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Abstract

The purpose of the research is to analyze the prospects for the agriculture development in the Central Asian region and Tajikistan in particular, in terms of identifying the main favorable and constraining factors for the further agriculture development. The Pyanj river is one of the main tributaries of the Transboundary Amu Darya River in the Central Asian region, whose waters are a source of drinking water supply for the population and 80% used for irrigation of agricultural land. The trend of deteriorating water quality of Central Asian River systems recently has been increasing, and monitoring water quality from the formation zone to the downstream of the rivers is a problem in the region. The statistical methods and Pearson correlation to the meteorological conditions monitoring of the river basins were used. In the Laboratory of Environment and Geology of the Department of Geological Sciences of the University of Colorado at Boulder (USA), as well as in the Laboratory of Moisture Chemistry of the Institute of Arctic and Alpine Research (USA) by use of an inductively coupled plasma mass spectrometer (ICP-MS) and ion chromatography was conducted the element analyses of waters. The physical and chemical analyses of water samples was conducted using the “TaLab” spectrophotometer following the relevant state standards. The suitability of water for irrigation were determined by the calculation of the coefficients of sodium adsorption (SAR), the percentage of sodium (Na%), the percentage of sodium solubility (SSP), and the percentage of exchangeable sodium (ESP). The contribution of the Gunt River to the enrichment of the main Pyanj River with Fe, Co, Ni, Sr, Ca, Mg, Na, and K elements are established. The assessment of the natural water quality of the Pyanj and Gunt rivers for irrigation was carried out using various index methods, such as SAR, ESP, SSP and %Na.

Keywords: Collection; River Debris; Storage; Surakarta City.

1. Introduction

The current stage of human development is taking place in conditions of constant challenges caused by global climate changes, which make significant changes in the functioning of ecosystem components. Among all the ecosystem components, the mountain ecosystem is the most vulnerable and particularly sensitive to climate change. Current trends in the development of natural phenomena (climate warming, natural emergencies, etc.) are of particular concern to mountain countries and call for decisive measures to reduce the effects of climate change.

For example, Government Resolution No. 209 of May 3, 2010, approved the State Program for the study and conservation of glaciers of the Republic of Tajikistan for 2010-2030 for the continuous monitoring and study of glaciers in Tajikistan. The need to approve such a program is justified by the fact that despite the small area of the territory (just over 10% of the total area of Central Asia), Tajikistan has more than 11146 km2 of glaciation area, covering more than 14509 glaciers (Kayumov & Salimov, 2013) and forming more than 65% of the Central Asia water resources.

Rising temperatures around the world have caused environmental changes that have accelerated the water cycle, exacerbated extreme hydrological events, reduced water availability, and increased water resource vulnerability (Arnell & Gosling, 2016; Saiko & Zonn, 2000; Siegfried et al., 2012). Rivers in arid regions, which are mainly supplied with precipitation and meltwater, are particularly sensitive to changes in the global climate (Petrov & Normatov, 2010) since fluctuations in temperature and precipitation increase the complexity of the hydrological processes of rivers and water resources.

Therefore, it is important to assess the impact of climate change and glacier retreat on hydrology and water resources in snow-covered and glacial river basins to prepare for a new hydrological regime in the future, as future modified runoff characteristics will pose new challenges for water management and flood prevention strategies in these basins.

Central Asian countries are among the highest water consuming economies in the world. The intensification of agricultural water usage has resulted in environmental consequences like desertification and salinization with the most representative example the shrinkage and salinity of Aral Sea in the northern parts of Central Asia. The Aral Sea Basin comprises the drainage area of two major rivers, the Amu Darya and Syr Darya that cross all the Central Asian countries. The rivers originate from the Tien Shan Mountains and the Pamir and run through Tajikistan, Kyrgyz Republic, Afghanistan, Uzbekistan, Turkmenistan, and

Kazakhstan. The Aral basin is home to almost 60 million people and provides irrigation to 11.4 million ha. Irrigated agriculture uses 90% or 140–160 km^3 of Aral basin's water sources and is one of the key drivers of economic growth, employment, poverty reduction and food security in the region (FAO, 2012).

The irrigation efficiency in the region is estimated at about 30% (i.e., only 30% of the withdrawn water reaches the plant roots), and the average annual abstraction for irrigation is over 15,000 m3 per ha (World Bank, 2017). Tajikistan is the poorest country in Central Asia, with 49% of its rural population living below the poverty line. Approximately 73.6% of the country's population of 8.55 million reside in rural areas, where paid jobs are scarce (FAO, 2015). About 46.5% of the overall population is employed in agriculture, while productivity in the sector represents 21% of national GDP (World Bank, 2017a).

Agricultural land in Tajikistan covers about 4.6 Mln. ha, with a potential irrigable land of 1.57 Mln. ha (FAO, 2001). However, currently only 753,083 ha of irrigated land and 201,370 ha of rain fed arable land is cultivated due to technical and economic constraints (FAO, 2015). The average amount of arable land held per person was 0.08 hectares for 2016. Due to differences in climatic conditions, the agriculture in Tajikistan is dependent on irrigation, which in some regions is highly energy intensive due to the reliance on irrigation pumps.

The rise of the issues contributes to the expansion of agricultural land, the production of goods by maximizing the use of natural resources, and the development of the economy. This, in turn, leads to an anthropogenic load on water resources. According to statistics, over 50 years (1960-2010), the population of Central Asia has grown from 14 million to almost 49 million people, and the area of irrigated land has increased from 4.5 to 7.9 million hectares. Over the past forty years, the specific water supply in Central Asia has decreased from 8.4 thousand m3 / year people to 2.5 thousand m3/year people and tends to decrease (Normatov et al., 2019).

In socio-economic significance, agriculture remains the most important sector of the economy in most states of the Central Asia region. The livelihoods of the main population directly depend on the productivity and efficiency of agriculture, since most of the population of the region (from 43% in Kazakhstan to 75% in Tajikistan) lives in rural areas. The total area of arable land in the Republic of Tajikistan is 720.2 Th. ha, 502.8 Th. ha of which is irrigated (7.1% of the total area of irrigated land in the Central Asian region) (Normatov et al., 2021).

The current stage of agricultural development, accompanied by global warming, an increase in the demographic factor and an aggravation of the problem of food security requires a significant reconstruction and revision of the still existing standards and the sector activity modes.

