Assessment of the existent situation and the potential impact of climate change

at Bakhmaro Resort

Hydrological reports and analysis of water resources

About the project

Climate change has a strong impact on mountainous landscapes such as the resort area of Bakhmaro. Therefore, it is necessary to assess the impact of climate change before a resort development plan is created, or it should be part of a development plan.

According to the Government of Georgia, Bakhmaro will be turned into a ski resort. However, no assessment has been made of the impact of climate change on the Bakhmaro Resort area; Especially on such important components as: precipitation distribution and snow cover. This assessment will be an essential factor in the Climate Adaptation Plan, enabling relevant government agencies to pre-determine climate change adaptation measures.

CENN, with the support of the British Embassy, has launched the project "Climate Change Impact on Bakhmaro Resort", which aims to study the climate of Bakhmaro Resort. The project assesses the existing climate parameters, determines the impact of climate change and prepares recommendations on stable adaptation to climate change in order to facilitate informed decision making.

Research topics

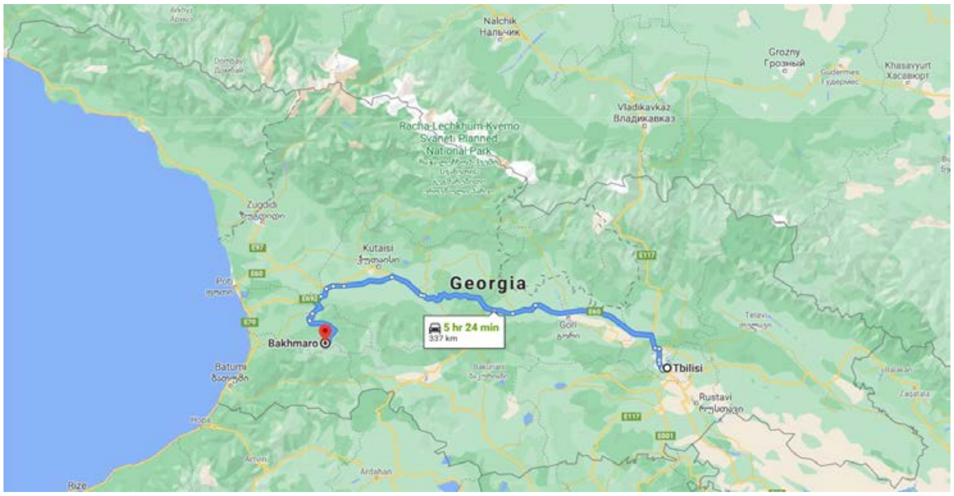
1. Hydrological and climate change assessment, identification of potential problems, and preparation of assessment reports on the impacts of climate change and future risks

2. At the local level, taking the necessary measures to achieve immediate action to mitigate climate change and improve water resources management

General description

Bakhmaro is located in Chokhatauri municipality, on the Adjara-Imereti ridge within 1800-2100 meters above sea level. The resort area is situated within the catchment area of the river Bakhvistskali and its tributaries. It is also surrounded by the central part of the Adjara-Imereti ridge and lateral ridges. Therefore, the area of Bakhmaro is in a topographically depressed area, where mainly mixed forests of spruce and fir are found. The resort zone is located 337 km away from Tbilisi.

Figure 1 Distance from the capital to the resort area

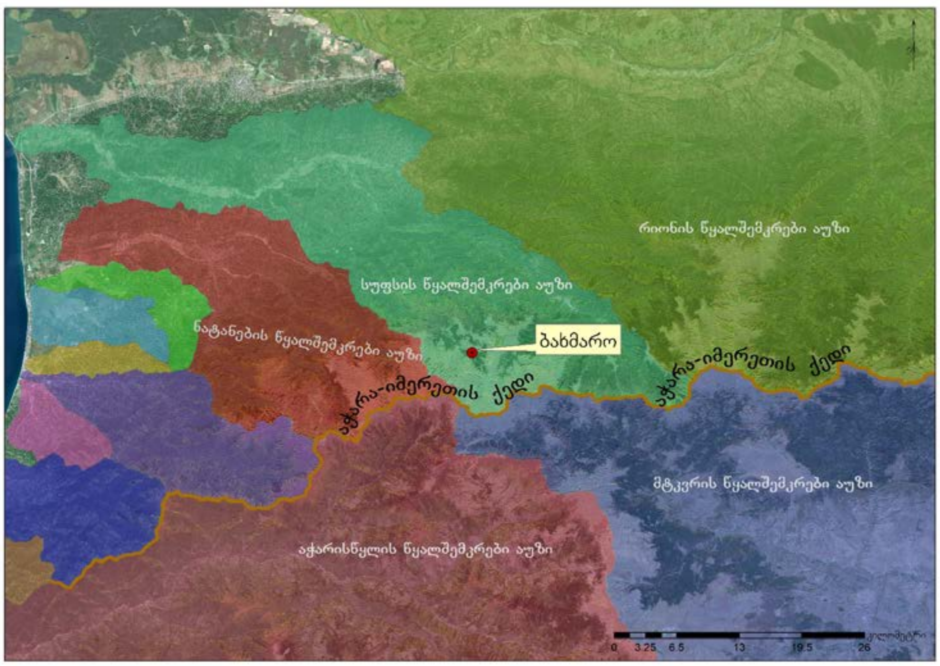


Due to the proximity to the sea, specific climate conditions are found in the surrounding area, which makes the resort very versatile.

Adjara-Imereti ridge is the most extensive and orthographically best-developed .Its length, going from Erge (896 m) to Kokola (1341 m), is 182 km in total, where 151.0km are in a straight line. The widthof the Adjara-Imereti ridge on the Fersati meridian is 40-45 km. From Erge to the ridge of Sakornia (2755 m) it has a sub-meridian (SD-cha) direction, from where it has a general longitudinal direction to Kvishkheti. The highest peak is Mepistskaro (2850 m). The sub-meridian section of the ridge is a watershed between the right tributaries of Adjaristskali and the rivers Chakvistskali, Kintrisha and Natanebi basins. The latitudinal watershed separates the river. Watersheds of the left tributaries of the Mtkvari and Supsa-Rioni. There are the following peaks on the watershed of the longitudinal direction: Sakornia 2755 m), Zoti mountain (2676 m), Khalkhamo (2635 m), Didmaghali (2588 m), Lomismta (2187 m), Dedabera (1838 m). There are 2100-2300 m high passes in this section of the ridge. Notable is Zekari (2182 m), on which the Abastumani-Sairme-Baghdati road goes through.

The relief of the surrounding areas of Bakhmaro is built of volcanic-sedimentary rocks of Eocene age: basalts, andesites, massive and thick-layer breccias, tuffs, tuff sandstones. In some sections Eocene diorites are present in the form of small areas. Wrinkle structures are complicated by cracks and crevices.

Figure 2 Hydro-morphological characteristic of the area around Bakhmaro



The Adjara-Imereti ridge located in the vicinity of Bakhmaro is divided into three main parts according to morphological, morphometric and relief genetic forms: watershed ridge, northern and southern slope. The watershed has a wavy morphology 100-200 m in height, with only in some sections separating the mountain massifs rising from the surface. A large role in shaping the relief belongs to the action of old glaciers. Glacial landforms i.e., doors, moraines, small troughs are connected to the peaks above 2400 m. It should be noted that the northern slopes of the ridges are rocky and steeper than the southern slopes.

The northern slope of the Adjara-Imereti ridge is quite wide, 20-24 km. From Sakornia Sub-meridian (north-western slope of Cha-sd direction is divided by the valleys of the rivers Natane, Kintrishi, Chakvistskali, Korolistskali and their tributaries, where the depth of erosion is 800-1200 m). There are several straight steps at different heights on the river divisions and their height is in the range of 1200-2200 m.

The Adjara-Imereti ridge has a longitudinal direction east of Mount Sakornia. Its northern slope is divided by tributaries of rivers. The branch is located on the western slope of the ridge, in the Supsa River basin, with flattened surfaces at altitudes of 1100, 1650, 2200 and 2600 m. In some sections, selective wear forms are found on the ridge.

The rivers flowing there and their tributaries develop quite deep. V-valleys were shaped in the north-western direction, the depth of the intersection is 800-1000 meters. The riverbed is often muddy. Several terraces in the extended sections are marked with relative heights of 6-10, 60, 90-100 and 180 m. Some streams intersect the embankment structures mostly perpendicularly and develop into deep, antecedent valleys with strongly sloping slopes. Sometimes the morphology of the valleys in the longitudinal sections is asymmetric. Cutting depth is 1000-1200 m and the bed has rapid downpour. On the watersheds of the river basins, which are at the same time branches of Adjara-Imereti, the old flattened surfaces are preserved (terraces are preserved only in the lower parts of the gorge).

Climate conditions

Geographically, Bakhmaro, as well as the whole territory of Georgia is located on the northern periphery of the subtropical belt, which is why it is characterized by moderate cloudiness. Cloudiness rates vary considerably with the proximity to the Black Sea and the elevation of the site. That is why the Bakhmaro Resort, for the territory of Georgia, is distinguished by its climatic characteristics, which are well subject to the vertical zoning of the place.

The north-western side of Bakhmaro is open and therefore the air masses from the sea easily reach the valley, which in turn contributes to the formation of a mild mid-mountain climate. Breeze-like mountain-winds are also frequent, which contributes to its good ventilation and air circulation.

In addition, its impact on atmospheric precipitation and temperature is important, which is one of the main indicators of climate change, as they have a direct impact on snow cover and its quality, as well as water resources.

In the resort of Bakhmaro, a meteorological station has been operating since 1936. Unfortunately, as in the case of many other meteo stations or hydrological checkpoints, the station in the village has been closed since the 1990s, causing temperature readings (as well as precipitation and consequently river runoff). ????

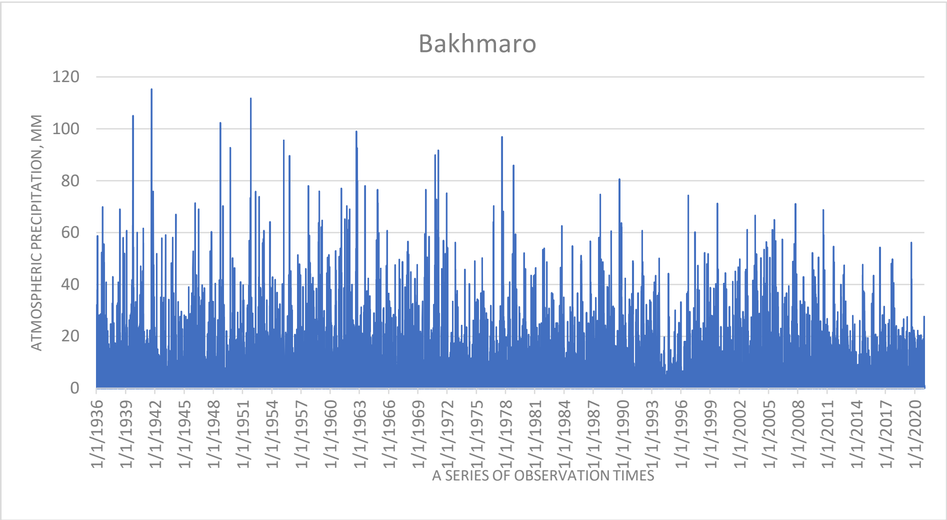
Analysis of the data, which covers the period from 1936 to 2020, reveals that the average annual multi-year precipitation in Bakhmaro is 1500 mm. In terms of months, the most rainy month is October, with an average of 182 mm of rainfall. As for the minimum rate, in this respect April stands out when the rate of atmospheric precipitation is equal to 79 mm. According to the seasons, autumn-winter is the rainiest season.

Figure 3 Resort Bakhmaro

Table 1 Distribution of rainfall by months, Bakhmaro Resort, 1936-2020

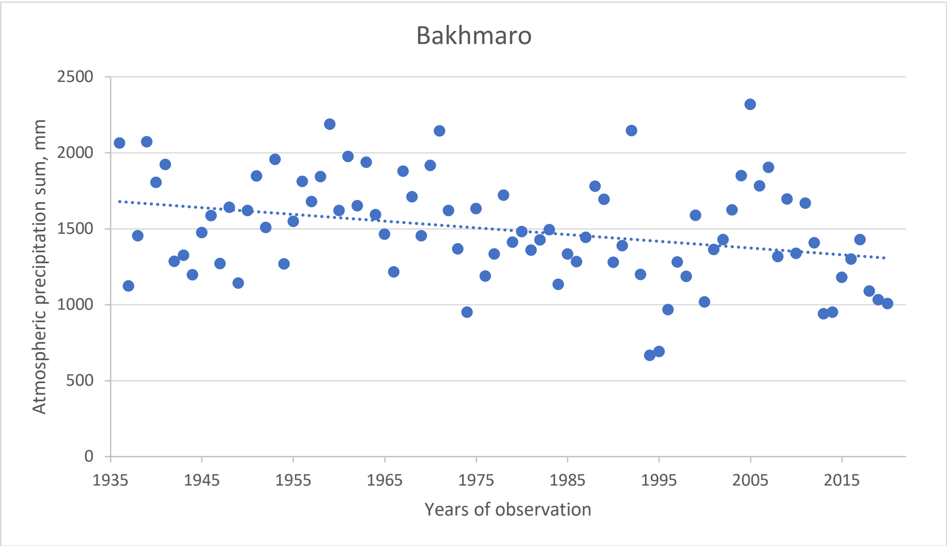
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	total
149	125	106	79	91	112	89	112	145	182	154	149	1493

Figure 4 Daily precipitation, Bakhmaro resort, 1936-2020.



In addition to the above data, it is interesting to note that a small decrease in precipitation is observed in the resort of Bakhmaro and its surrounding area, especially in the last 10 years, which is well seen in Figure 5. Since there is no on-site monitoring, satellite information is used to extend the data queue. Although the reliability of satellite information is low, the trend of decreasing precipitation is clearly evident, which was also confirmed by snow planning data. It is therefore noteworthy that some of the effects of climate change have already been reflected in the resort area and the surrounding area. As of today, the shifting seasons and the scarcity of water resources at certain points in time are evident, especially during the winter (January, February) and summer-autumn (August-September) seasons, which negatively affects both water resources and snow cover.

Figure 5 Sum of Atmospheric Precipitation by Years and Trend Line, 1936-2020



In addition to atmospheric precipitation, obvious changes due to climate change are evident in the temperature regime. It is noteworthy that not only the average temperature of the year changes but also the seasonal change is obvious.

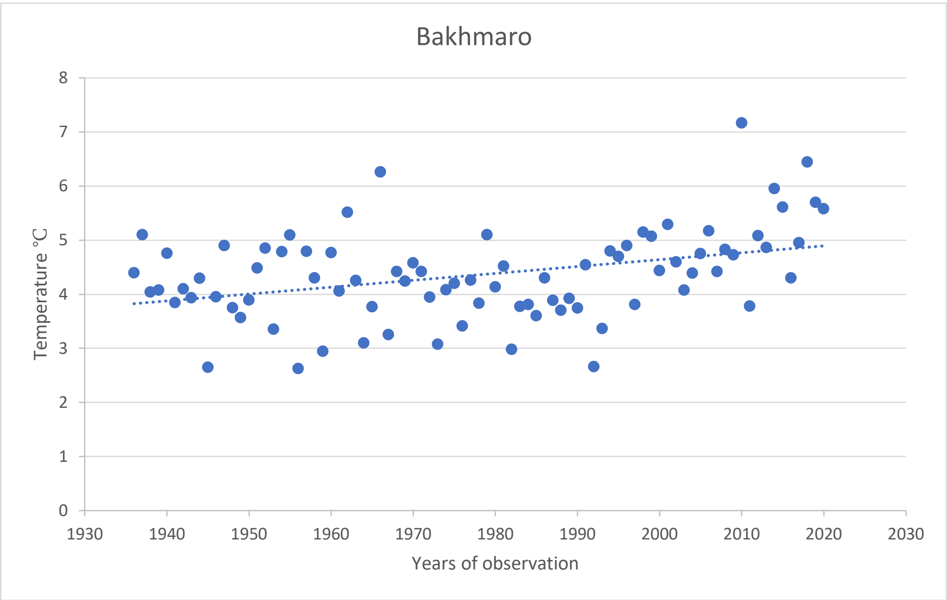
Analysis of the data shows that the average annual temperature is 4.3 ° C. The indicator of the coldest month of the year is -5.13 ° C, while the average perennial temperature of the warmest month of the year is 13.6 ° C (Table # 2)

Table 2 Medium Perennial Temperature (° C) Regime, Bakhmaro Resort, 1936-2020.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Ave.
-5.1	-4.7	-2.0	3.3	7.8	10.9	13.5	13.7	10.3	6.0	1.2	-2.9	4.3

It should be noted that the influence of temperature regime is most visible in the spring (March, April) and autumn (October) months, at which time a high warming tendency is evident. As for the rest of the months, there is a slight increase in temperature in the summer months, and a decrease in the winter months.

