in willingness to pay surveys because the implicit assumption is made that they are neglected in the values of goods and services delivered by water - a hypothesis that would be justified only if perfect contingent markets were in operation (Satterthwaite, 2008).

Real options for water supply are the result of a policy choice between water conservation and development (Marques et al., 2014). Water conservation may imply deferring investment in residential water supply, whilst concentrating resources in the rehabilitation of the existing network and wastewater treatment. This in turn might result in a combination of services with greater variability over the territory: more reliable water supply for a subset of existing users and lower distribution losses for one part of the city, with no reliable or absent services for other users. Because of limited development and balanced use of financial resources, higher recreational and non-use values of freshwater sources could also be expected in this scenario. Alternatively, emphasizing development over conservation would produce a bundle of characteristics such as a more extensive network of potable water supply, a lower variance of the amount and the quality of water services throughout the cities, higher average unreliability, water scarcity and pollution levels.

Figure 12

Use of water from the Greater Caucasus



The result

Physical and geographical factors influencing the flow of the Greater Caucasus rivers were analyzed and special attention was paid to the study of the interactions between these factors. The geology of the Greater Caucasus, and the age of sediments and rocks are noted. The ways of rock formation are described.

The effect of evaporation and solubility on the river flow was determined by hydrographs. The importance of now water in the nutrition of Gudyalchay, Gusarchya, Damiraparanchay, Agsuchay, Balakanchay and Goychay rivers was noted. New proposals have been made to calculate the total evaporation from the river basins. Based on these proposals, the average multi-year value of evaporation from, river basins was found. Zoning was carried out according to the distribution of average temperature and average precipitation in the area. The dependence of the average perennial precipitation layer on the average perennial air temperature was obtained. The new connections obtained are confirmed by instrumental observations. The effect of temperature on the flow of rivers passing through different heights was noted.

The anthropogenic impact on the river regime in the highlands is almost negligible and can be considered a natural regime. Methods for assessing the impact of anthropogenic factors on river flow are given. The impact of economic activity on the flow of rivers on the north-eastern slope of the Greater Caucasus was assessed and tabulated.

Domestic and industrial wastewater from the cities of Guba and Khachmaz caused the pollution of the Gudyalchay. Waste from the cannery in Guba is dumped into the Guydalchay. Nevertheless, rivers flowing from the southern and north-eastern slopes of the Greater Caucasus rivers have been classified as moderately polluted according to recent studies.

Various formulas are given to calculate the ecological flow. New methods have been proposed that allow the calculation of ecological flow for riverbeds. Based on these proposals, the ecological flow was calculated not only for the closure points, but also for the river mouths, which allows a more accurate assessment of the ecological condition of the rivers.

Changes in water resources and river flow under the influence of climate change have been assessed. There are various methods for assessing the impact of climate change on river flow. These methods are mainly statistical and deterministic methods. Statistical methods are mainly based on the analysis of the ups and downs of flows and current–producing factors over a long period. There are different models of deterministic methods.

Purposes and sources of water ue of the Greater Caucasus river were noted. The use of water in households, agriculture and industry and their impact on water resources have been assessed. The current state of water resources in the Greater Caucasus was assessed. There is a table showing the calculated average diversity of the Greater Caucasus rivers and the observed maximum and minimum water consumption.