A deep and scientifically grounded analysis of the cause-and-effect relationship in the development of the agricultural complex is a reliable basis for finding optimal and effective directions for the development of this sector. To achieve high productivity indicators and reduce the negative impact of global warming on the ecological balance, it is necessary to adjust the existing modes of agricultural work. Naturally, to fulfill its main mission of ensuring food security, agriculture needs to provide favorable water and land conditions. There is no doubt that the quality of irrigation water plays an important role in fulfilling the main mission of agriculture-ensuring food security by increasing the productivity of irrigated land. The use of polluted poor-quality water leads to a violation of the agrochemical composition, soil structure, and thus to a sharp decline in crop yields. The accumulation of salts in the root zone limits the availability of water, and the plant can absorb less water, which leads to a decrease in crop yields (Shakoor et al., 2015).

The problem of the water quality and development of mechanisms of its control is still actual and concerns not only the separately taken country of Central Asia (CA) but also all the states of the region. Nowadays one of the most polluted rivers of Central Asia is Zeravshan river. The river water is changed under the influence of collector drainage water of irrigating basin zone and wastewater of Samarqand, Kattakurgan, Navoi, and Bukhara cities. Mineralization of water exceeds from origin to estuary: from 0.27–0.30 to 1.5–1.6 g/l. The most exceed of maximum permissible concentration (MPC) among heavy metals is observed in Cr and Zn.

The problem of water quality in transboundary river basins, in the Zeravshan river basin is compounded by the fact that up to now there is no network sharing of information regarding the quality of the waterways between the neighboring states of Central Asia. Herewith, a uniform standard for assessing the anthropogenic load degree on geoenvironmental systems (maximum permissible concentration) are not developed. The problem of water quality of the Zeravshan river is mostly associated with its pollution by wastewater of the Anzob mountain-concentrating combine — the mining enterprise for extraction and enrichment of mercury-antimony ores of the Dzidzikurut deposit (Groll et al., 2015; Normatov 2014; Normatov

2015a; Normatov et al., 2015b; Normatov et al., 2015c; Normatov et al., 2016; Normatov et al., 2017).

A high concentration of salts and the presence of various chemical elements with concentrations exceeding the established agrochemical standards can change the balance of plant nutrients in the soil (Irfan et al., 2014; Shakoor et al., 2015). The irrigation water quality alone is not sufficient to assess the potential salinity and hazards that irrigated agriculture may face. Quality is not a single concept, but a collection of them can be so dissimilar that they may coexist, so it makes no sense to talk about quality as a single factor. It is most correct to talk about a high-quality profile. This means that instead of presenting single indicators, we can provide a variety of indicators to achieve a better understanding of the water type (Almeida et al., 2008).

Even water with a significantly high salt concentration can be used for irrigation without compromising soil productivity if irrigation is properly managed. The key point is how to maintain the existing salt balance in the root zone of plants (El Ayni et al., 2012). Thus, integrated monitoring of river water quality is a useful tool not only for assessing the suitability of surface water for irrigation but also for ensuring effective water management and protection of aquatic flora and fauna (Kannel et al., 2007). Therefore, monitoring of environmental parameters is one of the highest priorities in assessing the ecological state of water resources and in environmental protection policy (Wua & Chen, 2013). It is extremely important to have reliable information about water quality characteristics for assessing its safety in irrigation, as well as for effective pollution control and water resources management (Fan et al., 2010).

The hydrochemistry of rivers can be explained by the geology of the river flow areas, in particular by the change in the mineralogical composition of the bedrock from the upper to the lower reaches. A similar effect of bedrock composition on water quality is described in (Gamvroula et al., 2013). Obviously, the ionic composition of water is the result of several factors in the interaction of water and rocks (Hamzaoui-Azaza et al., 2011).

Changes in the geochemical characteristics of saltwater can be caused by the interaction of water and rocks, including the exchange of bases with clay minerals, adsorption on clay minerals, and carbonate dissolution–precipitation (Thilagavathi et al., 2012). In particular, the main factors controlling the mineralization of water seem to be the mineral dissolution of highly soluble salts and, equally important, ion exchange. The high content of chloride and

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sodium water is mainly due to the dissolution of anhydrite, gypsum, and halite (Tlili-Zrelli et al., 2013).

Several indicators regulate the quality of water used in irrigation in order not to destroy the agrochemical properties of the soil.

To assess the quality of water for irrigation purposes, the alkaline hazard is widely used, expressed as the proportion of sodium cations capable of absorption (SAR), the percentage of sodium cations (%Na), the percentage of soluble sodium (SSP), the sodium exchange coefficient (ESP), and the magnesium coefficient (%Mg). This is because at low and high content of calcium and sodium cations, respectively, in the composition of irrigated waters, due to the course of ion exchange reactions, the soil is enriched with sodium cations and the soil structure is destroyed, i.e., the dispersion of clay granules. Such soils reduce plant growth.

The statistics of recent years on the indicators of river water quality confirm the presence of negative trends in the mineralization increase both in time and in the length of riverbeds. The chemical composition is a determining indicator of the suitability of water for irrigation of agricultural crops (Normatov et al., 2021).

Surface water is one of the most easily polluted natural resources due to its high mobility and universal solvent nature (Khan et al., 2020), and its quality has a direct impact on its safe use for industrial, agricultural, and drinking purposes. Unfortunately, among the studies that examine water resources, relatively few concerning water qualities. In the Central Asian region of the Aral Sea basin, most of these studies focus on the water quality of the Syrdarya River, and insufficient attention is paid to the study of surface waters in other parts of Central Asia (Ma et al., 2020). The hydrochemical characteristics of the water indicate the climate and environment in the area where the river flows. As an important factor determining the use of water for domestic, irrigation, or industrial purposes, hydrochemical characteristics are of great importance for the sustainable management of water resources and the protection and ecological balance of the environment. Chemical ions in water are considered as natural "indicators" and the analysis of the basic ionic composition of water can be used to identify and control the main processes that affect its chemical composition, such as the weathering of rocks in river basins, evaporation, and the entry of atmospheric chemical compounds through precipitation (Erickson et al., 2017; Tomas et al., 2017).

Hydrochemical characteristics are the result of the long-term interaction of a water body with the environment during circulation, which may indicate the history of water formation and migration (Rashid & Romshoo, 2013). Rivers are important nodes connecting land and ocean, and they are the main channels for the exchange of materials and energy (Xu et al., 2018). The analysis of the hydrochemical composition of the basin can determine the geochemical source of the dissolved substances in the river and the relevant information, including the weathering and climate of the catchment area (An et al., 2015).

Chemical weathering is an important source of basic ions in river water. Chemical weathering of various rocks gives different combinations of dissolved cations and anions (Pant et al., 2018; Wu, 2016). For example, Ca2+ and Mg2+ mainly are formed because of carbonate and silicate weathering and dissolution in evaporation, while Na+ and K+ are introduced because of dissolution in evaporation and silicate weathering (Zhang et al., 2019). As for anions, SO42- and Cl- arise from the dissolution of evaporites or the oxidation of sulfides.