Figure 6 Temperature regime (average annual rate) by years and trend line, 1936-2020



Temperature increases in the spring and autumn months affect the formation of snow cover, which directly affects the length of the ski season and the quality of incoming snow.

Based on the objective and better assess the change in temperature, the existent observation data was subdivided into periods of twenty years. As a result, four maps representing the average perennial temperature for twenty years were prepared. The maps include the perennial averages of daily temperatures recorded by the meteorological checkpoint for different years. Twenty years periods include data for 1941-1960, 1961-1980, 1981-2000, 2001-2020.

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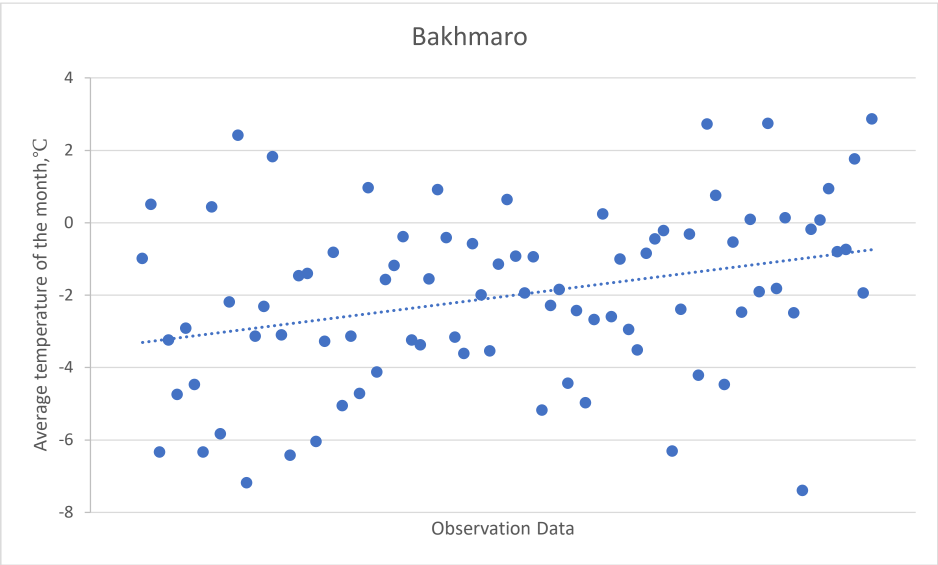
As it is known, the meteorological station was located in the Bakhmaro Resort at 1850 meters above the sea level. Therefore, the temperatures within the catchment area were distributed through interpolation, which isfollowing the rule of the temperature gradient, or applied when the temperature drops by 0.6 degrees per 100 meters. In addition, satellite information was added to the observation data and the existing gap (meteorological station, closed in Bakhmaro Resort in 1992) was supplemented using Meteoblue data.

Figure 7 Average temperature (° C) in March and trend line, 1936-2020



Maps prepared for better representation of temperature regime change are given in Figure 8-11.

Figure 8 Bakhmaro Resort and surrounding area, 1941-60 Average perennial temperature (° C)

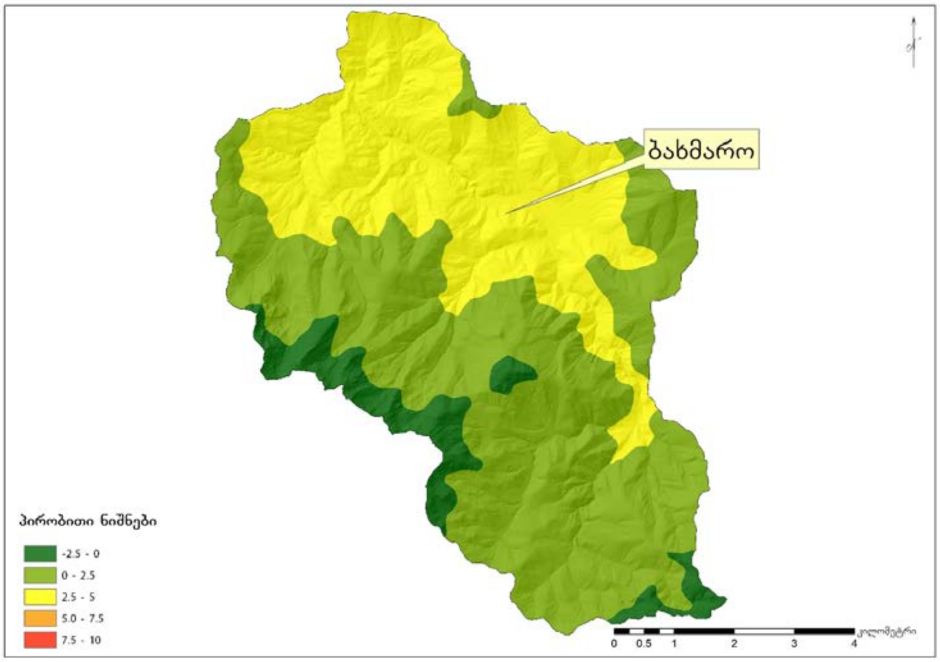


Figure 9 Bakhmaro Resort and Surrounding Area, 1961-80 Average Perennial Temperature (° C)

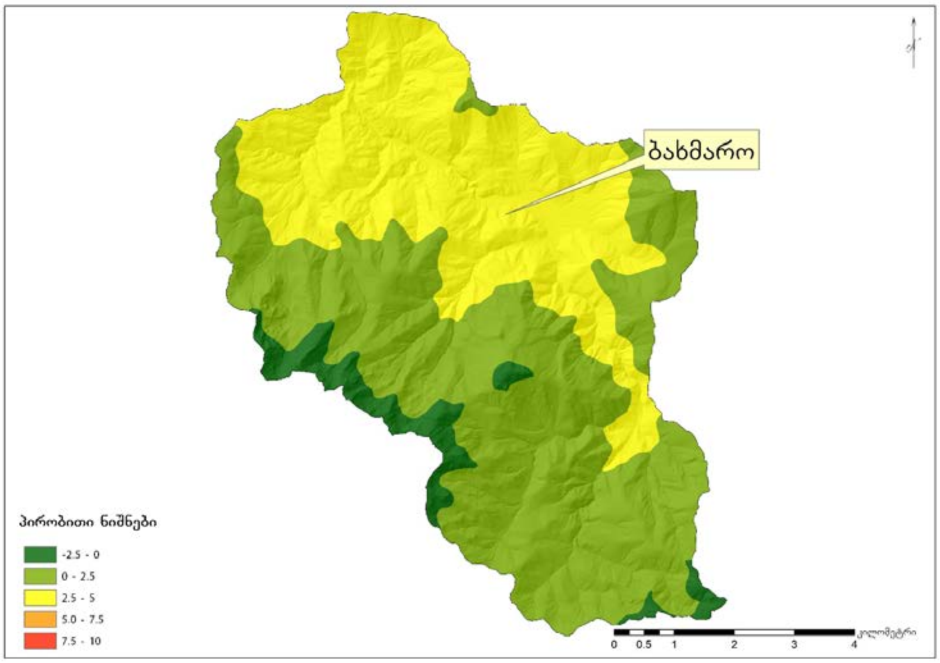


Figure 10 Bakhmaro Resort and surrounding area, 1981-00 Average perennial temperature (° C)

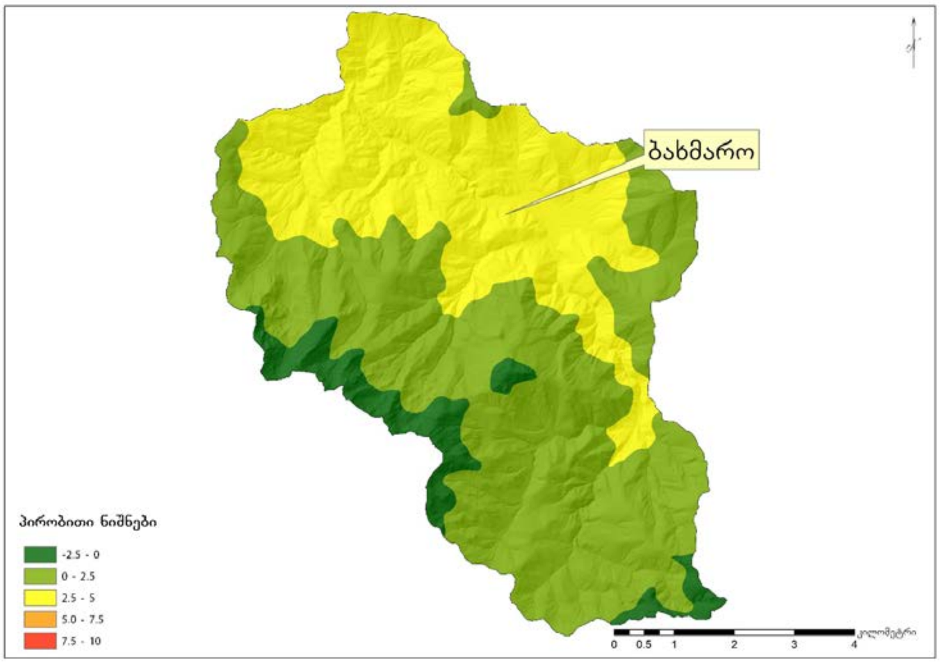
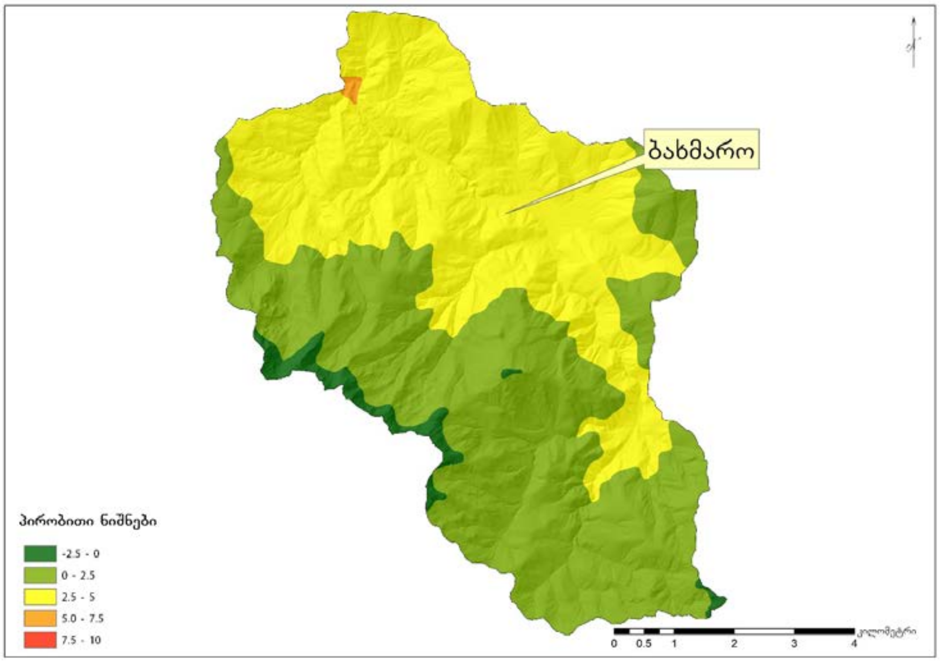


Figure 11 Bakhmaro Resort and Surrounding Area, 2001-20 Average Perennial Temperature (° C)



Analysis of the data shows that the average temperature of the year has increased by about 0.5 ° C over the last twenty years. Despite the change in temperature regime, the highest change compared to the last 80 years is seen in the last 20 years.

This radical difference may be due to the fact that from 2001 to 2020, temperature data were extracted from MeteoBlue databases. But this reasoning is refuted by the data of continuously operating terrestrial meteorological observation stations in a number of cities in Guria, Adjara, Samegrelo and Imereti. Which, like the information used for the resort of Bakhmaro, indicate a significant increase in the average annual temperature, especially in the last 20 years.

Hydrology

Hydrological research has a long history in Georgia. In particular, intensive similar studies have been conducted since the 1950s, during which time the network of observations increased considerably and consequently the monitoring of river runoff expanded. But, as in the case of meteorological stations, hydrological monitoring has ceased on most rivers since the 1990s, and today the monitoring system takes place mainly on large rivers, such as Mtkvari, Aragvi, Alazani, Rioni, Enguri, Supsa, etc. Although the system has improved to some extent in recent years, it still has not been and unfortunately still is not enough today for accurate assessment of river hydrological resources.

The current approaches to determining the average multi-year flow of rivers are based on data from hydrological checkpoints that are scattered throughout the country (major rivers, and in rare cases even first-line tributaries). This approach is known as the "Georgian Water Balance", developed by L. Vladimirov, in the 70s of last century. This approach uses the daily costs of the existing hydrological checkpoints up to 1968 and distributes them on the territory of Georgia by the method of interpolation. Based on the orographic origins of the country, the author of the method divides the country into so-called hydrological areas that coincide with the boundaries of major rivers and their primary tributaries (Figure 12).

Given that this approach is based on data from 1968 onwards, it is quite outdated and fails to reflect the present. The data of the hydrological checkpoint on the river Bakhvitskali is also problematic. Besides the fact that the last measured expense dates back to 1978, the accuracy of the data itself is questionable. For example, in January 1959, the amount of water was steadily 0.104 m3 / s, while meteorological data for the same period changed steadily (Figure 13). A similar situation exists not only during this period, but in fragments throughout the entire time of the observation series. This calls into question the reliability of the data, especially given that a long time has passed since the last measured flow and the impact of climate change is evident in the river valley.

Based on the problems mentioned above, it was decided to prepare hydrological modeling for the assessment of the river hydrological resource, which on the one hand restores the missed period, and on the other hand will allow us to see some impact of climate change.