Reference

1. Abbasov, R. K. (2007). Assessment of ecological flow for the mountain river of the Kura basin. Proceedings of the Annual Meeting & International Conference of the American Institute of Hydrology: "Integrated Watershed Management: Partnerships in Science, Technology, and Planning". April 22-25, Reno, Nevada, USA.
2. Abbasov, R.K. (2000). Influence of anthropogenic factors on the regime of the Lesser Caucasus rivers and environmental flow calculation. Author's abstract of the candidate's thesis. Baku, pp. 18.
3. Abbasov, R. K. (2019). Integrated land use management of municipality lands in mountain communities of Azerbaijan. Baku, GIZ.
4. Acreman, M. C., Overton, I. C., King, J., Wood, P. J., Cowx, I. G., Dunbar, M. J., ... & Young, W. J. (2014). The changing role of ecohydrological science in guiding environmental flows. *Hydrological Sciences Journal, 59*(3-4), 433-450.
5. Agarwal, A., Delos Angeles, M.S., Bhatia, R., Cheret, L., Davila-Poblete, S., Falkenmark, M.,... & Wright, A. (2000). *Integrated water resources management.* Stockholm: Global water partnership.
6. Aliyev, F. G., & Khalilova, H. K. (2014). The anthropogenic impact on surface water resources in Azerbaijan. *Energy & Environment*, *25*(2), 343-356.
7. Alizadeh, A. A., Guliyev, I. S., Kadirov, F.A., & Eppelbaum, L.V. (2016). Geosciences of Azerbaijan (Vol. 1, p. 237). Heidelberg: Springer.
8. Amini, M. A., Torkan, G., Eslamian, S., Zareian, M. J., & Adamowski, J.F. (2019). Analysis of deterministic and geostatistical interpolation techniques for mapping meteorological variables at large watershed scales. *Acta Geophysica*, *67*(1), 191-203.
9. Anderson, J. L., B. Wyman, S. Zhang, and T. Hoar. (2005). Assimilation of surface pressure observations using an ensemble filter in an idealized global atmospheric prediction system. *Journal of the Atmospheric Sciences*, *62*(8), 2925-2938.
10. Arheimer, B., Donnelly, C., & Lindstrom, G. (2017). Regulation of snow-fed rivers affects flow regimes more than climate change. *Nature communications*, *8*(1), 1-9.
11. Arismendi, L., Safeeq, M., Dunham, J. B., & Johnson, S. L. (2014). Can air temperature be used to project influences of climate change on stream temperature?. *Environmental Research Letters*, *9*(8), 084015.

12. Askew, A. J. (1987). Climate change and water resources. *The influence of climate change and climatic variability on the hydrologic regime and water resources, 168*, 421-430.
13. Balke, K. D., & Zhu, Y. (2008). Natural water purification and water management by artificial groundwater recharge. *Journal of Zhejiang University SCIENCE B, 9*(3), 221-226.
14. Bathia, R. (2000). Balancing between water for livelihoods and water for ecosystems: the key role of valuation techniques. How to bring ecological services into integrated water resources management. Report from the GWP – seminar, 15-17. *Beijer Institute of Ecological Economics*, Stockholm.
15. Biswas, A. K. (2004). Integrated water resources management: a reassessment: a water forum contribution. *Water international, 29*(2), 248-256.
16. Bouwer, H. (2000). Integrated water management: emerging issues and challenges. *Agricultural water management, 45*(3), 217-228.
17. Bouwer, H. (2022). Integrated water management for the 21st century: problems and solutions. *Journal of Irrigation and Drainage Engineering, 128*(4), 193-202.
18. Browning, K. A. (1986). Conceptual models of precipitation systems. *Weather and forecasting*, *1*(1), 23-41.
19. Burn, S., Hoang, M., Zarzo, D., Olewniak, F., Campos, E., Bolto, B., & Barron, O. (2015). Desalination techniques – A review of the opportunities for desalination in agriculture. *Desalination*, *364*, 2-16/.
20. Candido, L., Coelho, G. A. G., de Moraes, M. M. G. A., & Florencio, L. (2022). Review of Decision Support Systems and Allocation Models for Integrated Water Resources Management Focusing on Joint Water Quantity-Quality. *Journal of Water Resources Planning and Management*, *148*(2), 03121001.
21. Chapman, S., Watson, J, E., Salazar, A., Thatcher, M., & McAlpine, C. A. (2017). The impact of urbanization and climate change on urban temperatures: a systematic review. *Landscape Ecology*, *32*(10), 1921-1935.
22. Cheng, B., & Li, H. (2018). Agricultural economic losses caused by protection of the ecological basic flow of river. *Journal of Hydrology, 564,* 68-75.
23. Clarke, J. W. (1993). Observations on the geology of Azerbaijan. *International Geology Review*, *35*(12), 1089-1092.
24. Cook, B. I., Mankin, J. S., & Anchukitis, K. J. (2018). Climate change and drought: From past to future. *Current Climate Change Reports*, *4*(2), 164-179.