A comprehensive review of the literature on the selection of optimal indicators for a comprehensive assessment of surface water quality is presented in (Amirgaliev et al., 2019).

The water resources of the Central Asia region are formed mainly (80%) in the upstream of the rivers in the territories of Tajikistan and Kyrgyzstan and up to 90% of the annual surface runoff of the region (116.5 km^3/year) is used for irrigation of 85% of the agricultural land of the downstream countries (Kazakhstan, Turkmenistan, and Uzbekistan). The quality of irrigation water is relevant because the use of polluted water of poor-quality leads to a violation of the agrochemical composition, soil structure, and thus to a sharp decline in crop yields. In addition, there is a high probability of transfer of some chemical elements of the irrigation water composition to the human body through the chain “soil-plant-human body”.

This work aims to study the processes of enrichment of the waters of the Pyanj and Gunt rivers with chemical elements and to assess the applicability of river waters for irrigation of agricultural land. The theoretical concepts of rock weathering mechanisms and Gibbs' theoretical assumptions on the establishment of weathering of rock types depending on the ratio of cations and anions in the composition of river water are used in the paper. The standards of applicability water for irrigation by concentrations of alkaline and alkaline earth elements limit were used (Drever & Zobrist 1992; Gaillardet et al., 1999; Gibbs 1970; Meybeck et al., 2003; Millot et al., 2002; Wang et al., 2022)

2. Methods

The variety of climatic conditions in Central Asia, finding the patterns of changes in meteorological processes depending on the geographic and geo ecological features of the region led to the need for climatic zoning (Kurbonsho et al., 2014). In the development of the concept of climatic zoning, the Pamir is considered as an area where the humid, cold Mediterranean climate changes to the dry Central Asian one. The mountainous Pamir is the main formation zone of the Pyanj river water flow. Pyanj river is a transboundary river (on the border of the Republic of Tajikistan and Afghanistan) the left tributary of the Amu Darya in Central Asia. The length of the Pyanj river is 921 km and the area of basins is 114,000 km^2 that formed by the confluence of the Pamir and Vahandarya rivers. The average discharge of water is 1032 m^3/s. Currently Pyanj river is used mainly for irrigation.

The territory of the Republic of Tajikistan is in four climatic zones. In turn, the Gorno-Badakhshan Autonomous Region, which covers almost the entire mountainous Pamir and is the formation zone of the transboundary Pyanj River, is characterized by three climatic zones: warm continental (Mediterranean continental) climate; cold semi-arid climate; dry cold climate. The meteorological conditions of river basins are key factors in the formation of runoff and an indicator of any changes in hydrological characteristics at the climate change influence.

The study of the meteorological features of mountain regions is of great importance for forecasting, determining the dynamics of changes in water resources and, ultimately, in planning the prospects for the development of economic sectors.

The monitoring meteorological conditions of the Pyanj river basin was carry out by used of the data from meteorological stations : Irkht (3290 m a.s.l., 38^{o}6' 72^{o}36'); Ishkoshim (2600 m a.s.l., 36^{o}43' 71^{o}36'); Darvaz (1279 m a.s.l.,38^{o}26' 70^{o}47'); Dzavshangoz (3410 m a.s.l., 37^{o}21' 72^{o}27'); Khorog (2077 m a.s.l., 37^o 30' 71^{o}33').

Water sampling from the Gunt and Pyanj rivers was carried out at the points: 1(N38.87092E69.99751), 2(N37.63049 E71.51358), 3(N37.92010 E71.40069), 4(N38.11634 E71.32416), 5(N38.30353 E71.33006), 6(N38.34317 E71.19719), 7(N38.40696 E71.13829), 8(N38.44870 E71.02927), 9(N38.46246 E70.76193), 10(N38.35925 E70.65354), 11(N38.34769 E70.60247), 12(N37.98391 E70.25198) (Fig.1).

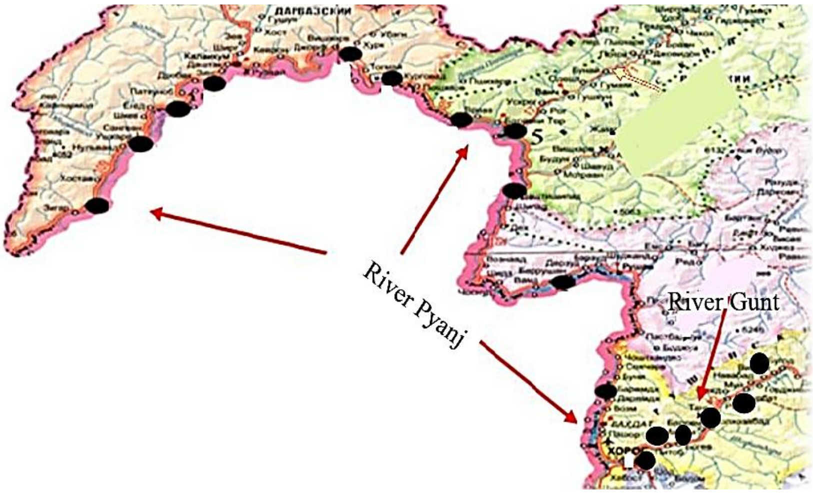

Figure 1. Water sampling points (●) from the Gunt and Pyanj rivers

Ten samples were taken at each sampling point to determine the trace elements. Acid-washed plastic containers (250 ml) were used. Samples were taken manually from subsurface water (30 cm deep and in the middle of the river). The samples filtered through a 0.2 mm cellulose acetate filter and stored in polypropylene acid-washed bottles immediately after sampling (Misaghi et al., 2017; Rengasamy 2018; Williams et al., 2016).

Elemental analysis was conducted in the United States in the Laboratory of Environment and Geology of the Department of Geological Sciences of the University of Colorado at Boulder, as well as in the Laboratory of Moisture Chemistry of the Institute of Arctic and Alpine Research using an inductively coupled plasma mass spectrometer (ICP-MS) and ion chromatography.

The physical and chemical analyses of water samples were carried out using the “TaLab” spectrophotometer following the relevant state standards. At chemical analyses and interpreting the results, we were guided by the normative document (Amirgaliev et al., 2019) about approval of Rules of reference of water, object to sources of drinking water supply.

Sodium and K^+ were determined flamephotometerically, Ca^{2+}, Mg^{2+}, were volumetrically determined by titration with ethylene diamine tetra acetic acid (versinate), Cl^- was determined by titration with silver nitrate. Sulfate anions (SO_4^{2-}) were precipitated by barium chloride as barium sulfate and gravimetrically deter-mined (*Jackson 1973*).