Figure 12 Hydrological zones, prepared by Vladimirov

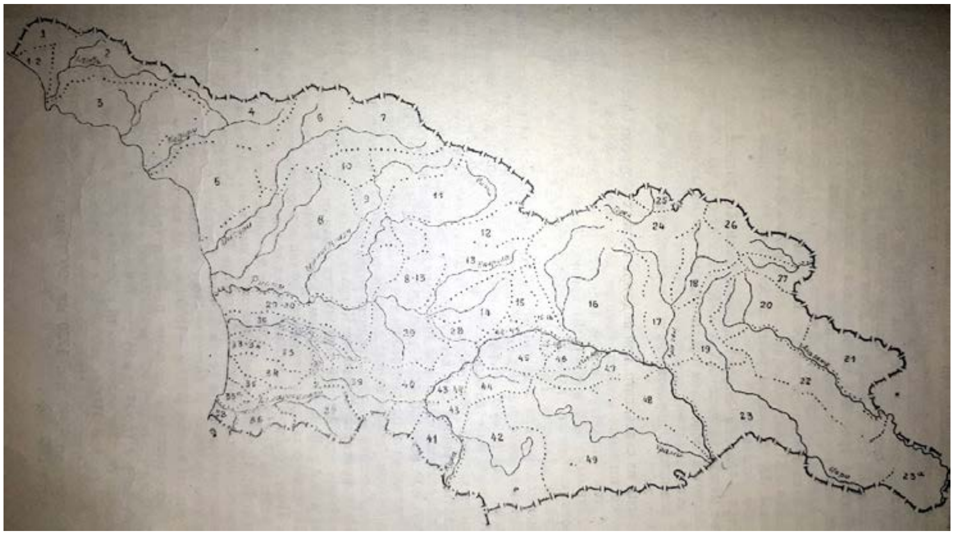
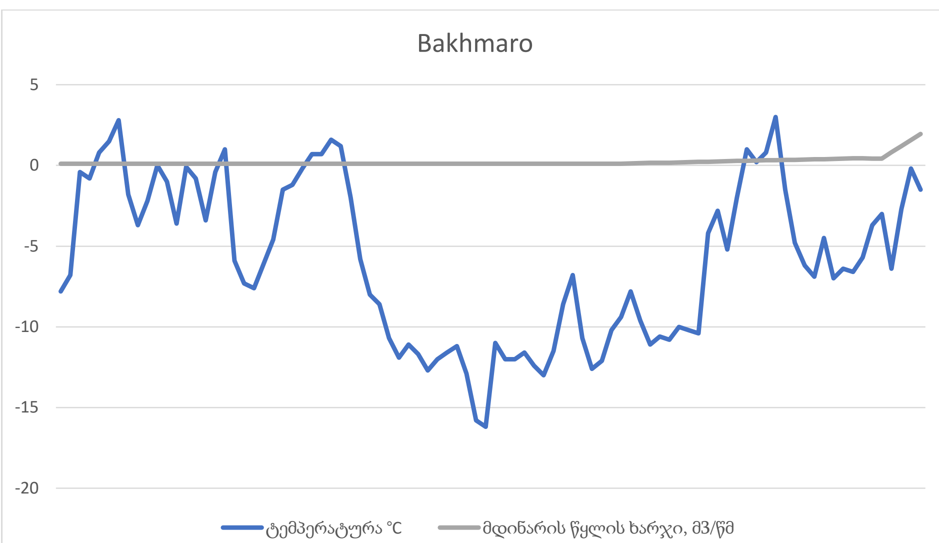
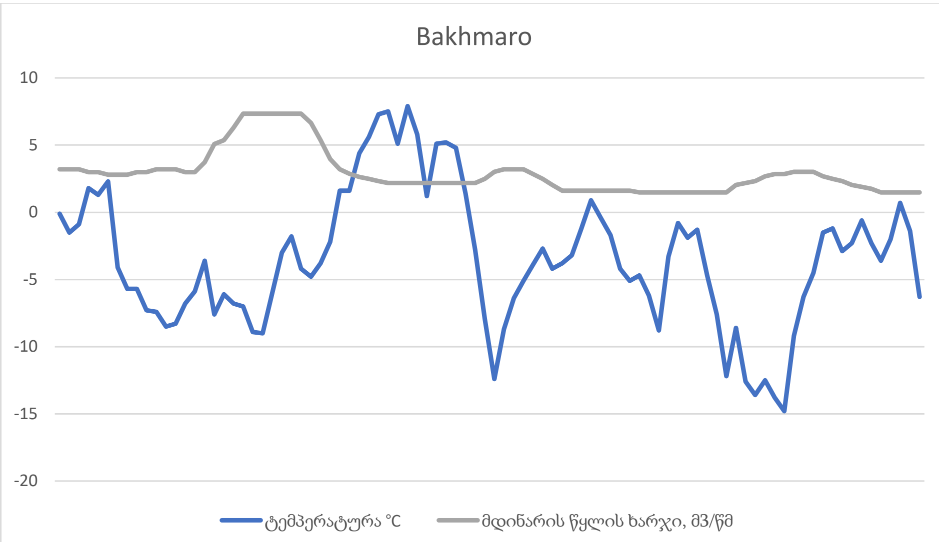


Figure 13 Data from the Meteorological and Hydrological Checkpoints, January-March 1959



In addition, it is also unclear what caused the fairly high rates of river flow during the winter months, when temperatures remained negative (Figure 14).

Figure 14 Meteorological and Hydrological Checkpoint Data, December-February 1970-71



As mentioned above, the hydrological checkpoint on the river Bakhistskali operated (intermittently) from 1947 to 1978, and continuously from 1959 to 1978 (Table 3). The analysis of the data shows that the average multi-year flow of the river at the intersection of the hydrological checkpoint is 1.86 m^3 / s. and the runoff layer per square kilometer is equal to 55.7 l / s.

Table 3 Data of Bakhvistskali River Hydrological Checkpoint, Bakhmaro. m^3/sec

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Ave.
1947	0.75	0.68	1.07	1.97	2.56	1.52	1.07	0.97	1.51	1.79	1.26	0.57	1.31
1949	0.42	0.32	0.35	0.77	5.81	4.14	0.87	0.48	0.59	1.69	0.81	0.42	1.39
1950	0.38	0.32	0.34	3.48	6.77	4.20	1.25	0.90	0.58	1.28	1.65	0.89	1.84
1953	0.45	0.38	0.33	2.03	7.24	5.09	1.47	0.86	0.48	0.68	0.65	0.44	1.67
1955	0.46	0.49	0.90	4.53	6.62	2.61	1.54	1.42	1.36	1.17	1.61	1.28	2.00
1956	1.10	0.99	0.95	2.08	3.97	4.79	2.76	0.67	1.00	1.03	0.98	0.78	1.76
1957	0.51	0.42	0.74	4.67	8.24	5.66	3.56	0.40	0.66	1.58	1.17	1.02	2.39
1959	0.07	0.07	0.30	3.90	9.89	4.88	2.38	0.96	1.86	2.00	1.19	0.57	2.34
1960	0.42	0.47	0.53	3.83	4.81	3.84	1.14	0.62	0.41	0.43	0.43	0.43	1.45
1961	0.42	0.42	0.42	2.12	12.25	4.02	1.30	0.50	1.13	0.89	0.93	1.17	2.13

1962	0.61	0.55	0.67	1.74	5.06	2.90	1.08	0.62	1.59	1.58	1.12	0.69	1.52
1963	0.60	0.54	0.56	1.34	3.07	3.15	1.64	1.70	0.61	0.90	1.23	0.94	1.36
1964	0.98	0.89	0.79	1.75	5.80	3.25	1.46	1.12	0.79	1.15	0.79	0.70	1.62
1965	0.51	0.29	0.63	1.65	4.42	4.03	1.50	0.56	0.45	0.70	0.72	0.58	1.34
1966	0.45	0.46	1.02	2.65	3.02	2.28	1.28	0.90	0.68	0.42	0.33	0.35	1.15
1967	0.25	0.22	0.24	1.02	5.57	5.52	4.06	3.43	1.70	0.85	0.65	0.62	2.01
1968	0.58	0.58	0.57	3.94	7.05	4.13	2.89	1.92	1.40	1.32	1.15	1.09	2.22
1969	0.97	0.92	1.06	2.31	4.48	2.53	1.15	1.05	1.06	1.71	1.20	1.26	1.64
1970	1.21	1.10	1.31	4.51	8.54	5.81	3.32	2.52	2.50	3.26	2.85	3.10	3.34
1971	1.50	1.39	1.24	2.96	12.96	7.91	3.22	3.20	0.91	1.26	1.43	1.03	3.25
1972	0.56	0.39	0.33	5.01	5.18	4.71	1.76	1.26	0.71	0.69	1.15	1.05	1.90
1973	0.77	0.56	0.57	1.41	4.84	2.10	1.72	1.15	0.63	0.53	0.87	0.79	1.33
1974	0.46	0.36	0.86	0.94	4.90	2.35	0.77	0.90	0.83	0.65	0.64	0.52	1.18
1975	0.58	0.52	0.59	6.60	7.82	7.64	3.44	1.74	0.86	0.51	0.35	0.30	2.58
1976	0.23	0.20	0.41	1.75	3.84	3.26	2.33	1.43	1.73	2.05	0.72	0.32	1.52
1977	0.26	0.29	0.42	1.69	2.55	1.41	0.75	1.00	1.28	1.21	0.99	1.05	1.08
1978	0.86	0.85	0.84	1.41	4.16	5.26	4.24	3.44	3.05	3.69	3.86	2.46	2.84
საშ.	0.61	0.54	0.67	2.67	5.98	4.04	2.00	1.32	1.12	1.30	1.14	0.90	1.86

It is noteworthy that within the project, hydrological parameters were processed at the lower boundary of the Bakhmaro recreation area, so river flows were determined using the transfer coefficient for the selected intersection. Therefore, at the selected intersection, the average multi-year flow of the river was set at 2.75 m^3 / s instead of 1.86 m^3 / s.

As of today, there is no hydrological observation post in the valley (closed in 1978), neither meteorological gauge (closed in 1993), nor hydrological modeling calibration and its validity is difficult to verify. Because, on the one hand, we have unreliable hydrological data and on the other hand satellite data is available only from 1981. It is therefore essential that significant infrastructural measures be preceded by several years of high-quality hydrological monitoring and full-fledged monitoring of both the hydrological part and the climate, soil and vegetation cover.

Hydrological modeling

Hydrological modeling is based, both on historical data, mainly precipitation and temperature indicators, and on various parameters that ensure the conservation and redistribution of water resources in river valleys, including important parameters such as soil, vegetation, slope exposure, slope inclination, temperature, etc.

Hydrological modeling is based on an approach that can be used to convert atmospheric precipitation at the expense of the river and to redistribute it over time. Therefore, when building a model, great attention is paid to the various parameters and their accuracy. Accordingly, it can be said that the accuracy of the results obtained from hydrological modelers is 100% dependent on the correctness of the parameters included in it.

The initial stage of modeling is the processing of relevant data in the geoinformation system, during which the boundaries of the river catchment area and its area are determined / specified. The next step is to divide the selected section into sub-pools at which time it is necessary to take into account the orography of the place. The need for subdivision is essential to increase the reliability of the model and the results obtained from it, as it is not a homogeneous structure and the water formed in it is related to different constituents. Including primarily the hypsometric height and the corresponding temperature regime which lead to the formation of various characteristics. Among them, it should be noted that the presence and condition of soil and vegetation, in this or that type of catchment is directly related to the measured hypsometric characteristics and temperature regime. Furthermore, the physical composition of the soil and the structure of the vegetation cover the distribution of water resources in the river. In particular, the subsurface is responsible for the speed and amount of water moving in the river valley. It is therefore necessary to divide the catchment area into small sub-basins within which the conditions are more or less similar (Figure 15).

Figure 15 Factors affecting the hydrological regime

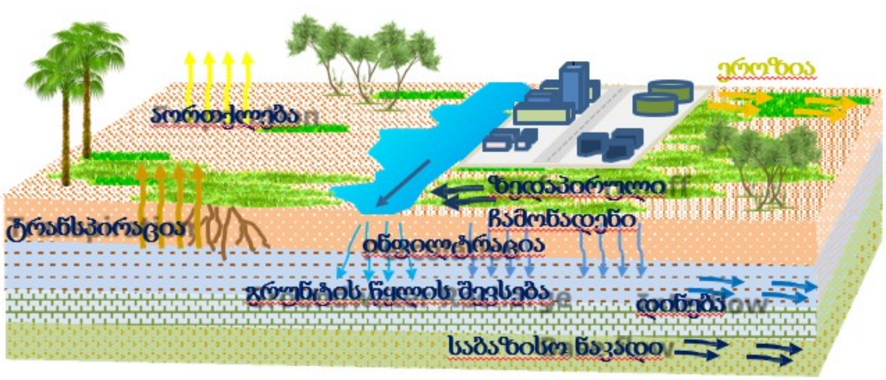
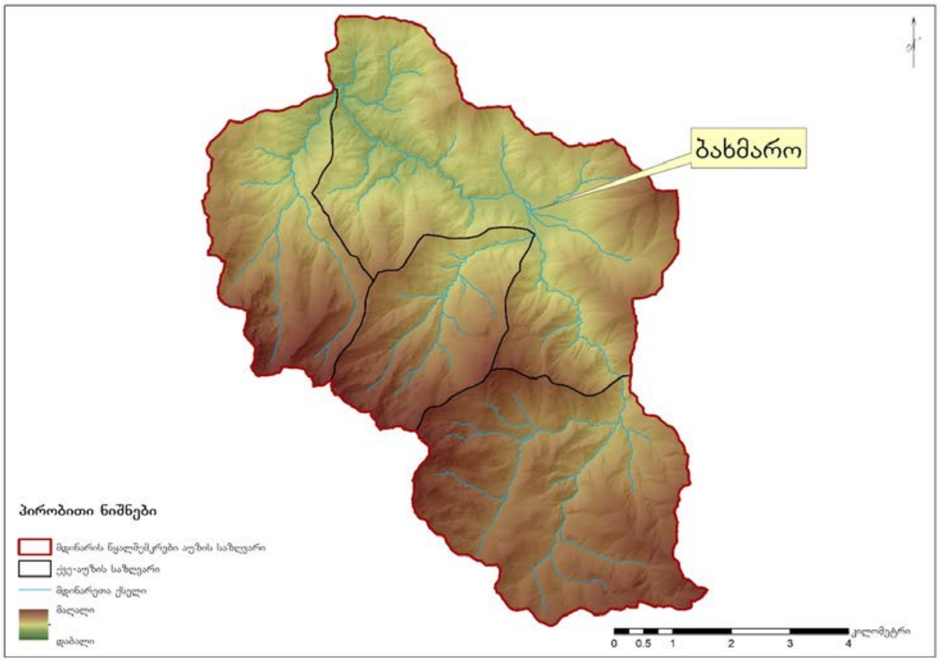


Figure 16 Bakhvitskali River catchment area

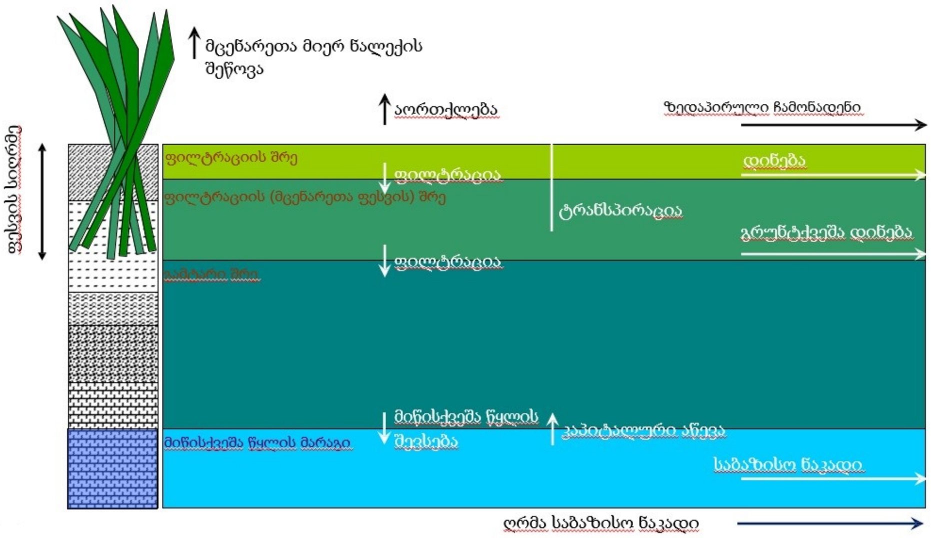


Based on the small area of the catchment area, the Bakhmaro Resort and the surrounding area were divided into four small sub-basins and appropriate parameters were prepared for hydrological modeling.

The vegetation areas and their types were first assessed. Soil maps and their physical composition according to horizons were also developed, as well as the exposure, average height, inclination, etc. As a result of data processing, a model based on TalsimNG was developed for hydrological modeling by sydro.

The working principle of TalsimNG is very similar to HEC-HMS, which is also based on the calculation of river runoff from precipitation and uses identical data. The difference is that the model created by Sydro is much more stable, especially when it comes to processing large amounts of information. This model is also used to manage and forecast hydrological resources and has been tested on many types of rivers, including in Georgia.