25. Cook, J. (2022). Understanding and countering misinformation about climate change. *Research Anthology on Environmental and Societal Impacts of Climate Change*, 1633-1658.
26. Davies, P. M., Nairman, R. J., Warfe, D. M., Petit, N. E., Arthington, A. H., & Bunn, S. E. (2013). Flow-ecology relationships: closing the loop on effective environmental flows. *Marine and Freshwater Research, 65*(2), 133-141.
27. Del Genio, A. D., Yao, M. S., & Jonas, J. (2007). Will moist convection be stronger in a warmer climate?. Geophys. Res. Lett, 34, L16703, doi:10.1029/2007GL030525
28. Delpla, I., Jung, A. V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International*, *35*(8), 1225-1233.
29. Delucchi, M. A. (2010). Impacts of biofuels on climate change, water use, and land use. *Annals of the New York Academy of Sciences*, *1195*(1), 28-45.
30. Dyson, M., Bergkamp, G., & Scanlon, J. (2003). Flow: the essentials of environmental flows. *IUCN, Gland, Switzerland and Cambridge, UK*, 20-87.
31. Eldarov, M., Aminov, N., & van Slageren, M.(2015). Distribution and ecological diversity of Aegilops L. in the Greater and Lesser Caucasus Regions of Azerbaijan. Genetic Resources and Crop Evolution, 62(2), 265-273.
32. Erler, A. R., Frey, S. K., Khader, O., d'Orgeville, M., Park, Y. J., Hwang, H. T., ... & Sudicky, E. A. (2019). Simulating climate change impacts on surface water resources within a lake-affected region using regional climate projections. *Water Resources Research*, *55*(1), 130-155.
33. Eyvazova Y. M. (2005). North-eastern slope of the Greater Caucasus and ecological flow of Shirvan rivers. Author's abstract of the candidate's thesis. Baku, p 29.
34. Fatullaev, G. Y. (2002). Modern changes in water regime of the rivers of the South Caucasus (Within the Caspian Basin), Baku.
35. Feyzi, H., & Rezaei Banafsheh, M. (2022). Simulations reference evapotranspiration using artificial intelligence and comparison with experimental methods (Case Study: East Azerbaijan). *Geography and Planning.*
36. Forte, A. M., Leonard, J. S., Rossi, M. W., Whipple, K. X., Heimisath, A. M., Sukhishvili, L., ... & Kadirov, F. (2022). Low variability runoff inhibits coupling of climate, tectonics, and topography in the Greater Caucasus. *Earth and Planetary Science Letters*, 584, 117525.
37. Fountain, A. G., & Tangborn, W. V. (1985). The effect of glaciers on streamflow variations. *Water Resources Research*, *21*(4), 579-586.

38. Garrote, L. (2017). Managing water resources to adapt to climate change: facing uncertainty and scarcity in a changing context. *Water Resources Management, 31*(10), 2951-2963.
39. Glasson, J., Therivel, R., & Chadwick, A. (1999). Introduction to Environmental Impact Assessment, 2nd ed. UCL Press Ltd., London.
40. Gordon, N. D., McMahon, T. A., Finlayson, B. L., Gippel, C. J., & Nathan, R. J. (2004). *Stream hydrology: an introduction for ecologists*. John Wiley & Sons.
41. Hajiyeva, A., & Jafarova, F. (2021). Role of ecological features of landscapes in the establishment of natural and economic base of livestock across the Greater Caucasus part of Azerbaijan. *Economic and Social Development: Book of Proceedings*, 25-32.
42. Hao, L., Pan, C., Fang, D., Zhang, X., Zhou, D., Liu, P., ... & Sun, G. (2018). Quantifying the effects of overgrazing on mountainous watershed vegetation dynamics under a changing climate. *Science of the Total Environment, 639,* 1408-1420.
43. Heathcote, I. W. (1998). *Integrated watershed management; principles and practice.* Canada, John Wiley & Sons.
44. Horowitz, L. W., Naik, V., Paulot, F., Ginoux, P. A., Dunne, J. P., Mao, J., ... & Zhao, M. (2020). The GFDL global atmospheric chemistry-climate model AM4. 1: Model description and simulation characteristics. Journal of Advances in Modeling Earth Systems, 12(10), e2019MS002032.
45. Hyra, R. (1978). Methods of assessing instream flows for recreation. Instream flow information paper #6, Fort Collins, Colorado.
46. Imanova, F. A. (1989). Anthropogenic changes in the water content of mountain rivers and periods of minimum runoff. Collection of reports on the Second Mladezka – School of Ecology and Space with international participation. 254-258.
47. Imanov, F. A. (1979). *Hydrological calculations*. 431.
48. Imanova, F. A. (2000). *Minimum runoff of the rivers of the Caucasus*. Baku.
49. Imanov, F. A., & Abbasov, R. K. (2007). Environmental flow and recommendations for their estimations. *Natural cataclysms and global problems of the modern civilization.*
50. Imanov, F. A., & Asadov, M. Y. (2011). Assessing the water resources and ecological state of the Samur river (Eastern Caucasus). *Geography and Natural Resources*, *32*(3), 297-300.
51. Imanov, F. A., Orlov, V. G. (1993). Assessment of the impact of irrigation on the minimum summer-autumn runoff of the rivers of the Caucasus. Reclamation and water management. 9-10.