To assess the relationship between the average values of the indicators and various physical and chemical parameters, a Pearson correlation analysis was performed. The sodium adsorption ratio (SAR), the percentage of sodium (%Na^+), solubility sodium ratio (SSR) and the exchangable sodium percentage (ESP) was calculated from the equations (Rengasamy et al., 2018):

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+}}} \quad (1)$$

$$\%Na^{+} = \frac{(Na^{+} + K^{+}).100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \quad (2)$$

$$SSR = \left(\frac{Na^{+}}{Na^{+} + Ca^{2+} + Mg^{2+}}\right) \cdot 100 \quad (3)$$

$$ESP = \frac{Na+}{(Ca^{2+} + Mg^{2+})} \quad (4)$$

The Mg^{2+} cation content is also an important indicator for determining the applicability of water for irrigation purposes. Magnesium deteriorates soil structure particularly when waters are sodium-dominated and highly saline. The Mg-ratio determined by use equation (Misaghi et al., 2017):

$$\text{Mg-ratio} = \frac{(Mg^{2+})}{(Ca^{2+} + Mg^{2+})} \quad (5)$$

3. Results and discussion

A wide range of processes, such as changing the state of glaciers, river flow and weathering of rocks, are mainly due to climatic factors on the Mountain rivers upstream Therefore, monitoring meteorological conditions, hydrological characteristics of rivers and studying their interconnectedness are of particular importance.

It can be assumed that the intensity of weathering of rocks varies depending on temperature and, accordingly, in rivers with a catchment at different altitudes relative to sea level. The results of systematic monitoring of temperature, precipitation in the basin of the Pyanj River and its tributaries are presented below.

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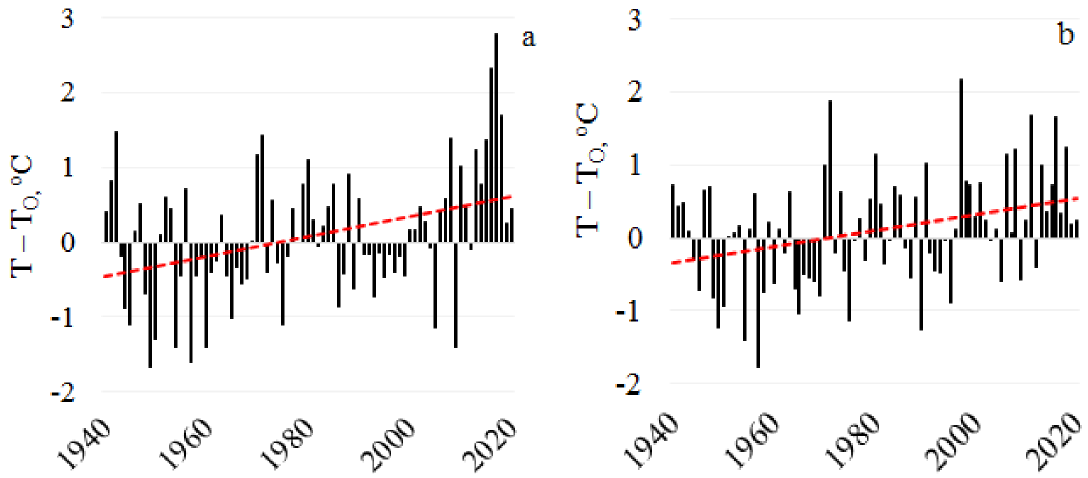
3.1. The temperature and precipitation on the Pamir Mountain climatic zones

The basin of the transboundary Pyanj river and its tributaries that mainly cover the mountain Pamirs are characterized by spacious areas of glaciation. The total glaciation area of the Pyanj river basin is 2,960 thousand km^2 and has more than 4,700 glaciers. The water runoff formed in the Pyanj river basin determined by the state of glaciation, glaciers of rivers basin. The noticeable degradation of the ice reserves in the last decade has led to changes of the water balance in the Central Asian region and an increase the number of extreme natural disasters - flooding, avalanches and the formation of glacial lakes that pose a threat to residents of mountain villages and valleys. Consistently and systematically monitoring the meteorological and hydrological conditions of river basins is necessary in terms of timely response to changes the state water and ice resources state and the emergence of hotbeds of emergencies in the highlands had will have an impact on the water flow of rivers. Systematization and processing of long-term meteorological and hydrological data can become a basis for creation long-term forecasts and scenarios for the water content of river systems and water supply of downstream.

The dynamics of temperature changes on the Pyanj river basin according to the meteorological station of the basin for the period 1940-2020 are presented in Fig.2. It indicates that in all climatic zones of the Pamir there is an increase of temperature and by 2050 an average temperature is expected to increase to 0.31-0.54 °C. In: Dzavshangoz - 0.36 °C; Khorog-0.33 °C; Irkhta-0.39 °C and Ishkashim-0.54 °C (Fig.3).



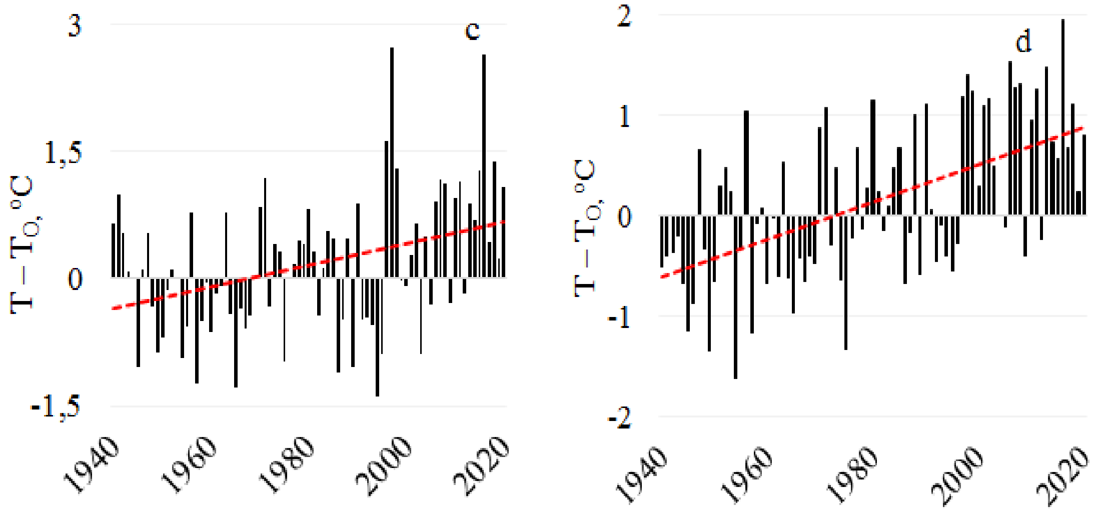


Figure 2. Dynamics of temperature changes in the Pyanj river basin for the period 1940-2020 to the base period 1960-1990 according to the Dzavshangoz (a) Khorog (b), Irkht (c) and Ishkoshim (d) meteostations