Figure 17 Soil and vegetation structure. Their influence on the formation of river runoff



The great influence on the formation of river runoff is well manifested when dealing with the calculation of maximum and minimum discharge. In other words, it directly depends on the physical composition of the soil and the vegetation during the rainy season. Maximum amount of water and minimum runoff during drought.

Typically, a raindrop travels a rather difficult path before it hits a riverbed (Figure 16). Therefore, for the stability of the model and the maximum accuracy of the results, it is necessary to thoroughly process the mentioned data and accurately determine the relevant parameters.

Table 4 Classification characteristics of land use for Guria region

Features	
Agricultural lands: sown crops	
Row crops (vineyard, orchard)	
Pastures	In poor condition
	In good condition
Mowing / meadow in good condition	
Forest	Heavily degraded
	Rare forest
	Dense

Open spaces:	
In good condition, with grass cover> 75%	
In fairly good condition with grass cover 50 - 75%	
Shrub with grass	In poor condition
	In good condition
Building roofs with waterproof surface 85%	
Industrial sites: with waterproof surface 72%	
Settlements:	
Average area	% Waterproof area
500 m^2	65
1000 m^2	38
1300 m^2	30
2000 m^2	25
4000 m^2	20
Concrete-asphalt pavement, curbs and drains	
Gravel	
Crushed stone	

After classifying soil and land use, the main focus is on processing existing data on precipitation and temperature. Since, no hydrometeorological observations are carried out in Bakhmaro and the surrounding area, the model requires the use of satellite (precipitation and temperature) data and its validation, so the satellite data was processed and corrected by the Bias-correction method to obtain proper results. This approach involves the correction of data according to the interdependence of terrestrial observation and satellite information. For this, it is necessary to find the same uniform period of observation between the satellite information and the data of the meteorological station. Because the ground meteorological station was operational until 1992, and satellite measurements began in 1981 this period is used to verify the data.

Figure 18 Interrelation of meteorological station data and satellite information to Bias-correction

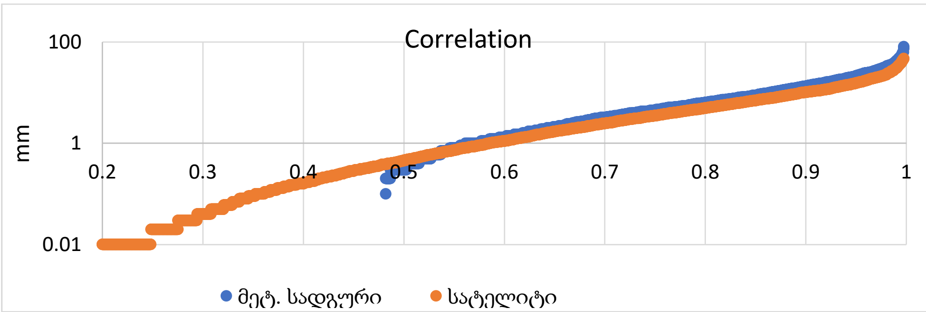
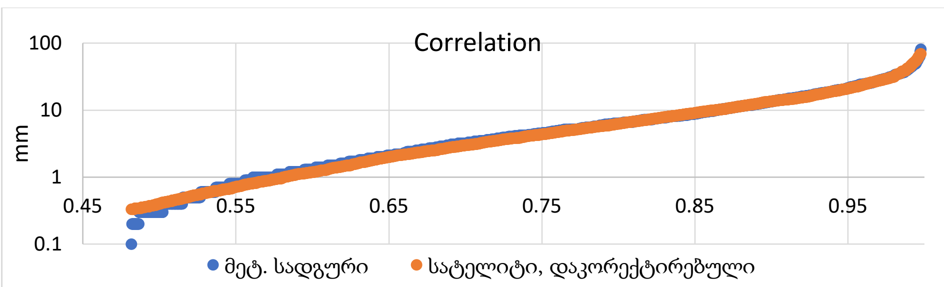


Figure 19 Correlation between meteorological station data and satellite information after Bias-correction



It should be noted that despite the high quality of the correction, it is difficult to say that the data processed by this method restores the climatic data from 1992 to the present with absolute accuracy, as the data used to correct satellite information includes only information from 1981 to 1992. In addition, it should be noted that a similar approach, like almost all scientific methods, has its limitations.[1].

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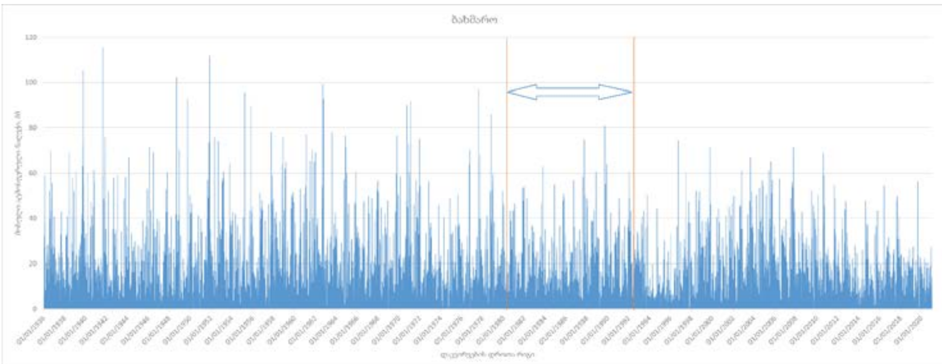
[1] Cannon, Sobie, & Murdock, 2015

Figure 20 Atmospheric precipitation, Bakhmaro, 1936-2020



As can be seen in Figure 20, the Bias-correction was prepared using a fairly small stretch of time. Accordingly, the period after 1992 is completely restored using satellite data. It should also be noted that the adjusted period more or less repeats the maximum and minimum limits of the interval at which the interval was corrected. This is why the peak precipitation in the data restored according to satellite data for the last 30 years does not exceed the peak rate of 1981-1992, while in the whole previous period there are numerous cases when the amount of precipitation in 24 hours exceeds 80 mm and sometimes 100 mm. Even. Nevertheless, the data between the maximum and minimum limits show well the general trend of the climate. Interestingly, according to these indicators, the driest period is also evident, that the driest period, from 1936 to the present is 1996, which is also confirmed by data from other terrestrial meteorological stations in the region. For example, in 1996, the rainfall at the resort Goderdzi was about 750 mm, while the multi-year average was 1200 mm, and in the town of Chokhatauri about 1050 mm (the multi-year average is about 1700 mm). The readings of the same year for the Bakhmaro Resort is 968 mm, so it can be boldly said that the precipitation indicator reflects to some extent and is not very far from the reality.

After processing the data, at the last stage of hydrological modeling, for the selected intersection, using the collected hydrometeorological data, the average multi-year flow of the river was calculated and the hydrological checkpoint data were extended.

Due to the fact that the quality of the hydrological checkpoint data is questionable, the calibration of the modeled costs was considered inappropriate. In this way, in addition to avoiding further distortion of meteorological parameters, we have the opportunity to see the impact of precipitation and temperature regime on the catchment. It should also be noted that when the reliability of hydrological checkpoint data is questionable, it is best for the model to rely on environmental conditions and relevant determinants such as soil, slope, exposure, precipitation, etc.

After data processing (Figure 21), the average multi-year flow of the Bakhvitskali River was calculated for the selected intersection, which is 1.93 m3 / s according to the modeled flow and 2.74 m3 / s according to the observation data. Floodless periods coincide with the temperature regime caused by snowmelt. There are two water short periods in the valley, winter (January-February) and summer-autumn (August-September).

Figure 21 Hydrological modeling results and H/ S Bakhmaro data for the selected section, 1959-2020.

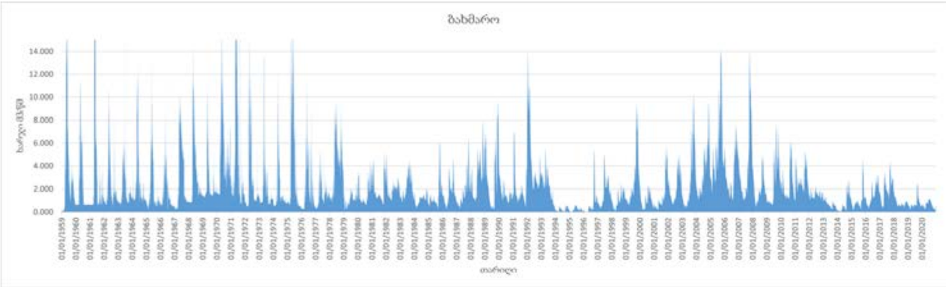
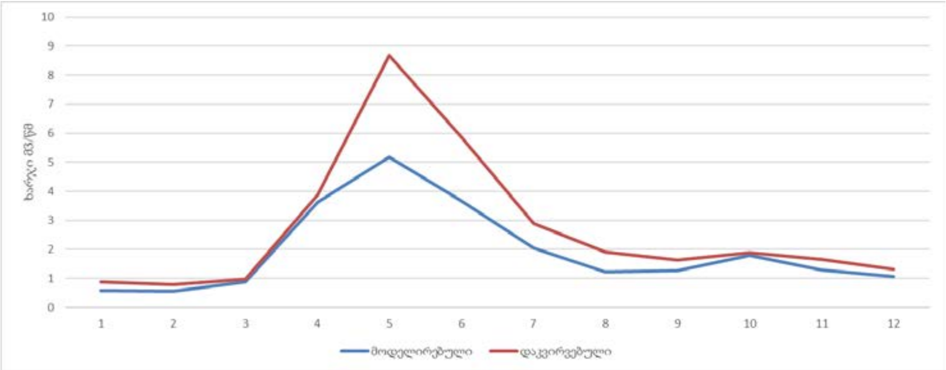


Figure 22 Average perennial flow at selected intersection of the Bakhvitskali River



Fieldwork and snow stakeout

The fieldwork aimed to gather a variety of information including snow cover stakeout and drinking water supply, given in the Bakhmaro Development Plan[2], assess the reliability of the information, and find alternative ways.

Snow stakeout works

Snow cover stakeout work carried out in the Bakhvitskali River basin is regulated by the principle of zoning 1800-2200 m. Snow cover routine stakeout is carried out by the field-expedition method adopted to date. The survey was conducted in March (usually 1-15 meters of snow route planning is carried out in Georgia).

During the research, points were selected according to the height zonation, the difference of which is 100 meters. The snow cover at the snow point was protected from both overturned and wind-reduced snow. At each point in the study area, the entire depth of the snow cover was taken with a density measuring tool. In the case of strong and dense snow cover, a shovel is removed, which facilitates the work of the measuring tool and the determination of the snow structure. According to the measured materials, the water content of the snow layer was determined, which was reflected in the field materials and is presented in the form of a total table.

Atmospheric precipitation in the river Bakhvistskali basin (snow stock accumulated during the winter) plays an important role in the formation of the river hydrological regime.

The main task of studying the snow cover is to determine the thickness, density and water content of its layer. To determine the snow stock, snow is observed and measured. Introduced in the 90s of the last century, the study of snow cover by remote methods includes: 1) aerial photography, 2) aerovisual assessment, 3) aerovisual assessment. The latter method is carried out by means of aerial and meteorological satellites.

When studying snow cover, three main methods are used: 1. Measurement of snow cover by means of a precipitation gauge, 2. Permanent snow gauge on the ground by means of a surveyor's rod, and 3. Snow route stakeout.

1. Snow cover measurement is performed by precipitation meter at all meteorological stations. The height of the water layer corresponding to the amount of incoming snow is determined by melting the snow in the sediment meter at room temperature and measuring the height of the resulting water layer.
2. Snow gauges are used to systematically measure snow height in centimeters at meteorological stations, and snow density is measured by station snow gauges.

[2] http://bakhmaro.info/

3. Snow measurement stakeout provides more accurate data in different terrain conditions. During the snow stakeout, surveys were conducted at pre-defined points in the Bakhvitskali River basin. The points in the office studies were selected by analyzing large-scale maps, 1: 25 000 - 1:50 000 topographic arcs, aerial photographs of different years.

Under field conditions, the snow cover water level of the study area was determined with an instrument, which is a metal cylinder, each part of which corresponds to 5 grams or 5 cm3. The cross-sectional area of the metal cylinder is 50 cm2. One end of the cylinder is closed with a valve, the other end is open. The outside of the cylinder is marked with a scale every one centimeter. When taking a snow sample, a metal cylinder with an open end was screwed into the snow before the soil boundary. To determine the height of the snow, the counter was taken on a cylinder and the weight of the snow was determined using a special scale.

Snow density is calculated by the formula

$$p = \frac{5n}{50h} = \frac{n}{10h}$$

Where, n are divisions in grams, h is the height of the snow cover in cm which is calculated per cylinder. Therefore, the formula for determining the density of snow cover finally looks like this

$$p = \frac{n}{10h}$$

To determine the water content of a snow cover, the density of the snow cover is multiplied by its height.

Because the density of the snow cover is measured in mm and the height in centimeters, the final result is multiplied by 10. The height of the water layer in the snow cover is denoted by S. respectively S = 10hp

from where,

$$p = \frac{S}{10h}$$

If we compare formulas 2 and 3, it will be found that the scale observation n, which is obtained during the weighing of the snow sample, expresses the water supply in the snow cover in mm. therefore

$$\frac{n}{10h} = \frac{S}{10h}$$

this is the same as n=S.

Also, during the snow cover survey, the average height of the snow cover, the average density, the average water supply in the snow were determined.

Snow cover stakeout results

During the field work, the density of the snow cover, the average, maximum, minimum height and water content of the snow cover were measured.

Table 6 provides information on the number of snow cover height density measurements on slopes of different exposures and hypsometry.

Table 5 Total number of snow cover measurement

Id	X	Y	Elevation
1	277671	4636300	1810
2	278328	4636378	1850
3	278855	4636191	1850
4	279484	4635854	1900
5	278009	4636653	1900
6	279843	4635586	1950
7	278064	4637130	1950
8	278234	4637705	2000
9	279987	4635466	2000
10	280096	4635379	2028
11	278739	4637318	2050
12	279576	4637208	2088
13	279879	4637137	2100
14	280533	4635403	2107
15	280813	4635305	2150

Table N6 provides information on the snow stakeout table for the Bakhmaro area at an altitude of 1800-2200 meters.

Table 6 Snow cover measurement data

Id	X	Y	Altitude above sea level	Surveyor rod height	Measurement of snow cover			
					Height density on the measuring cylinder	Weight with scale lever partitions	Density g / cm3	Water content, mm
1	2	3	4	5	6	7	8	9
1	277671	4636300	1810	109	108	346	0.32	349
2	278328	4636378	1850	114	114	353	0.31	353
3	278855	4636191	1850	116	113	350	0.31	360
4	279484	4635854	1900	125	125	363	0.29	363
5	278009	4636653	1900	120	120	336	0.28	336
6	279843	4635586	1950	121	120	300	0.25	351
7	278064	4637130	1950	117	117	339	0.29	339
8	278234	4637705	2000	129	128	358	0.28	361
9	279987	4635466	2000	131	129	374	0.29	380
10	280096	4635379	2028	133	133	306	0.23	306
11	278739	4637318	2050	139	139	375	0.27	375
12	279576	4637208	2088	142	142	383	0.27	383
13	279879	4637137	2100	161	160	435	0.27	435
14	280533	4635403	2107	170	170	442	0.26	442
15	280813	4635305	2150	180	180	471	0.26	471

Table N7 provides information on the total snow stakeout table for the Bakhmaro area at an altitude of 1800-2200 meters.