52. Israfilov, R. G. (2002). Groundwater anomalies in the urban areas of Azerbaijan. *In Current Problems of Hydrogeology in Urban Areas, Urban Agglomerates and Industrial Centres*. Springer, Dordrecht. 17-37.

53. Israfilov, Y. H., Israfilov, R. H., Guliyev, H. H., & Efendiyev, G. M. (2016). Risk assessment of the water resources losses of the Azerbaijan Republic due to climate changes. *News of ANAS, Earth Sciences*, 3-4.

54. Jeon, D. J., Ki, S. J., Cha, T., Park, Y., & Kim, J. H. (2018). New methodology of evaluation of best management practices performances for an agricultural watershed according to the climate change scenarios: A hybrid use of deterministic and decision support models. *Ecological Engineering*, 119, 73-83.

55. Kajiwara, N., Ueno, D., Monirith, I., Tanabe, S., Pourkazemi, M., & Aubrey, D. G. (2003). Contamination by organochlorine compounds in sturgeons from Caspian Sea during 2001 and 2002. Marine Pollution Bulletin, 46(6), 741-747.

56. Kazimova, M. A. (2006). Regional climate change and river flow in the Greater Caucasus region. Problems of balanced development of mountainous areas. Materials of the scientific-practical conference, Baku. 522-525.

57. Kumar., A., & Hoerling, M. P. (1995). Prospects and limitations of seasonal atmospheric GCM predictions. *Bulletin of the American Meteorological Society, 76*(3), 335-345.

58. Lam, A., Karssenberg, D., Van den Hurk, B. J. J. M., & Bierkens, M. F. P. (2011). Spatial and temporal connections in groundwater contribution to evaporation. *Hydrology and Earth System Sciences, 15*(8), 2621-2630.

59. Lenton, R., & Muller, M. (20212). *Integrated water resources management in practice: Better water management for development. Routledge.*

60. Loperfido, J. V., Noe, G. B., Jarnagin, S. T., & Hogan, D. M. (2014). Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale. *Journal of Hydrology*, *519*, 2584-2595.

61. Lorenz, M., Klingbeil, K., & Burchard, H. (2021). Impact of evaporation and precipitation on estuarine mixing. Journal of Physical Oceanography, 51(4), 1319-1333.

62. Maharramova, A. R. (2018). General analysis and description of physical and geographical factors of rainfall in Azerbaijan. *Advances in Biology & Earth Science*, *3*(1), 93-99.