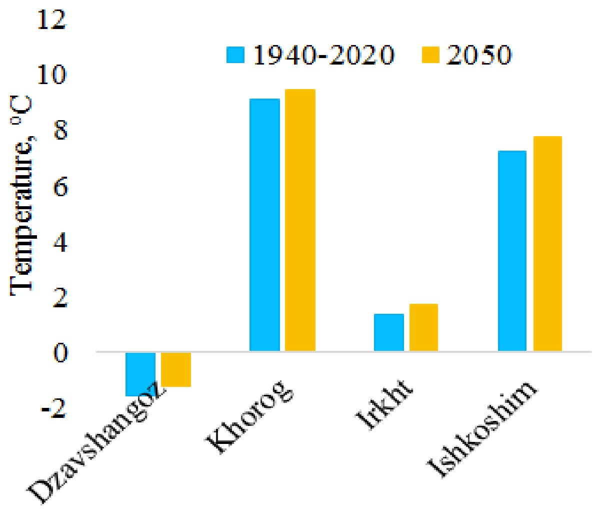


Figure 3. The average annual temperature of the Pyanj river basin for the period 1940-2020 and by 2050 according to the meteostations of the basin

Atmospheric precipitation, along with temperature, is an important climatic parameter in terms of moisture supply of basin and water content in the river network of the Pyanj river basin. The dynamics change in atmospheric precipitation according to the Dzavshangoz, Khorog, Irkht, Ishkoshim meteorological stations of the river. Pyanj shows its ambiguous behavior in different climatic zones due to the influence factor of the highland's orography on the distribution of air masses (Fig. 4).

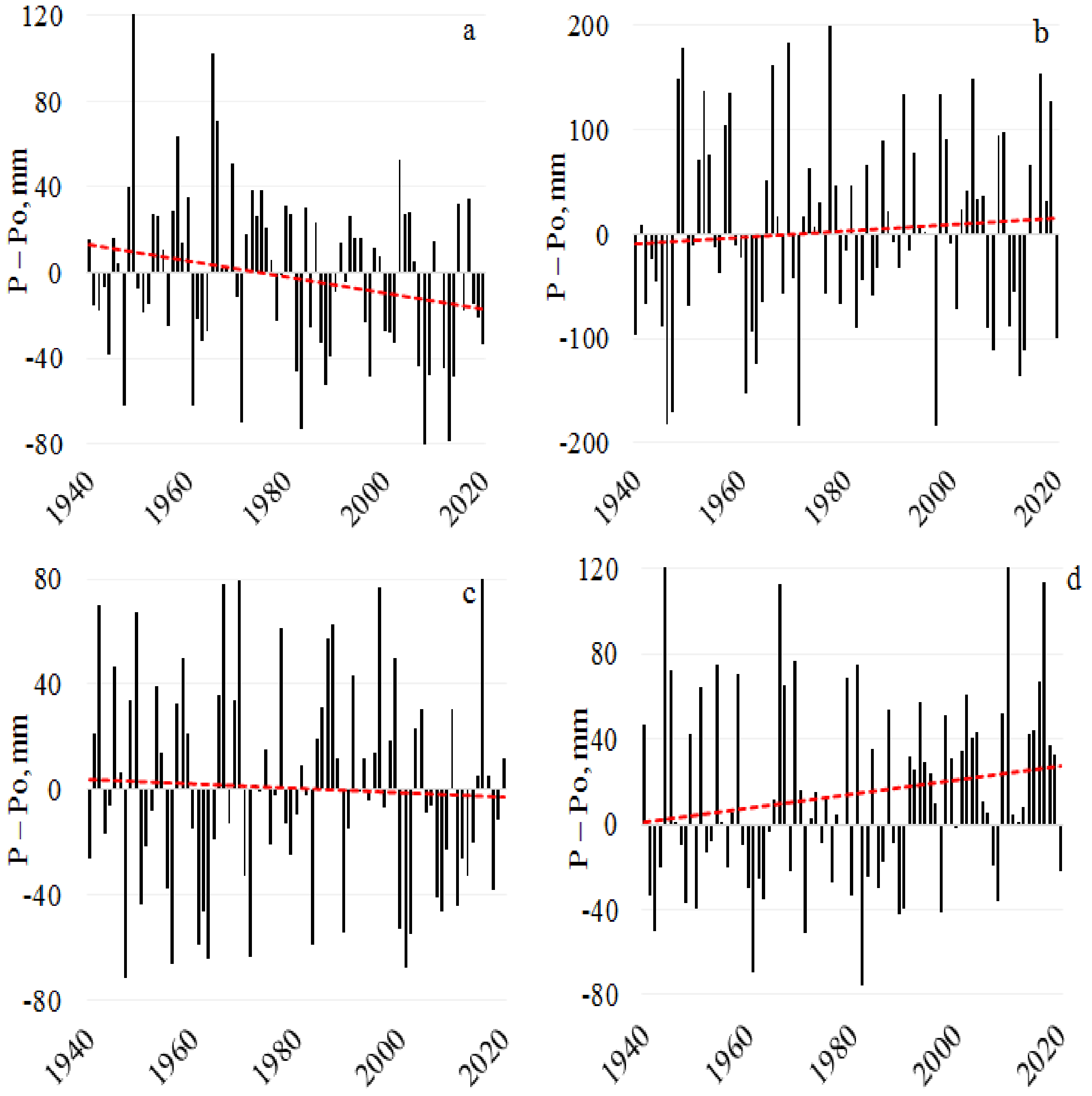


Figure 4. The average annual value of atmospheric precipitation in the Pyanj river basin for the period 1940-2020 in relation to the base period 1960-1990 according to the Dzavshangoz (a), Khorog (b), Irkht (c) and Ishkoshim (d) meteostations

Forecasts show increase of precipitation in the Pyanj river basin on 0.9% by 2050 compared to the 1950-2020 period. Although according to the Irkht and Dzavshangoz meteostations the precipitation decreases by 2% and 7.7%, and according to the Khorog and Ishkoshim weather stations, it increases by 5.5% and 9%, respectively. (Fig. 5).