Table 7 Average information of snow cover

Snow stakeout total table							
N	Height	The amount of snow height density measurement	Snow cover height, cm			Average density, g / cm3	Average water content , mm
			average	Biggest	smallest		
1	2	3	4	5	6	7	8
1	1800-1900	3	113	115	109	0.31	350
2	1900-2000	4	121	125	117	0.28	339
3	2000-2100	5	135	142	129	0.27	366
4	2100-2200	3	170	198	161	0.26	442

Based on snow stakeout materials conducted in March 2021 (1800-2200 m), it was determined that the average height of snow cover for the entire study area was 135 cm for snowmaking in Bakhmaro Resort (locking section X-277771 Y-4636300 Z-1810). The average density is 0.28 g / cm 3. The water supply in the snow cover was 378 mm, ie. Over the entire area of the catchment area (study area - F = 34.5 km2), 34 500 000 m2 of water accumulated in the form of snow 378 mm, or 0.378 m. Considering the above parameters, the volume of melt water is equal to 13 041 000 m3

Figure 23 Field measurement

Drinking water supply network

The current situation and possible solutions are described and given in the Bakhmaro Recreational Land Master Plan. According to the data, on October 1-2, 2016, potential sites that can be used for the arrangement of a drinking water supply system were explored. A total of 10 springs and one well were debited at that time (Table 8. According to the total data, it is possible to collect 20.2 liters of water per second and deliver it to the customer

Table 8 explored sources and their debit as of October 1-2, 2016

№	X	Y	Q
source №1	277613	4637470	0.3 l/sec
Source №2	277579	4637595	0.5 l/sec
Source №3	277625	4637512	0.5 l/sec
Source №4	278033	4637470	5.0 l/sec
Source №5	278033	4637470	0.5 l/sec
Source №6	279790	4636123	0.5 l/sec
Source №7	279790	4636123	0.5 l/sec
Source №8	279765	4636083	2.0 l/sec
Source №1g	281050	4634323	5.0 l/sec
Source №2g	281039	4634295	5.0 l/sec
Borehole 1	278645	4636080	0.4 l/sec

In order to verify the information given in the above document, during the snow stakeout, the indicated sources were verified in parallel by using the relevant coordinates and surveying the local population. Most of the sites visited during the survey were arid, indicating that the source outlets are actually surface groundwater, which is why water does not actually flow during the winter. In addition, the vast majority of the selected sites are located on the southern slopes, which typically receive more solar radiation than the northern slopes, hence the high rate of evaporation and transpiration by plants. It is therefore unlikely that the above sources are consistent, as confirmed by a local population survey. The second problem has to do with the amount of water and the date the photos were taken. In the first case, the method of measuring water is not given, by which the researcher determined the source debit. It is also not given what objective circumstances allowed them to make the assumption that they had established the permanence of the source debit, except that the locals were interviewed. The springs marked during the survey in March 2021 were dry (due to low temperatures, which is a common occurrence during the winter). Also inconsistent and questionable are the photos posted on the website, as an aerial photograph taken by landsat 8, dated 2 October 2016, clearly shows that there is snow cover in Bakhmaro and the surrounding area. Which means the previous period was a rainy period and it may have temporarily increased water expenditures.

Figure 24 aerial photograph taken by Landsat 8, October 2, 20216

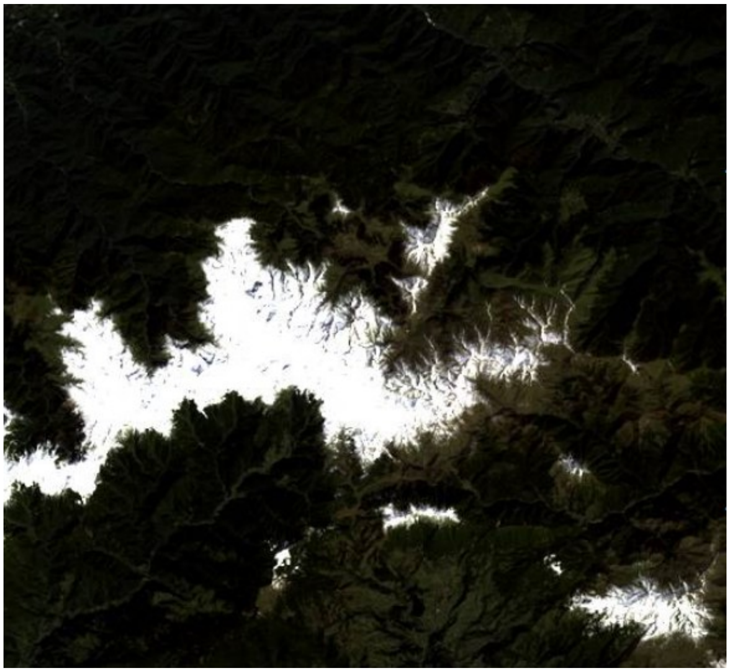


Figure 25 Photographs given in the Comprehensive planning report, 1-2 October 2016

Impact of climate change

The impact of climate change is evident in Bakhmaro and the surrounding area. Especially the temperature regime, which has a great influence on the hydrological characteristics, including the seasonality of runoff, snow cover, floods, minimum runoff. Therefore, in order to better present the results, this chapter discusses climatic parameters, snow cover and hydrology in the relevant chapters.

Statistical analysis and impact on precipitation and temperature

The data on temperature and precipitation used are of two types: measured by a meteorological station (1936-1992) and recorded by satellite (1981-2019).

The data recorded at the meteorological station include the daily results of the observations from January 1, 1936 to February 28, 2011, although some day data are incomplete. This is the total number of 2140 days in different years (1993, 1994, 1995, 1996, 1997, 1998, 2000, 2007, 2008, 2009). In total, the total database includes 27,453 days of data, including flawed data. The average, minimum and maximum temperatures of the day, as well as precipitation were measured daily at these meteorological stations.

Satellite data covers the total amount of precipitation each month from January 1981 to December 2019.

Objective

The objective of the conducted analysis and modeling on the meteorological parameters of Bakhmaro is:

1. Creation of linear regression model that shows the dependence of satellite data on meteorological station data.
2. Using the created model, assumtion of what precipitation rates would have been recorded at the meteorological station from 2011 to December 2019.
3. Establishment of a multi-year trend of temperature variability.
4. Determination of whether there is a statistical difference between the 10-year groups of temperature data.
5. Establishment of a multi-year trend of precipitation variability.
6. Determination of whether there is a statistical difference between the 10-year precipitation data groups.

Data for analysis was prepared for various statistical operations using data already available in Microsoft Excelჰ

Correlation and regression analysis was performed using statistical programming language_R. Also, analysis of variance and other statistical operations were done with the help of the same software language.

Before performing the correlation test, I checked the variables on a normality test that shows whether the values of the variable are normally distributed. According to the normality test, the values of none of the variables were normally distributed. Accordingly, for the correlation test, I chose the Spearman method, which is a nonparametric correlation test.

Table 9 The results of the correlation test

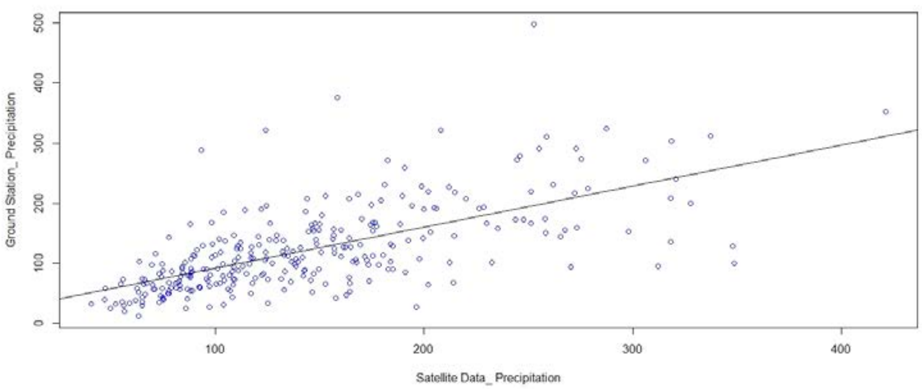
	Average.of.Tmean	Max.of.Tmax	Min.of.Tmin	Average.of.Tmax	Average.of.Tmin	Sum.of.PRCP	SAT_PRCP
Average.of.Tmean	1.0000000	0.94591198	0.96060695	0.9963336	0.9976225	-0.12134635	-0.2638032
Max.of.Tmax		1.00000000	0.89262335	0.9495248	0.9399843	-0.08865107	-0.2317101
Min.of.Tmin			1.00000000	0.9495078	0.9667435	-0.09592288	-0.2306321
Average.of.Tmax				1.00000000	0.9898486	-0.12944539	0.2838449
Average.of.Tmin					1.00000000	-0.11316852	-0.2450855
Sum.of.PRCP						1.00000000	0.6906831
SAT_PRCP							1.00000000

The correlation test determines that the correlation between the temperature readings is close to 1. As for the variables of interest for regression analysis (total precipitation rates measured by meteorological station and satellite), they are statistically reliable (p-value <2.2e-16) and high (0.6906831).

As a result of the regression analysis, we obtained a linear function that shows how to determine the total value of precipitation recorded at a meteorological station, the total value of precipitation measured by satellite.

$Y = 0.68251X + 23.45063$, where X is the total value of precipitation measured by satellite, and Y is the total value of precipitation recorded at the meteorological station.

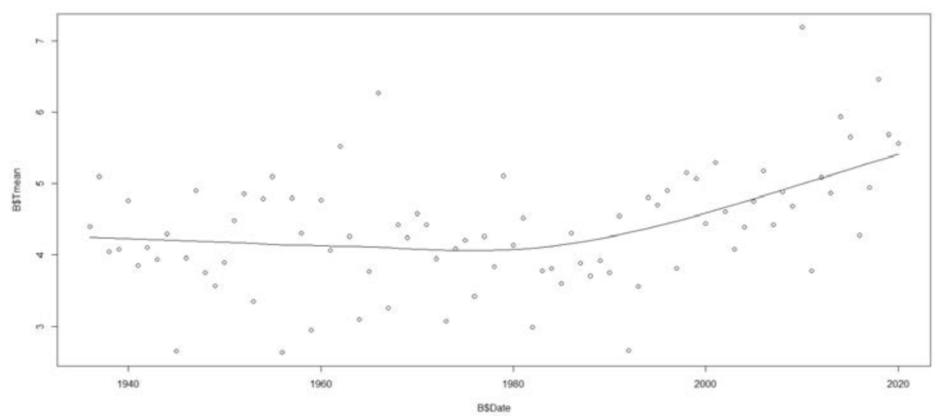
Figure 26 Graph of the dependence of the precipitation indicators measured by the satellite and recorded at the meteorological station and the linear regression line drawn on it



Based on the satellite data with this linear function, I assumed the total value of precipitation from 1981 to 2019 for the months in which no data is found at the meteorological station.

Multi-year temperature trend and analysis of variance for 10-year temperature groups

Figure 27 Perennial temperature trend

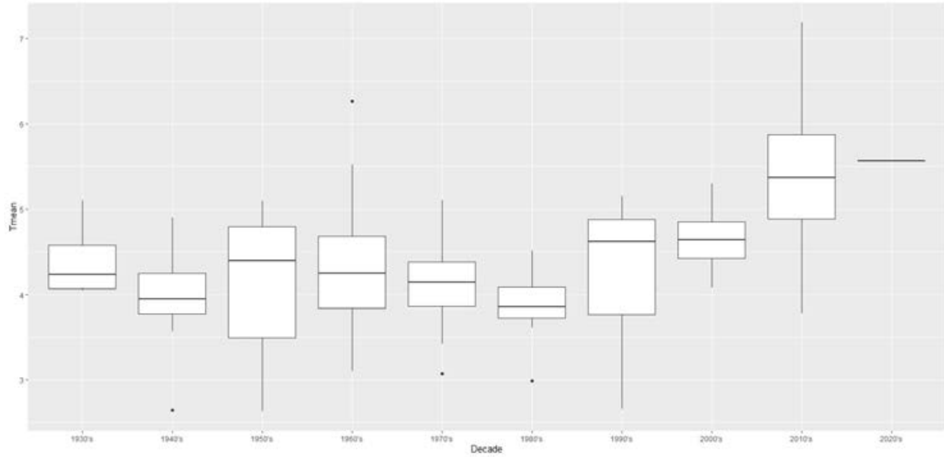


The multi-year trend in temperature shown in the graph shows the increase in temperature since the 1980s.

I used analysis of variance (ANOVA test) to determine the differences between the groups divided by the annual average temperature, which showed whether the mentioned temperature data differed by the decades and whether this difference was statistically significant.

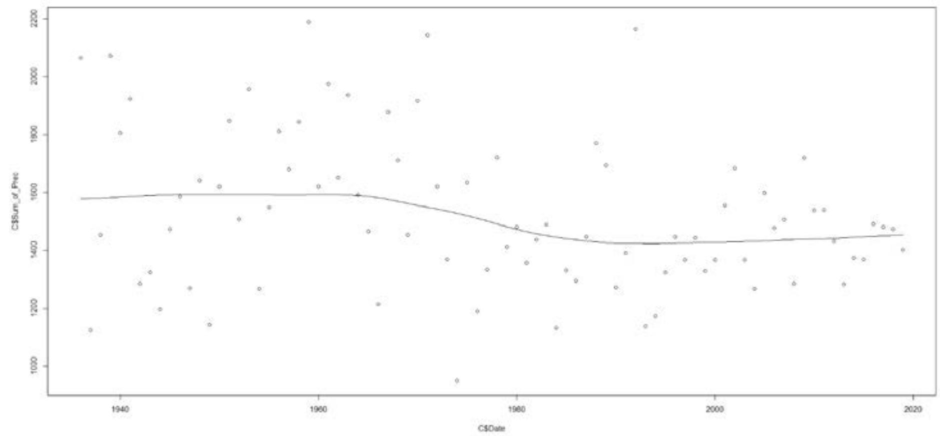
As a result of Anova, it was found that the average annual temperature values differ by decades (reliability coefficient - 0.000602).

Figure 28 Box graph showing the frequency of average annual temperature readings by decades.



Multi-year precipitation trend and analysis of variance for 10-year precipitation groups

Figure 29 Multi-year precipitation trend

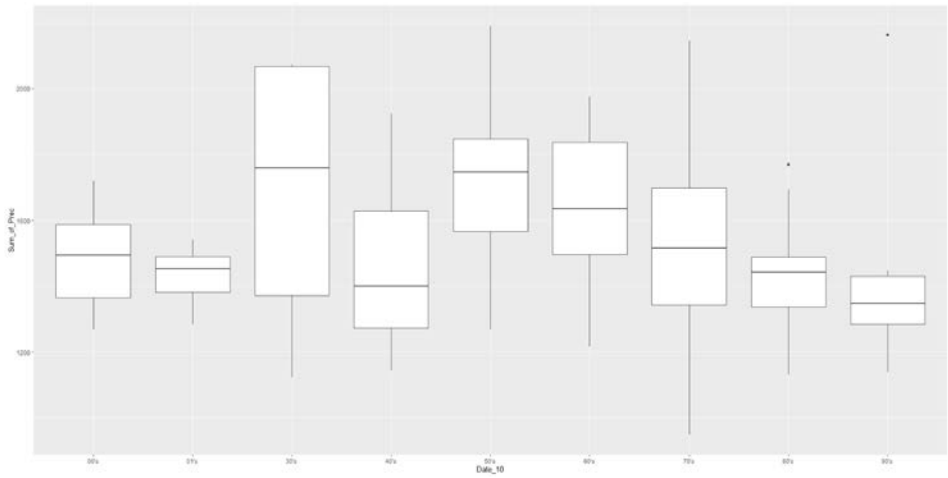


The values on the graph of the annual total precipitation values are the data recorded at the meteorological station until 2011 and the estimated values after the regression model after 2011. The graph shows that the precipitation data for 1990, and especially for the following period of 2011 are concentrated relative to the curve, before that it was quite scattered from the curve. This can be explained by the fact that 18 years after 1990 (1993, 1994, 1995, 1996, 1997, 1998, 2000, 2007, 2008, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018) the data partially or completely represent modelled data, which may be the reason for concentrating this data with the curve.

Analysis of variance used to determine the difference between precipitation data in groups according to decades was shown to be more or less reliable (reliability coefficient - 0.0684).

The frequencies of total precipitation rates by decades are presented in Fig. 30.

Figure 30 Bar graph showing the frequency of annual total precipitation rates by decades.



