

CLIMATE CHANGE IMPACT ASSESSMENT
AKHALKALAKI HPP PROJECT ON PARAVANI AND KHORKHI RIVERS



Tbilisi, Georgia

2020

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Abbreviations

Climate Change – CC

World Bank Group – WBG

Kilometre – km

Metter – m

Millimetre – mm

United States Geological Survey – USGS

Evapotranspiration – ETp

Objective

In general, average hydrological regime shift (resulted in an increase of winter flows and a decrease of the spring/summer peak), increased hydrological variability (very dry and very wet seasons/years) and increased frequency of extreme floods influence the long term production prospects and safety of the HPP projects' infrastructure.

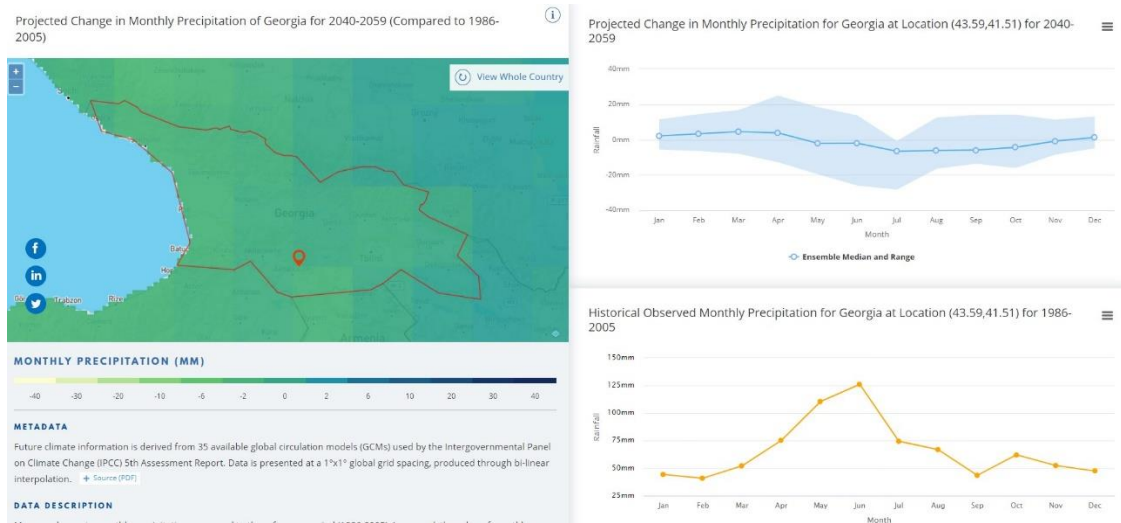
The main objective of the climate change risk assessment report is to define a single approach for the management of Fund's portfolio Akhalkalaki HPP project. Akhalkalaki HPP project comprises two HPP schemes Akhalkalaki 1 HPP (7.5 MW) and Akhalkalaki 2 HPP (1.6 MW) on the Paravani and Korkhi rivers respectively.

Approach

The method for the climate change risk assessment is based on the recommendations of the International Hydropower Association "Climate Change Resilience Guide for Hydropower" issued in 2019.

Climate change has a significant impact on the hydrological regime, it directly affecting precipitation, rate and intensity, temperature, radiation, evapotranspiration and all base attribute which are responsible for hydrology and its distribution in a catchment area. To apply climate change (CC) characteristic and determine simply approach, CC projections on the World Bank Group's (WBG) Climate Change Knowledge Portal has been used. This information helps us to see long term change regarding climate change and accordingly modify the hydrology the river. The scale of information which is given on portal is monthly based and it impossible to modify the project's daily or monthly hydrology, but it is useful to see how climate change will effect on precipitation and temperature regimes.

Figure 1. CC projection on the WBG website



As mentioned, World Bank Group’s Climate Change Knowledge Portal data has been used for the climate change projections. Satellite information available from the USGS website and existing metrological data within the Akhalkalaki HPP project and the region have been analyzed and incorporated in the assessment.