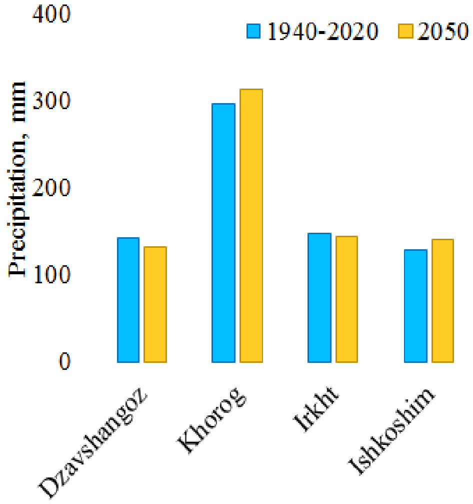


Figure 5. The average annual atmospheric precipitation in the Pyanj river basin for the period 1950-2020 and by 2050 according to the basin meteorological stations

The spatial distribution of atmospheric precipitation and snow depth in the upstream regions of the Pyanj river, including the Gunt and Vanch rivers, covering different climatic zones of the Pamir, is caused by the orography of the mountainous terrain and irregularities in air mass movements. The western climate zone is characterized by more abundant precipitation than the eastern zone. It is assumed that the duration of snow cover is determined by the temperature regime of the area. Penetration of air masses from the Mediterranean and the Caspian Sea to the Gunt river basin kept the atmospheric precipitation almost constant for more than 70 years in the western part of the river basin.

The opposite was found in the eastern part of the Gunt river basin. It is assumed that the decreasing trend in atmospheric precipitation in the eastern part is because of the dry air mass inflow. The air mass of the Indian monsoon is unloaded during the passage of the high mountain ranges and only dry air enters the eastern part of the Gunt river basin. The hydrological regimes comparison of the Gunt river for the periods 1940-1970 and 1986-2016 shows a change in the seasonal distribution of the river discharge. The change indicates that the Yashilkul Lake lost its influence that earlier smoothed the water level of the Gunt river. In the Vanch river basin, precipitation remained almost constant during the period 1956-2016, whereas temperature shows a slightly increasing trend. A comparison of the river discharge for the periods 1940-1970 and 1986-2016 revealed an increase, which is associated with the degradation of the ice sheet in the headwater of the Vanch river basin (Normatov & Normatov, 2020).

The assessment of changes in the area and volume of 67,028 glaciers in High Asia with a total area of 122,969 km^2 (indicated in the Randolph Glacier Register 2.0) by use the regional climate model RegCM 3.0 with a resolution of 25 km, taking into account the forecast of temperature and precipitation changes in connection with the IPCC A1B scenario showed that the total loss of glacier area in highland Asia in 2050 will be 22% (in the tuned model) or 35% (without the tuning) compared to 2000. The average annual rate of decrease in the total area and volume of glaciers will be 0.65–0.70% and 0.41– 0.52%, respectively.

The results show that of the 67028 glaciers, 24% will be stationary or advancing, and 76% will retreat in the 2000–2050 period (Zhao et al., 2014). The relative contributions of the four different water sources in rivers are likely to change in the future. Precipitation patterns will change, and temperatures will rise, which will lead to a decrease in the contribution of snowmelt and especially glacier melting. Even though more than 50% of the glacial ice volume will remain, they will be at higher altitudes, so melting will be lower. The analysis shows that the inflow to the downstream areas by 2050 will decrease by 26-35% for the Amu Darya.

The main consumer of freshwater in the region is irrigated agriculture. About 97% (93800 million m^3 per year) is consumed by irrigated agriculture, while other sectors, such as utilities and industry, consume about 2700 million m^3 per year. Climate change will not only reduce available water resources but also increase the demand for them from crops, as higher temperatures lead to higher evaporation rates. Based on the assessment tools developed for the regions, the total water demand in the Amu Darya basin will increase by about 4% -5%. It is expected that for the two main rivers of Central Asia (Syr Darya, Amu Darya), the total water deficit in 2050 will be 43 km^3 per year. Moreover, the regimes of monthly runoff will change significantly, especially for the Amu Darya River, due to the retreat of glaciers and a decrease for snowfall (Punkari et al., 2014).

3.2. Formation and dynamics of changes in the hydrochemistry of the Gunt and Pyanj rivers

Soil-plant-human is recognized as the main route of radionuclide transmission to humans. Continuing the chain of soil-plant-human transmission of radionuclides adding of irrigation water it can be assumed that transmission of several other chemical elements that pose some threat to public health. Plants receive precipitated chemical elements from the soil fed by irrigation water, called the soil-to-plant transfer factor (TF), is used to calculate the human radiological dose. In general, transport factors exhibit a wide range of variations depending on several factors, including soil properties such as pH, clay mineral, Ca, K, organic matter content, plant species, and other environmental conditions, and the chemical composition of irrigation water.

Among the environmental issues, water pollution affects human health and agricultural production to a high extent. Knowledge of water pollution and its environmental characteristics is thus vital to understanding water suitability for various purposes (Erickson et al., 2017). Soil irrigation is an important component in achieving the desired agricultural productivity indicators, especially in regions where precipitation is insufficient to provide sufficient water during the growing season of crops. The quality of irrigation water impacts the productivity of the agricultural lands. The obvious that good quality water with a low content of dissolved salts helps increase soil productivity, and with an increase in the concentration of salt in the water, there is a decrease in the growth and yield of crops (Misaghi et al., 2017).

Salinization of irrigation water can lead to the accumulation of salts in the soil layers above the threshold level and the impact on crops of osmotic and ion-toxic effects (Rengasamy, 2018). Irrigation of soils with saltwater leads to a high level of adsorbed sodium in soils and deterioration of the soil structure with a decrease in infiltration and water movement and inadequate aeration (Munns et al., 2008). The ratio of air permeability to water permeability increases exponentially with the percentage of exchangeable sodium (ESP), while for percentage of exchangeable potassium (EPP), the increase is not significant.

Table 1 shows that the Pyanj and the Gunt rivers are characterized by a rich set of chemical elements, and the observed insignificant concentrations indicate their origin, i.e., the natural weathering process of the river basin's rocks. The concentration difference of chemical elements in table 1 follows that the Gunt river enriches the main Panj river with elements Va, Eu, Na, Rb, Rh, Si, and Zn. Other chemical elements enter the Pyanj river from its other tributaries.