Based on multi-year data on temperature and precipitation in Bakhmaro, a linear regression model was developed to fill in the precipitation data for a period of time that was incompletely or not recorded at the meteorological station.

The increase in average annual values of temperature has been observed in the perennial variability of temperature since the 1980s. The average annual values of temperature differ statistically significantly between decades.

No significant perennial variability was observed according to the annual total values of precipitation. The lowest precipitation is recorded in the last four decades (1980s, 1990s, 2000s and 2010s), although at the same time the data in these decades is concentrated with average value, which can be explained by the fact that most of the data in these decades is due to linear regression.

Impact on snow cover

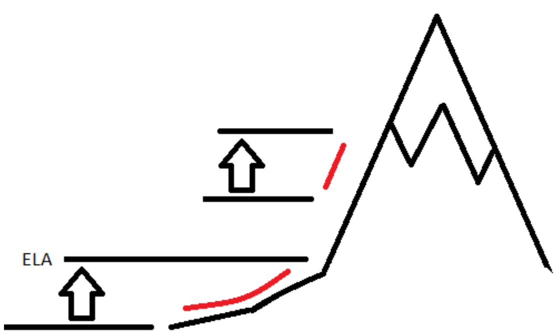
Two types of data are used to estimate the impact of climate change on snow cover. The first is obtained by analyzing satellite data to estimate the estimated change in area. And the second is the snow stakeout materials provided by the National Environment Agency.

Satellite images

To conduct an assessment regarding climate impact before the Bakhmaro resort will be built, it is essential to have a deeper look at trends in snow during the past 30 years. According to IPCC (Pörtner et al., 2019), there is a strong correlation between climate change and snow melt (both in area and depth); thus, we want to assess what are the immediate effects of climate change for the ski resort in Bakhmaro and more broadly speaking for western Georgia. Glaciers are often a good evidence for climate change and many glaciers have been found to retreat during recent years. This is materialized on the field by the retreat of their ELA (Equilibrium-Line Altitude), which is the fictive boundary between where accumulation is dominant and where ablation is dominant. Regarding snow, studies in India (Ali, et al. 2020) have found similar trends regarding snow areas throughout recent years as well as more frequent drought in non-glaciated and non-snowy area. However, climate "warming" is more complex and non-unidirectional findings regarding its complex effects have been gathered. Some Norwegian glaciers (in maritime context) are an evidence for increased accumulation in winter due to stronger evaporation and low enough temperatures for snow to be able to be generated in winter, for example (Allègre, 2018).

In Maritime context (and regarding mass balance) what is prominent is small change in temperature, because the geographical boundary between snow and rain is located close to 0 and even a small increase in temperature can dramatically increase the ablation season therefore contributing in accelerated melt of both ice and snow for large areas. Often, it is large areas that are going to be impacted by a small change in ELA because low gradients areas are most often located near the sea (figure 31).

Figure 31 The same change in ELA affects low gradient areas and high gradient areas in a different way. The red lines represent the area affected by the same rise in ELA due to climate warming.



In case of higher elevations and continental climates then the amount of precipitation during winter will determine if snow will be able to "survive" during the ablation season (typically summer). In a wetter climate (and with higher temperatures in winter) snow precipitation may be increased in mountainous maritime areas. Then, if the snow "survives" more than one year we talk about perennial snow; and perennial snow is the first foundation needed for the creation of glaciers. Of course, topography, exposition and other parameters are also prominent for their ex-nihilo creation.

The hypothesis we would like to test in the case of the Bakhmaro climate resort is two-folded:

- Has the Georgian government chosen the right location for the ski resort regarding water resource and potential climate change impact?
- Can climate change be favorable to the implantation of a ski resort due to the high elevated location of Bakhmaro (1950 m a.s.l.) near the Black Sea?

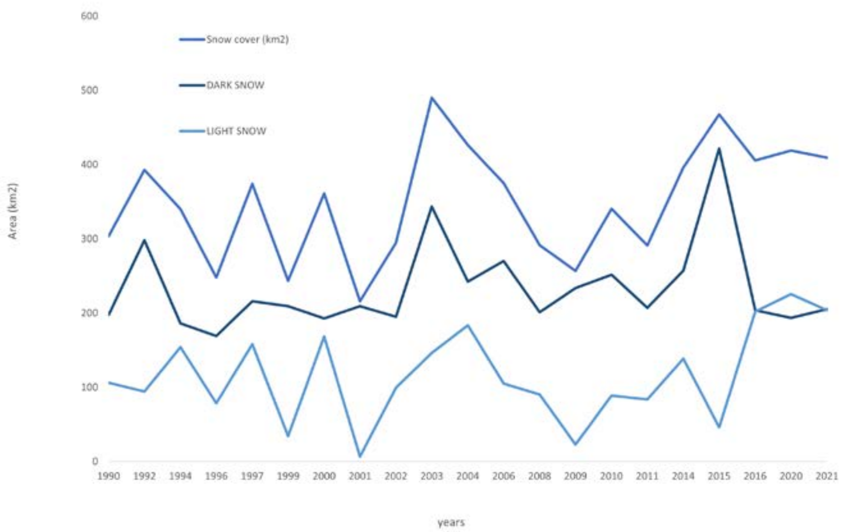
This rather empirical study will answer both questions and thus could even lead the way to climate modeling studies testing the effect of climate warming on the mountain chains of western Georgia.

Several maps have been created by the means of the software QGIS. The following appendix section present them, year per year, with a few temporal gaps, when pictures either were too cloudy or simply non-existing. The areal picture taken by Landsat 5 in 1994 shows the Bakhmaro watershed, and the bigger area surrounding it was chosen to have a more global picture of the snow-cover trends in this part of the Lower Caucasus mountains. As far as we know the Bakhmaro area is characterized by a “cuvette-zone” which is not characteristic of a different micro-climate zone in the Georgian mountains. However, very often this part of the Caucasus mountain is located above the clouds and this part of the

Caucasus mountain is characteristic for the quality of its fresh air. Therefore, picture with a lot of clouds were sometimes included because they still allowed us to have a good look at the snow cover.

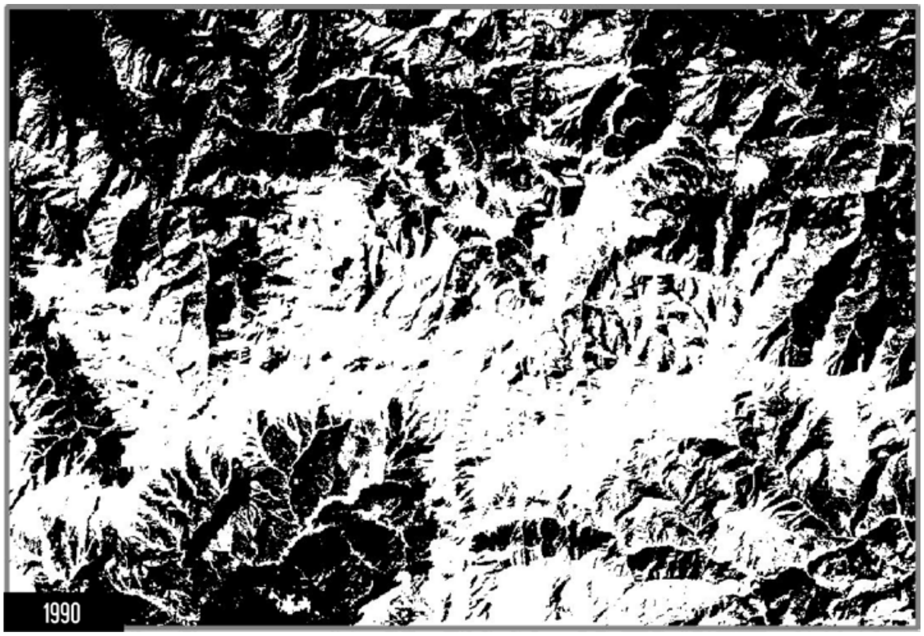
The Landsat 8 picture for 2018 was not included to calculate the snow cover (appendix) because of the too high uncertainty due to clouds.

Figure 32 Different areas of snow cover throughout the years analyzed from satellite imagery (QGIS).



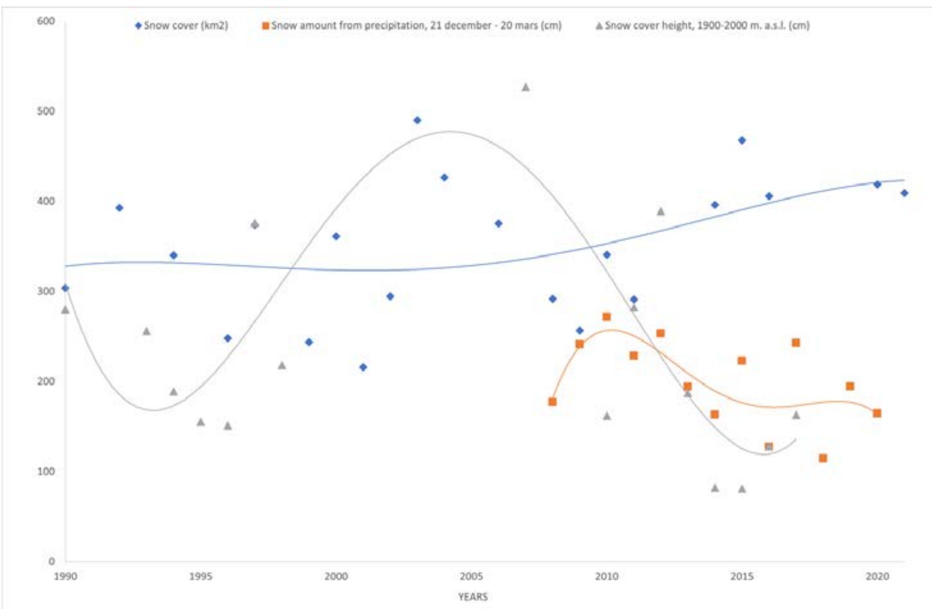
This diagram (figure 32) allows to see the evolution of snow cover directly interpreted from satellite imagery with its imperfection. The curves for dark snow and light snow added together permit to obtain the curve for the snow cover (dark blue).

Figure 33 Preliminary GIF showing the snow dispersal throughout the years starting 1990 – the snow is represented in white and the forest in dark



These snow maps covering a 30-year period permit to compute the snow area for each year (blue curve on fig. 32) by counting the pixels of one color in the image and the size of one pixel is known.

Figure 34 Comparison of the snow cover (satellite data) with the snow amount from precipitation (Meteo blue) and the snow height for the month of March (Georgian environmental agency) in the whole Bakhmaro area (see mask above – fig.1). The blue curve represents the snow cover in square kilometer, whereas the orange curve stands for the snow amount from precipitation and the gray curve shows the trend in snow cover height throughout the years (N.B. the gap in data from 1998 to 2008 for the snow height measurements).



The preliminary results in fig. 33 and fig. 34 display a slight increase in snow covered areas throughout the year starting from 1990 (a polynomial of degree 4 was used for obtaining the snow cover trend). This does not mean that there is more snow in the Bakhmaro area in recent years. In fact, both the trend in snowfall and in snow height are decreasing for the time-period starting from 2010.

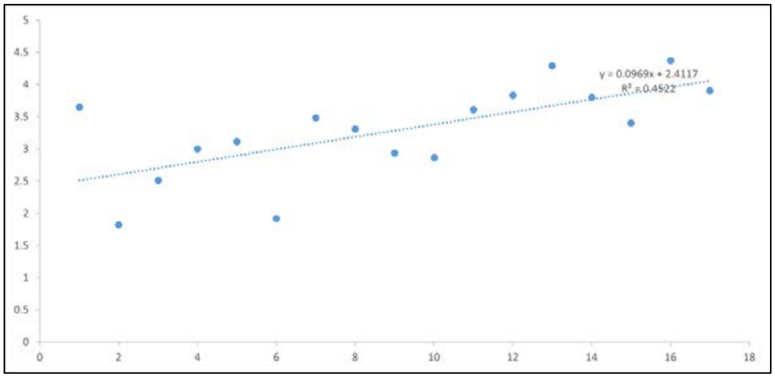
These results suggest that while there is an increase in snow dispersal throughout the whole Bakhmaro area (forest included) there is at the same time a decrease in snow precipitation and in snow height. In other words, **there has been less snow in recent years, but this latter is more widespread**.

This may or may not be due to the uncertainty during the measurement, which lead to an under-estimation of snow due to the snow being hard to detect when snow is under tree cover or forested areas. Satellite picture does not allow to account for the snow under tree cover, therefore making it difficult to account for the real change in snow cover.

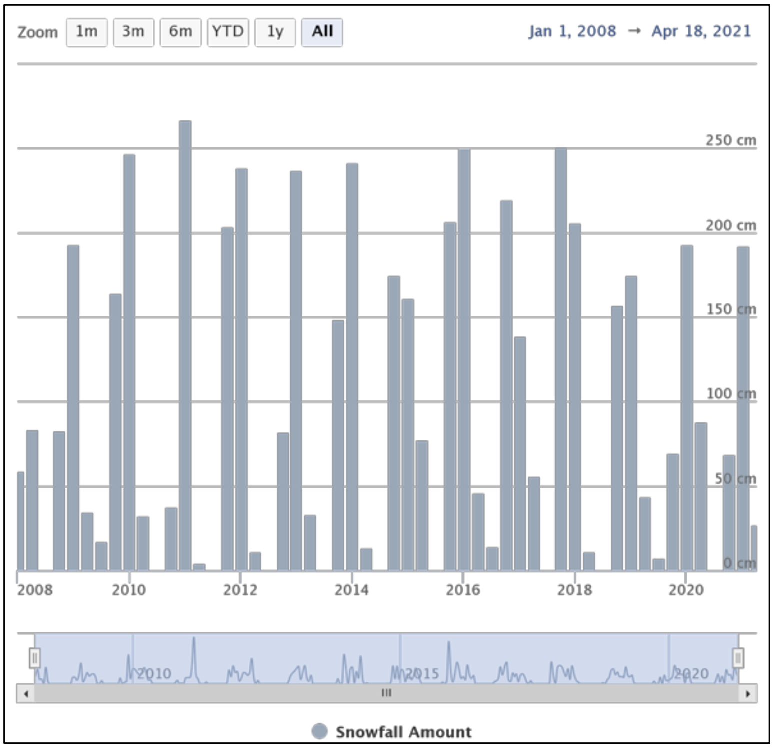
Climate data: a precious insight into the change in seasonality

Figure 35 (A). Average temperature for the month of April throughout the years, starting from 1936 (1); data taken from the Georgian environmental agency. (B). Monthly snow precipitation (high resolution data starting in 2008, from Meteo Blue).

A



B

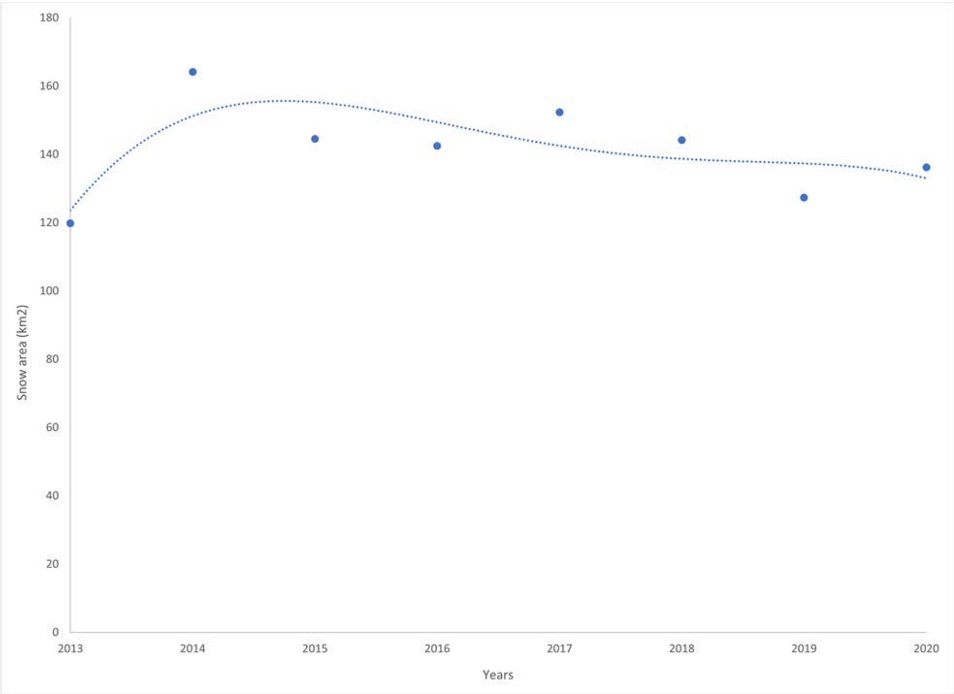


There is presumably a change in seasonality in the mountains of Bakhmaro in the South Caucasus. A strong evidence for that is the increase in mean temperature for the month of April, starting from 1936 (fig.35, A). However, more evidence is needed about the snow cover itself (fig. 34 and fig. 35, B).