63. Makhmudov, R. N. (2006). Hydrometeorology, climate change, natural disasters and life. Baku.

64. Makhmudov, R. N. (2003). Water Resources of the Republic of Azerbaijan. Baku. 24.
65. Makhmudov, R. N. (1998). Impact of regional climate change on river water regime. Climate change bulletin #1, Baku. 35-39.
66. Makhmudov, R. N. (2016). Regional climate changes and river runoff in Azerbaijan. *Russian Meteorology and Hydrology*, *41*(9), 635-639.
67. Makhmudov, R. N., Dadashova, F. S., & Yunuszade, E. R. (2020). Study of water pollution level in Azerbaijani water bodies. *Geography and natural resources*, *12*(2), 3-6.
68. Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B., & Knowlton, N. (2020). Climate change and ecosystems: Threats, opportunities and solutions. *Philosophical Transactions of the Royal Society B, 375*(1794), 20190104.
69. Mamedov, G. S., Shabanov, J. A., & Kholona, T. A. (2017). Ecological assessment of soils in high-mountain landscapes of northeastern part of the Greater Caucasus (Azerbaijan). *Eurasian Soil Science, 50*(5), 630-635.
70. Mamedov, R. G. & Ibadzade, Y. A. (1988). *Water economy of Azerbaijan and development prospects.* Baku.
71. Mammadov, G. S., & Abdullayeva, G. M. (2009). Evaluation of the soils of river basin Gusarchay-Gudyalchay of the northeast part of Azerbaijan. *RUDN Journal of Ecology and Life Safety,* (4), 28-37.
72. Marques, J., Cunha, M., & Savic, D. A. (2014). Decision support for the optimal design of water distribution networks: a real options approach. *Procedia Engineering, 70,* 1074-1083.
73. Meehl, G. A., Washington, W. M., Arblaster, J. M., & Hu, A. (2004). Factors affecting climate sensitivity in a global coupled model. *Journal of Climate*, *17*(7), 1584-1596.
74. Mehriban, P., Ansat, R., Sahibjamal, N., Timur, B., Ilhambek, J., & Inabat, P. (2022). StUDY RELATIONSHIP BETWEEN WATER RESOURCE AND CLIMATE CHANGE IN TERRITORY IN THE ARAL SEA REGION.
75. Meireles, I., Sousa, V., Bleys, B., & Poncelet, B. (2022). Domestic hot water consumption pattern: Relation with total water consumption and air temperature. *Renewable and Sustainable Energy Reviews*, 157, 112035.
76. Mirmousavi, S. H., Jalali, M., & Akbarzadeh, Y. (2022). Spatial and temporal study of areas vulnerable to hail on agricultural products of East Azerbaijan province. *Physical Geography Research Quarterly*.

77. Mossler, J. H., & Book, P. R. (1995). Bedrock geology. *Geologic Atlas Fillmore County, Minnesota, County Atlas Series C-8, Part A, Plate*, *2*(1), 100-000.

78. Monteith, J. L. (1965). Evaporation and environment. In *Symposia of the society for experimental biology* (Vol. 19, pp, 205-234). Cambridge University Press (CUP) Cambridge.

79. Mutikanga, H., Sharma, S., Vairavamoorthy, K., & Cabrera Jr, E. (2010). Using performance indicators as a water loss management tool in developing countries. *Journal of Water Supply: Research and Technology – AQUA, 59*(8), 471-481.

80. Naveau, P., Nogaj, M., Ammann, C., Yiou, P., Cooley, D., & Jomelli, V. (2005). Statistical methods for the analysis of climate extremes. *Comptes Rendus Geoscience*, *337*(10-11), 1013-1022.

81. Nuriyev, E. (2007). EU Policy in the South Caucasus: A view from Azerbaijan. *CEPS Working Documents*, (272).

82. Oki, T., & Kanae, S. (2004). Virtual water trade and world water resources. *Water Science and Technology*, *49*(7), 203-209.

83. Overland, J. E., Hanna, E., Hanssen-Bauer, L., Kim, S. J., Walsh, J. E., Wang, M., ... & Ballinger, T. J. (2015). Surface air temperature. The*Arctic report card*, 10-16.

84. Paxton, E. A., Chantry, M., Klower, M., Saffin, L., & Palmer, T. (2022). Climate Modeling in Low Precision: Effects of Both Deterministic and Stochastic Rounding. *Journal of Climate, 35*(4), 1215-1229.

85. Peel, M. C., & McMahon, T. A. (2014). Estimating evaporation based on standard meteorological data progress since 2007. *Progress in Physical Geography, 38*(2), 241-250.

86. Pereira, L. S., Oweis, T., & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural water management*, *57*(3), 175-206.

87. Poff, N. L., & Matthews, J. H. (2013). Environmental flows in the Anthropocene: past progress and future prospects. Current Opinion in Environmental Sustainability, 5(6), 667-675.

88. Raymondi, R. R., Cuhacivan, J. E., Glick, P., Capalbo, S. M., Houston, L. L., Shafer, S. L., & Grah, O. (2013). Implications of Changes in Temperature and Precipitation. *Climate Change in the Northwest*, 41.