Table 1. Concentration value (C) of chemical elements of the Gunt and Pyanj rivers

Elements	$C_{r. Gunt} \cdot 10^{-3}$ (mg/l)	$C_{r. Pyanj} \cdot 10^{-3}$ (mg/l)	$(C_{r. Gunt} - C_{r. Pyanj}) \cdot 10^{-3}$ (mg/l)
As	1,965009	7,399781	-5,435
Ba	78,44266	66,58783	**11,855**
Ca	26043,72	38136,12	-12092,4
Co	0,144358	0,291165	-0,1468
Cr	21,28617	23,15446	-1,8683
Eu	0,087628	0,076859	**0,0108**
Fe	463,3674	825,1237	-361,756
K	1876,749	2544,444	-667,695
Mg	3129,645	11204,27	-8074,63
Na	8125,401	6994,703	**1130,698**
Ni	4,296291	8,031145	-3,7349
Rb	2,179707	2,608462	**0,4288**
Rh	0,196241	0,070951	**0,1253**
Ru	0,174035	0,315868	-0,1418
Sc	1,925425	2,137632	-0,2122
Si	3141,679	2859,195	**282,484**
Sm	0,119713	0,11012	0,009593
Sr	101,4233	247,009	-145,586
U	2,067	2,586636	-0,5196
Zn	10,58779	7,245432	**3,3424**

The rocks contribution to the chemical composition formation of natural waters is regulated by the criterion according to which the predominance of the carbonate rocks weathering, i.e. calcite and dolomite, is observed at $(Ca^{2+} + Mg^{2+})/(Na^{+} + K^{+})>6$ and high values of the Mg^{2+}/Ca^{2+} molar ratios. Along with this, H_2CO_3 dominates the weathering processes concerning H_2SO_4 at $Ca^{2+}/SO_4^{2-} >1$. According to the results presented in Table 1, it becomes obvious that the formation of the chemical composition of the Grunt River occurs because of the silicate rocks weathering.

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The Gibbs diagram establishes the influence of three main factors, namely rock weathering, evaporation, and precipitation on the chemical composition of water. The precipitation area in the Gibbs diagram is in the lower right corner, where Na^+/ (Na^+ + Ca^{2+}) is relatively high in water samples. The zones of rock weathering and evaporation correspond to the area of the diagram where the ratio of Na^+/ (Na^++Ca^{2+}) is about 0.5 and high, respectively (Neogi et al., 2017). Calculations performed using the data presented in Table 1 showed that in our case, the ratio of Na^+/(Na^+ + Ca^{2+}) is 0.24, i.e. close to the conditions of rock weathering. As can be seen from the *Na: K* ratio (Table. 1), the concentration of K < < Na in the river water of the Gunt. This is probably because K+ cations have a weak migration ability and the resistance of potassium-containing minerals to weathering.

Correlation analysis between water quality parameters can contribute to understanding the relationships between these parameters that determine their sources of origin (Zong-Jie et al., 2018). The results of studies on the cations and anions relationship in the Gunt and Panj rivers, summarized in Table 2, show that SO_4^{2-}, Ca^{2+} and Mg^{2+} have positive correlations (R> 0.66).

Table 2. Pearson correlation matrix for the average chemical composition of water samples from the Gunt and Pyanj rivers

	Cl	NO3	SO4	Ca	Mg	Na	K	Sr	Fe	Co	Ni
Cl	1										
NO3	0.03	1									
SO4	-0.16	0.84	1								
Ca	-0.02	0.87	0.86	1							
Mg	-0.14	0.86	0.87	0.97	1						
Na	0.61	-0.50	-0.62	-0.66	-0.78	1					
K	0.16	0.81	0.77	0.93	0.87	-0.45	1				
Sr	-0.23	0.80	0.81	0.94	0.98	-0.85	0.80	1			
Fe	-0.12	0.82	0.79	0.97	0.99	-0.77	0.88	0.98	1		
Co	-0.10	0.81	0.80	0.97	0.97	-0.75	0.88	0.97	0.98	1	
Ni	-0.15	0.86	0.83	0.97	0.99	-0.78	0.87	0.98	0.99	0.98	1

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Table 2 also shows that there are many mutual positive correlations between the elements of the water composition of the Pyanj river and its tributary, the Gunt river. As an example, Fig. 6 shows the correlation dependences of the elements.

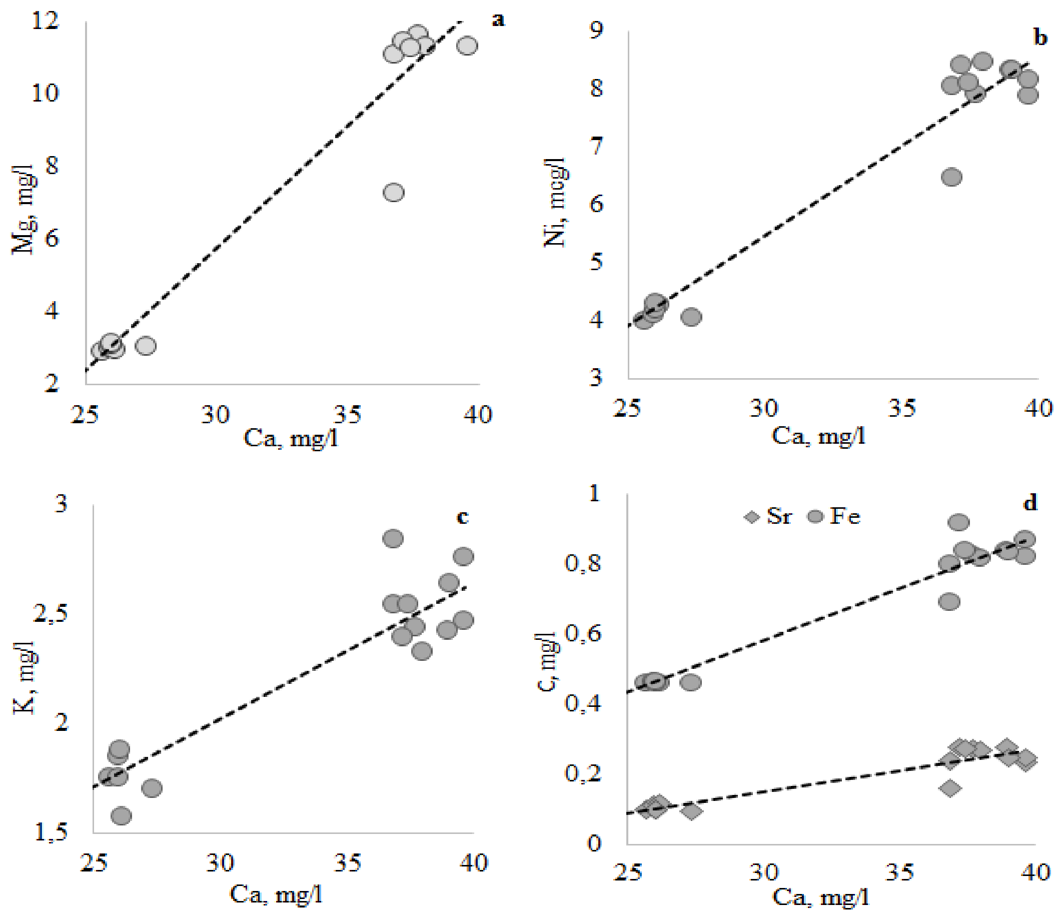

Figure 6. Correlation of magnesium (a), nickel (b), potassium (c), strontium and iron (d) cations on the content of calcium cations in the Gunt and Pyanj rivers

An indicator for determining the contribution of each of the three factors of the rocks weathering (silicate, carbonate, and dissolution of evaporites) is the Ca^{2+} / Mg^{2+} ratio, a high value of which indicates the predominance of bicarbonate weathering (Pandey et al., 1999). A low value of this ratio indicates the weathering of silicate rocks (Fig. 7).