Snow-trend based on Landsat 8 imagery alone

The preliminary results display snow changes for the whole mountain chain around Bakhmaro area, including the forested areas (fig. 33 and fig. 34). Based on these first results as well as on the climate data (fig.35) the analyze of the snow changes in the higher mountains (above the treeline) was undertaken for the month of April. The month of March did not show enough change in snow cover areas for such high elevation and the most change that were easy to observe were taking place in April and May, when snow is melting, and temperatures are getting warmer. If a decrease in snow cover will be observed then it will correlate with the temperature increase for the months of April, from the climate data (fig. 35, A) and at the same time it will give us stronger evidence about the snow result for both the month March and April (fig. 33, fig. 34 display the snow in March and fig. 35, B informs about the snow in April).

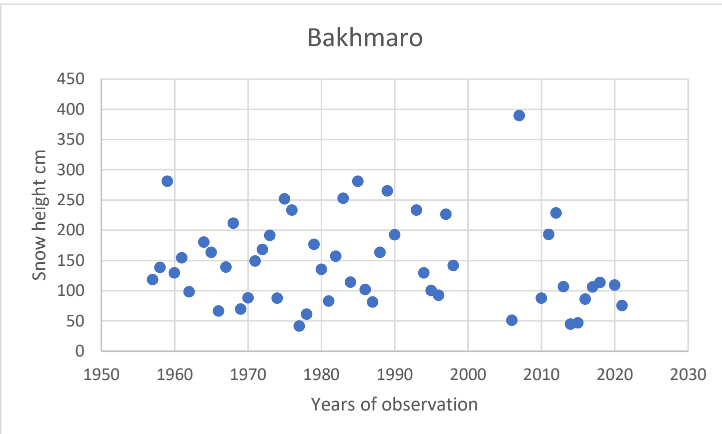
Figure 36 Snow cover change throughout the years in the Bakhmaro mountain chain (west of the South Caucasus). See appendix for another version of the figure including the Landsat 5 pictures and starting from 1992.



The snow trend obtained from Landsat 8 satellite imagery shows that there seem to be a decrease in snow cover in the most recent years for the areas located higher up in the mountains. These areas were chosen for the analyze because there were no forest present at altitudes higher than the treeline (2100-2200 m. a.s.l. in the southern Caucasus) thereby reducing greatly the uncertainty during classification. These results confirm the shortening of the accumulation season i.e., winter, and thereby the temporal increase of the ablation season in these areas of the southern Caucasus mountains. This is true even for the area above the treeline (2100-2200 m.).

Qualitative assessment of snow cover based on satellite data is difficult, in addition we used snow cover routine stakeout data to assess this issue. Which showed a significant change during the change in height of the snow cover.

Figure 37 Results of snow stakeout, 1957-2021



Impact on hydrological regime

The impact of climate change on the hydrological regime of the valley is of different types. Among them is the change of runoff regime. According to hydrological modeling and available climatic data, the number of days of minimum runoff has increased, as well as the maximum runoff has increased.

As of today, the impact of climate change on the shift of seasons is manifested by a change (decrease) in the temperature regime characteristic of the winter period. That is why the summer and related climatic conditions in Bakhmaro have been prolonged. The maximum runoff also increased with increasing temperature. In this case, the percentage increase in runoff is equal to 7% for each increment, which is noteworthy and requires appropriate steps to be taken.

Although no significant changes in the annual rainfall are observed, the situation by months is noteworthy. This variability is well illustrated by the approximate climate change scenarios given in Table 6. It can be seen that a significant part of the precipitation decrease is observed during the warm season, while the opposite results are expected in the winter months, which will have a direct impact on the hydrological regime of the river and its tributaries. The minimum runoff of the river is reduced by about 10%. An increase in this deficit is inevitable in the future, especially during the summer.

Table 10 Expected Changes by Month, Average indicator 2040-2059

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
mm	3.61	1.68	8.76	-22.34	9.95	-0.34	-5.38	-3.63	-4.58	-12.63	4.58	3.08

Possible ways of drinking water supply

The ability to supply drinking water to the resort of Bakhmaro is based on several factors, the most important of which are the permanence of the water and the height of the intake above sea level, so that the water can move in the system by itself. Taking into account the above facts will enable us, on the one hand, to provide the population with permanent drinking water and, on the other hand, to save on operating costs, which is a key component of sustainable development.

In order to select the site, a variety of information was processed, including temperature regime, precipitation, and evaporation. Also during the modeling great attention was paid to the exposure of the slopes and their inclination.

It should be noted that according to the results, sufficient water can be obtained only in the valley south of the resort Bakhmaro, which has more or less favorable hydrometeorological conditions and a high concentration of springs (Figure 38). In addition to the Soviet topographic map, satellite data show the advantage of this valley.

Figure 38 The valley south of Bakhmaro and the springs there

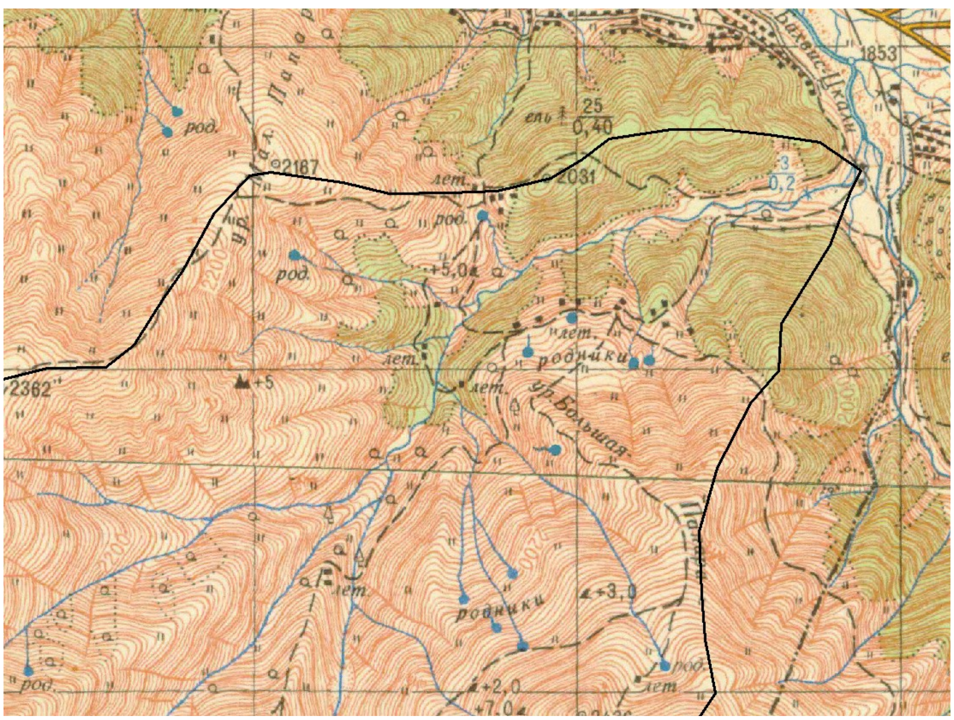


Figure 39 Evaporation and transpiration of incoming atmospheric precipitation from the valley

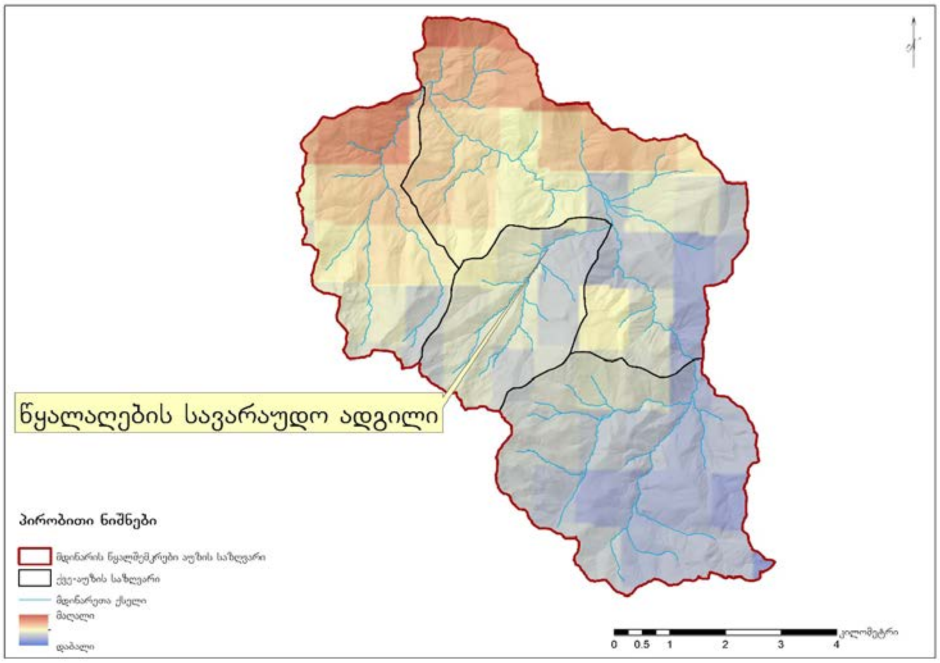
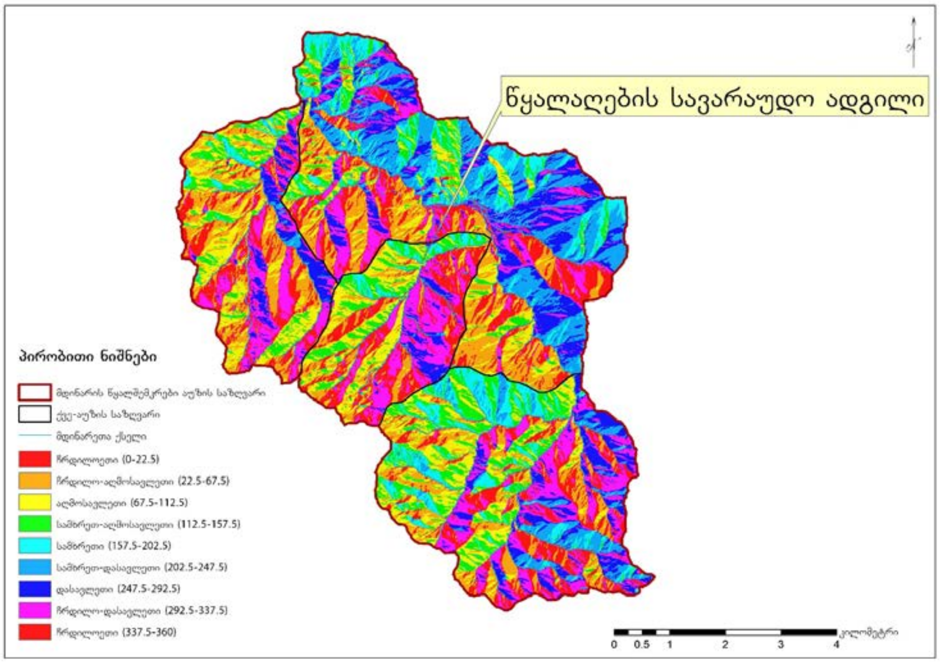


Figure 40 Slope exposure



Although there are sufficient resources in the above-mentioned valley for the supply of drinking water to Bakhmaro, it is necessary to protect the valley from anthropogenic influences.

Conclusions and recommendations

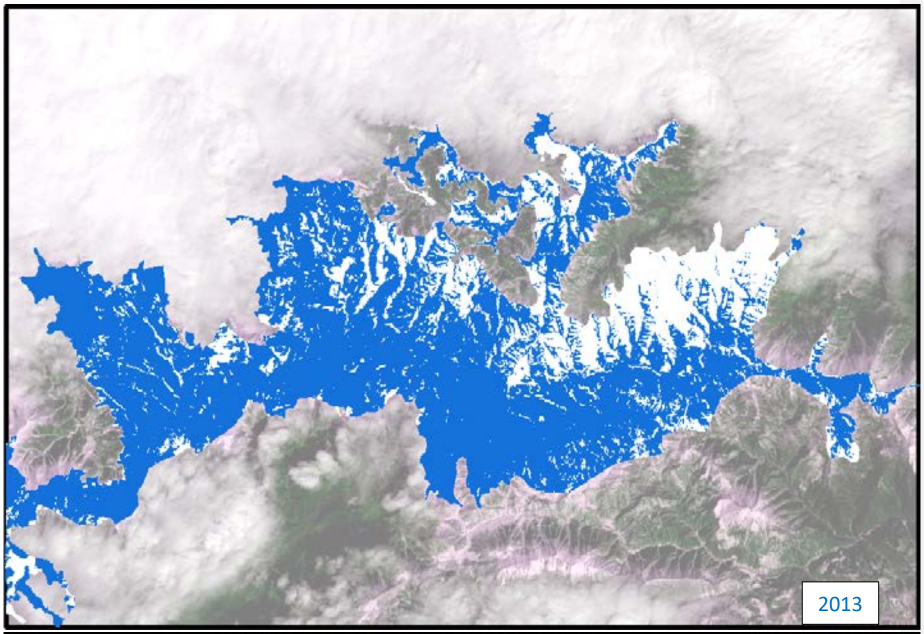
Many types of data were processed within the project, the results of which will help in the proper development of the resort. Especially on the road to adaptation to climate change, as the latter is clearly a major challenge even in the current situation. It is noteworthy that the impact of climate change on temperature is obvious today, which in turn changes the microclimate and general hydrometeorological parameters, which has led to two important aspects, including the change of seasons and the violation of the hydrological regime.

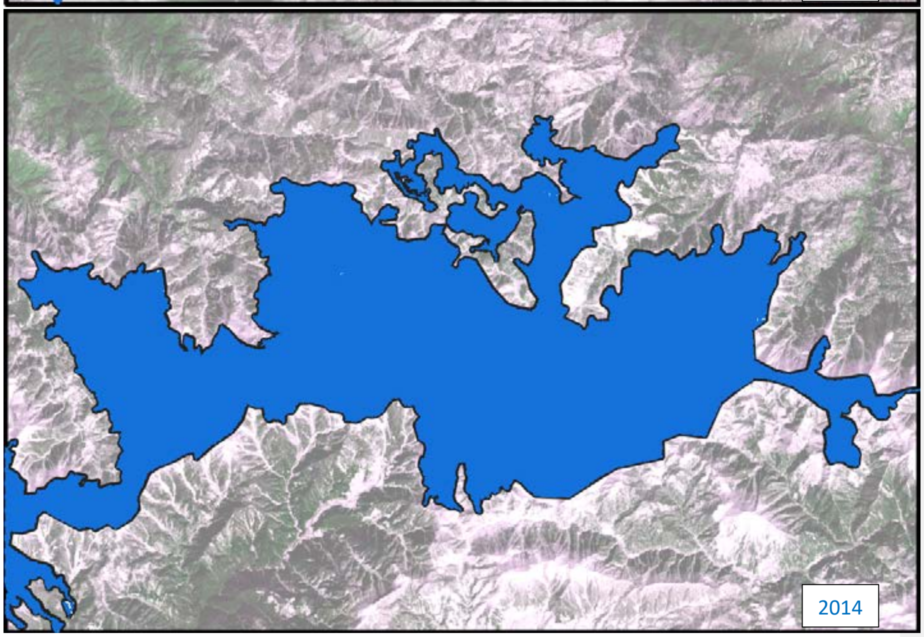
In terms of the change of seasons, the rapid change of temperature regime and the emergence of unambiguous warming parameters are noteworthy. Heavy rains and floods have also increased, which is why it is necessary to prepare a map of flood-prone areas and limit development as part of a comprehensive plan.