89. Rustamov, S. Q., Kashkay, R. M. (1989). *Water resources of the Azerbaijan SSR*. Baku. 180.

90. Salamov, A., Mammadov, V., & Khalilova, H. (2020). FORMATION OF SLIDING PROCESSES IN THE TERRITORY OF THE REPUBLIC OF AZERBAIJAN AND THEIR

THREATS (CASE STUDY: THE ABSHERON PENINSULA). *Polish Journal of Science*, (29-1), 31-39.

91. Satterthwaite, D. (2008, January). Climate change and urbanization: Effects and implications for urban governance. In *United Nations Expert Group meeting on population distribution, urbanization, internal migration and development* (Vol. 24). DESA New York.

92. Schaller, M. F., & Fan, Y. (2009). River basins as groundwater exporters and importers: Implications for water cycle and climate modelling. *Journal of Geophysical Research: Atmospheres, 114*(D4).

93. Seckler, D., Barker, R., & Amarasinghe, U. (1999). Water scarcity in the twenty-first century. *International Journal of Water Resources Development*, *15*(1-2), 29-42. https://doi.org/10.1080/07900629948916

94. Shahraki, N., Marofi, S., & Ghazanfari Moghadam, S. (2019). Modelling of daily rainfall sequence and extreme values in the East Azerbaijan province. *Iranian Journal of Irrigation & Drainage, 13*(4), 1075-1086.

95. Shiklomanov, I. A. (2000). Appraisal and assessment of world water resources. *Water International, 25*(1), 11-32.

96. Shiklomanov, I. A. (1989). Influence of economic activity on the energy stock. Gidrometeoizdat. Pp. 330.

97. Smakhtin V. U., Shilpakar, R. L., Hughes D. A. (2006). Hydrology-based assessment of environmental flows: an example from Nepal. *Hydrological Sciences-Journal-des Sciences Hydrologiques*, *51*(2), 207-222.

98. Sneyers, R. (1992). On the use of statistical analysis for the objective determination of climate change. *Meterologische Zeitschrift*, 247-256.

99. Somerville, R. C. J., Stoner, P. H., Halem, M., Hansem, J. E., Hogan, J. S., Druyan, L. M., ... & Tenenbaum, J. (1974). The GISS model of the global atmosphere. *Journal of the Atmospheric Sciences, 31*(1), 84-117.

100. Song, L., Liu, S., Kustas, W. P., Nieto, H., Sun, L., Xu, Z., ... & Li, Q. (2018). Monitoring and validating spatially and temporally continuous daily evaporation and transpiration at the river basin scale. *Remote sensing of Environment, 219*, 72-88.

101. Tennant, D. L. (1976). Instream flow regimes for fish, wildlife, recreation and related environmental resources. *Fisheries*, 1(4), 6-10.

102. Tharme, R. E. (2003). A global perspective on environmental flow assessment:emerging trends in the development and application of environmental flow methodologies for rivers. *River research and applications*, *19*(5-6), 397-441.

103. Vernichenko, A. A. (1984). Classification of surface waters based on their quality characteristics. Complex evaluation of surface waters. S.Petersburg.

104. Vladimirov, A. K., Imanova, F. A. (1994). Principles of the assessment of ecological flows. *Ecology and hydrology design*. St-Peterburg, RGGMI, #116, pp. 4-7.

105. Ward, J. V., & Stanfor, J. A. (1987). The ecology of regulated streams: past accomplishments and directions for future research. *In Regulated streams* (pp. 391-409). Springer, Boston, MA.

106. Webb, B. W., & Nobilis, F. (2007). Long-term changes in river temperature and the influence of climatic and hydrological factors. *Hydrological Sciences Journal*, *52*(1), 74-85.

107. Weingartner, R., Viviroli, D., & Schadler, B. (2007). Water resources in mountain regions: a methodological approach to assess the water balance in a highland-lowland –system. *Hydrological Processes: An International Journal, 21*(5), 578-585.

108. Xiong, M., Sun, R., & Chen, L. (2019). A global comparison of soil erosion associated with land use and climate type. *Geoderma*, 343, 31-39.

109. Yang, J., Ren, J., Sun, D., Xiao, X., Xia, J. C., Jin, C., & Li, X. (2021). Understanding land surface temperature impact factors based on local climate zones. *Sustainable Cities and Society, 69*, 102818.

110. Zalewski, M. (2000). Ecohydrology – the scientific background to the use of ecosystem properties as management tools toward sustainability of water resources. *Ecological Engineering*, *16*(1), 1-8.