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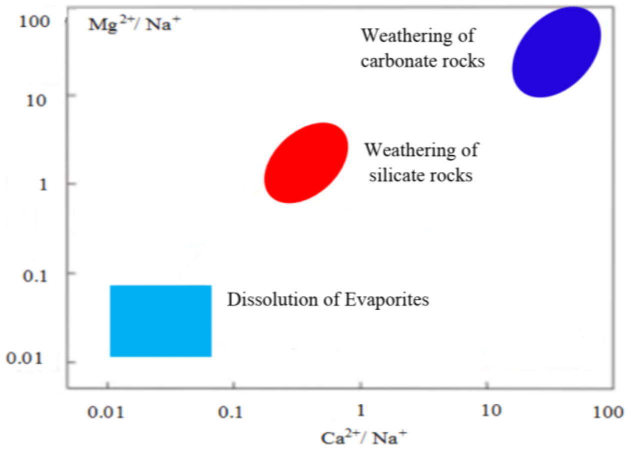

Figure 7. Dominance areas of the chemical elements input sources to rivers depending on the ratio of Ca^{2+} and Mg^{2+} cations (*Li et al., 2019*)

By use of the Gunt river alkaline and alkaline earth cations concentration in the Table. 1 the dependence of the ratios Mg^{2+} / Na^{+} and Ca^{2+} / Na^{+} was plotted (Fig. 8).

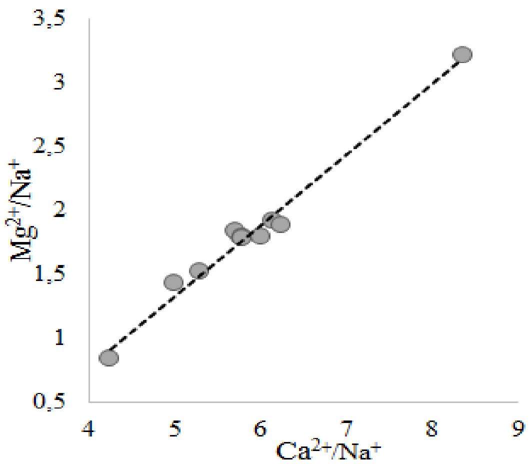

Figure 8. Relationship of Mg^{2+}/Na^{+} and Ca^{2+}/Na^{+} ratios for the Gunt river

Since bicarbonate weathering, as follows from Fig.7, is observed at the values of the Ca^{2+}/Na^{+} and Mg^{2+}/Na^{+} ratios greater than 10, the obtained dependence in Fig.8 indicates that the chemical composition formation of the Gunt river water occurs because of the silicate rocks weathering.

3.3. The applicability indices of the Pyanj and Gunt rivers water for irrigation

The suitability of water for irrigation can be known by analyzing dissolved salts. Generally, Na^{+} can replace Ca^{2+} and Mg^{2+} if there is an excess salinity of irrigation water.

The displacement reduces the permeability of soil and thus limits the flow of air and water. Sodium adsorption ratio (SAR), sodium percentage (Na%), sodium solubility percentage (SSP) and exchangable sodium percentage (ESP) (Equations (1), (2), (3) and (4)) were applied to evaluate the suitability of surface water for irrigation. The results of calculation SAR, %Na, SSP and ESP for the Pyanj and Gunt rivers are summarized in Table 3. A comparison of the results with the classes of irrigation water quality classes of SAR, %Na, SSP and ESP shows that the natural waters of the rivers fall under the "excellent" category.

Table 3. Irrigation water quality of SAR, %Na, SSP and ESP for the Pyanj and Gunt rivers

	SAR, $(mEql^{-1})^{1/2}$	%Na, %	SSP, $mEql^{-1}$	ESP, %
Pyanj river	0.256	16.21	12.40	10.70
Gunt river	0.396	25.53	21.78	22.10

4. Conclusion

This work aims to study the processes of enrichment of the waters of the Panj and Gunt rivers with chemical elements and to assess the applicability of river waters for irrigation of agricultural land. It is shown that in the conditions of climate change, the main factors determining the future development of agriculture in the Central Asian region will be the water availability of river systems and the demography of the region. The current state and forecasts for the next 100 years of glaciation in the region show significant glacier degradation and population growth.

Consequently, innovative approaches to the rational use of irrigation water and a significant improvement in the degree of agricultural land productivity are needed. It is shown that the quality of irrigation water is one of the important factors determining the meliorative state, structure, and agrochemistry of soils and, accordingly, the development of crops. A comprehensive chemical analysis of the Pyanj and Gunt rivers water revealed a rich composition of chemical elements. The essential role of the Gunt river in the enrichment of the main Pyanj river by chemical elements has been established.

The main channel for enriching rivers with chemical elements is the weathering of rocks with the participation of sulfuric acid bicarbonate acids. To assess the degree of applicability of the Pyanj and Gunt rivers for irrigation, the corresponding calculations of the Sodium adsorption ratio (SAR), percentage of sodium (%Na), sodium solubility percentage (SSP), and exchangeable sodium percentage (ESP) were carried out. The results of the calculations and their comparison with the classes of irrigation water quality showed that the natural waters of the rivers fall into the category favorable for irrigation.

There are potential opportunities for further research in the Republic of Tajikistan with its wide network of river systems (more than 600 rivers with a total length of 29000 km). In this direction, the research of climatic features of mountainous terrain on the formation of water resources and hydrochemistry of rivers opens wide prospects for obtaining important applied and fundamental results. There is no limitation to the continuation of the research.

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Author Contribution

Inom Normatov - formulation of goals and ideas, research methodologies, theoretical interpretation of results, preparation of the paper writing scheme and discussion of results

Akobir Karimzoda - conducting a literary search and compiling a literary review on the topic of the article, providing chemicals, participating in the discussion of the results

Parviz Normatov - collection, generalization, and systematization of data on meteorological data of river basins, creation of a data bank for meteorological parameters, data processing and creation of graphic materials

Rano Eshankulova - chemical analysis, interpretation of results, creation of a data bank for chemical elements of rivers

Ayubjon Normatov - participation in expedition work, sampling of water from rivers and delivery to the laboratory

Nurmakhmad Shermatov - the use of statistical, mathematical, computational methods for the analysis or synthesis of research data.

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