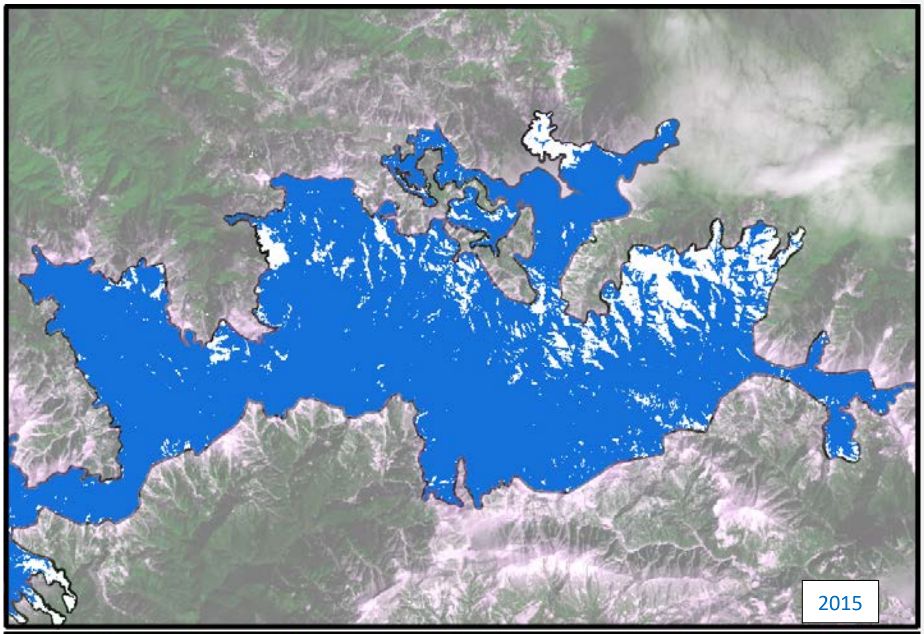
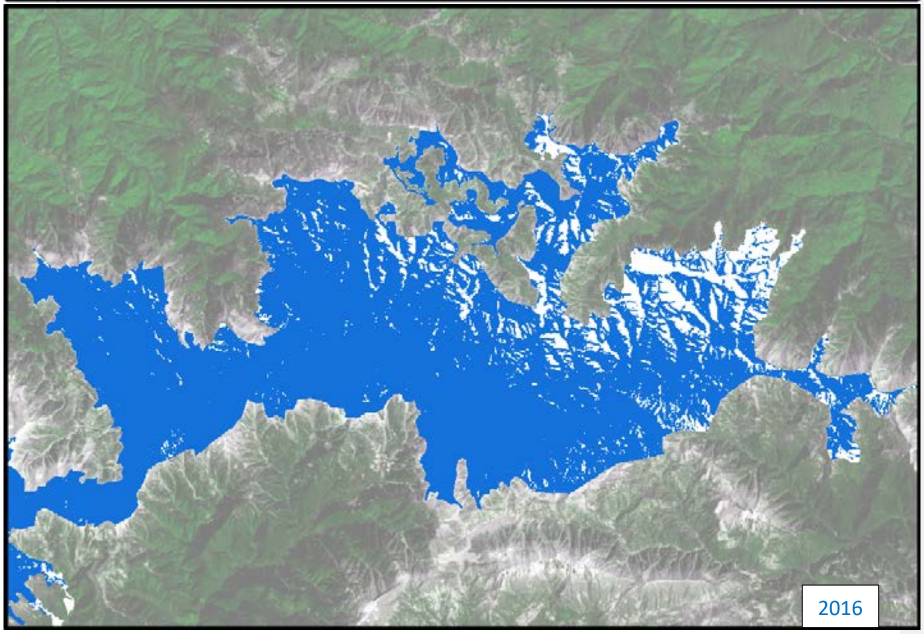
In order to adapt to climate change and make rational use of existing water resources, it is necessary to implement the following recommendations:

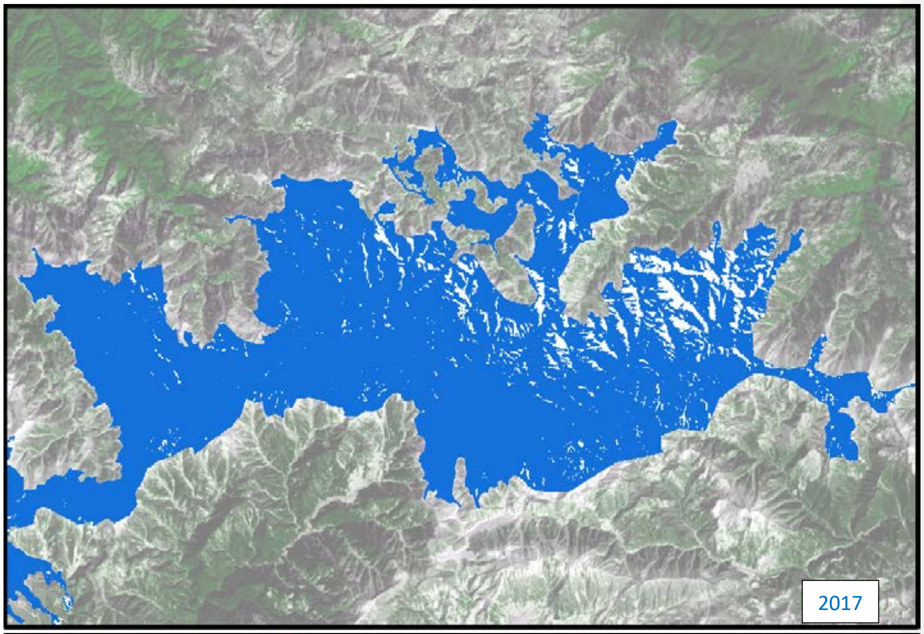
- In no case can the sources given in the Bakhmaro Recreational Land Master Plan be used to supply the resort with drinking water.
- Due to the scarcity of drinking water resources, it is necessary to declare the small catchment basin in the upper part of the resort as a sanitary zone and to prohibit the grazing and accommodation of cattle.
- Due to the water resources in the valley (especially during the winter), the use of springs as drinking water alone cannot provide 10,000 people at a time. It is therefore necessary to consider the placement of a full-fledged water intake facility and appropriate filter installations in the valley as an alternative route.
- Hydrological modeling has shown that vegetation cover health has a major impact on runoff stability. It is therefore necessary to minimize the negative impact on forest cover. In some cases, even promote planting activities.
- Drinking water supply and sewerage systems should be located below the maximum depth of ground freezing. For which it is necessary to conduct additional profile research before starting the activity.
- In order to develop Bakhmaro as a mountain ski resort, it is necessary to select the areas above 2100-2200 meters above sea level for the ski slopes.
- The quality of snow cover and indicators have deteriorated significantly, which has reduced the length of the ski season. It is therefore necessary to prepare a detailed study of the snow cover before making a final decision.
- It is necessary to consider the possibility of installing artificial snow systems and before making a positive decision it is necessary to find ways to supply water.
- In order to improve the hydrometeorological data and to maintain the appropriate ecological condition in the valley, it is necessary to update the monitoring of atmospheric events and water consumption.

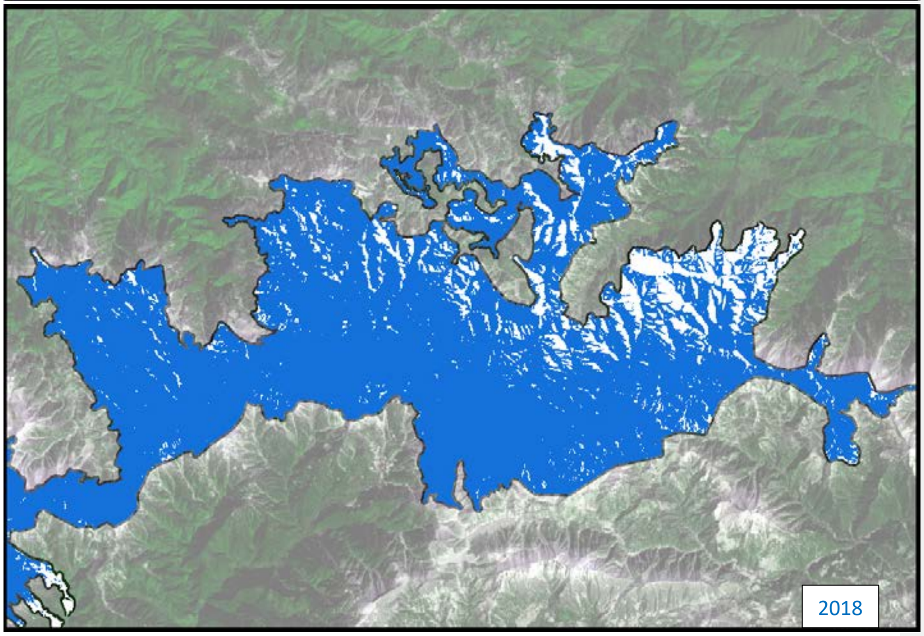
Appendix (snow in blue, non-snowy area in white):

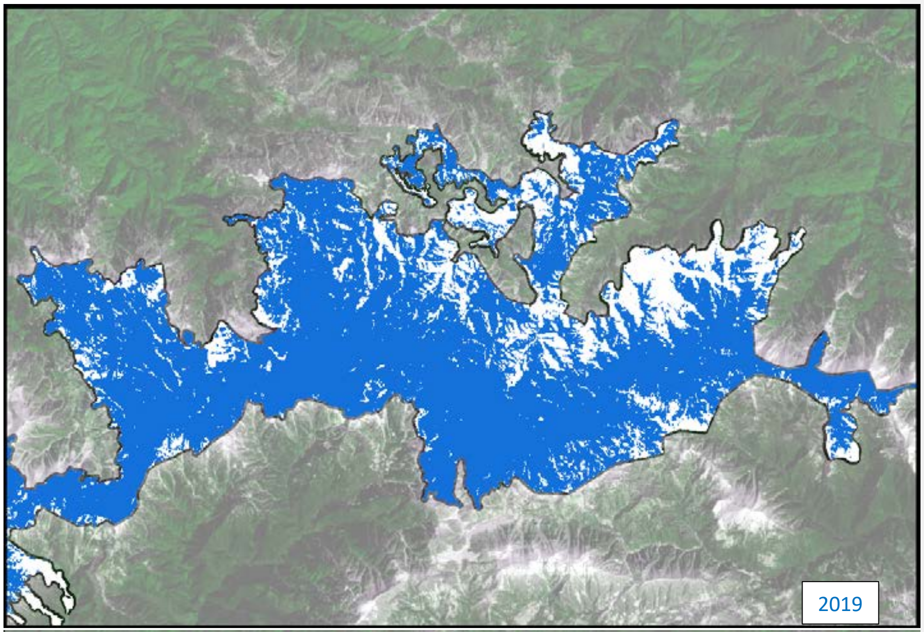


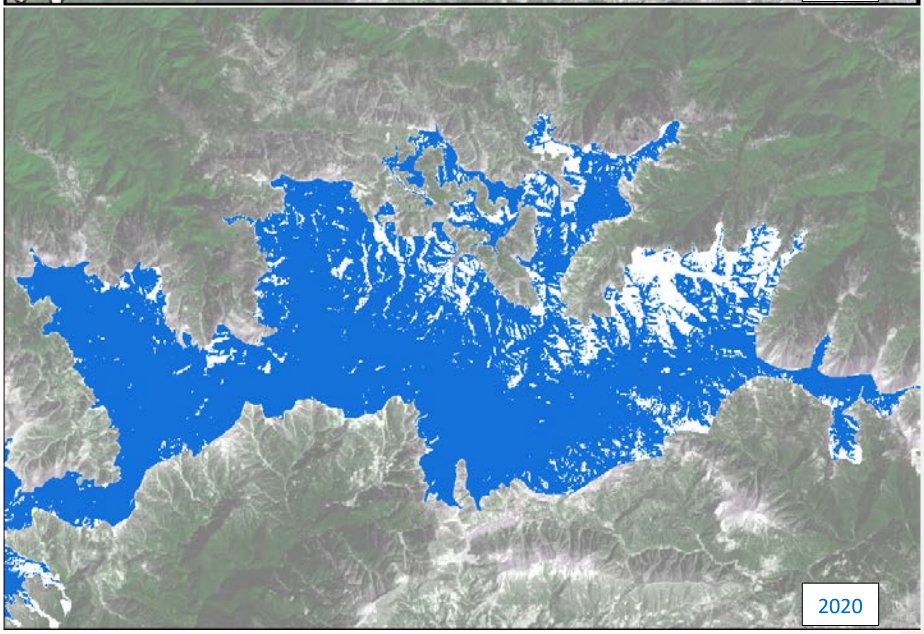


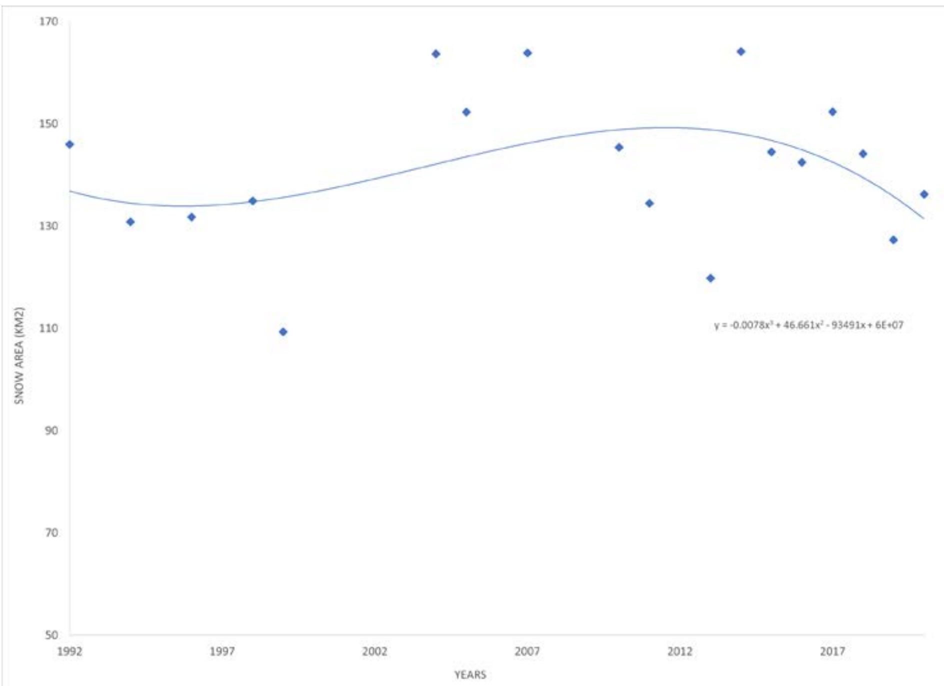

2015

2016


2017


2018


2019


2020



Complementary information to figure 36 – trend in snow-covered areas based on Landsat 5 and Landsat 8 areal pictures (polynomial of degree 3). Climate forcing has a nonlinear impact on the snow cover throughout the years: $y = -0{,}0078x^3 + 46.661x^2 – 93491x + 6E+07$. This is suggesting that climatic parameters alone cannot be the only factor explaining the snow dispersal in Bakhmaro area. It is normal that there is a great variability in the results since they are covering the whole month of April and even during climate warming there can be occurrences of very snowy years and very dry years happening 2 years in a row (e.g., 2013 and 2014).