Selected river

Paravani river originates at the southern end of the Paravani lake near the village Foka at an elevation of 2080 m a.s.l. And flows into the river Mtkvari from the right side near the village Khertvisi. Korkhi river (Baraletistskali) originates on the south-west slope of mountain Motskirkokhi (2249,5 m a.s.l.) at an elevation of 1854 m a.s.l. It Merges with the Paravani river from the right side close to the Korkhi village at an elevation of 1555 m a.s.l. Hydrological calculation given in the feasibility study is based on gauging stations. One gauging station was located in village Khertvisi (Paravani river) and second one was located in village Arakvi (Khorkhi river).

Table 1. General information

	Paravani	Korkhi
Watershed area (km ²)	1538.669	403.3028
Total length (km)	55.6	24.8
Slope (%)	14.65	18.37
Average elevation (m)	2236.52	2088.46
Intake coordinate (X)	372,139.184	372,327.250
Intake coordinate (Y)	4,587,581.574	4,592,299.877

The climate in the Javakheti region is dry with cold winter and warm summer. The driest season in the catchment area is autumn/winter when annual precipitation is around 200 mm, while the wettest is spring/summer when yearly rainfall is about 360 mm.

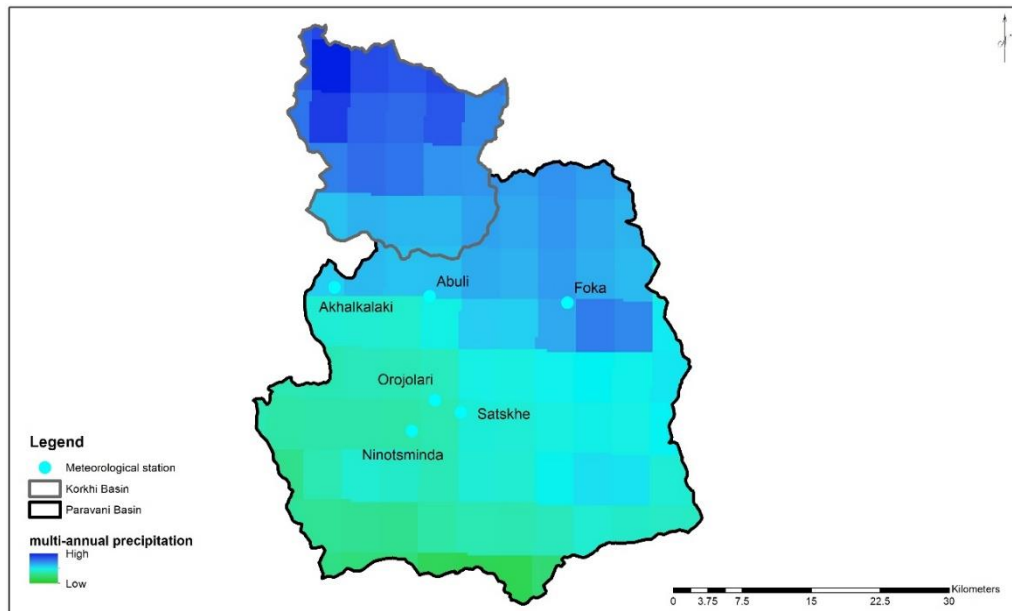
Multi-annual precipitation and discharge change

Evapotranspiration and Precipitation distribution

For climate change study, we are going to review, and use data provided by the world bank group. WBG climate change projection gives us the ability to see how the mother of nature is responding to the emission rate and estimate how the climate will change in the future. Based on the latest IPCC¹ projection (reference period for this projection is 1986-2005 yy), we can see a total change of precipitation in the catchment area. However, based on a meteorological station located in town Akhalkhalaki, we can see how precipitation has already changed since 2005.

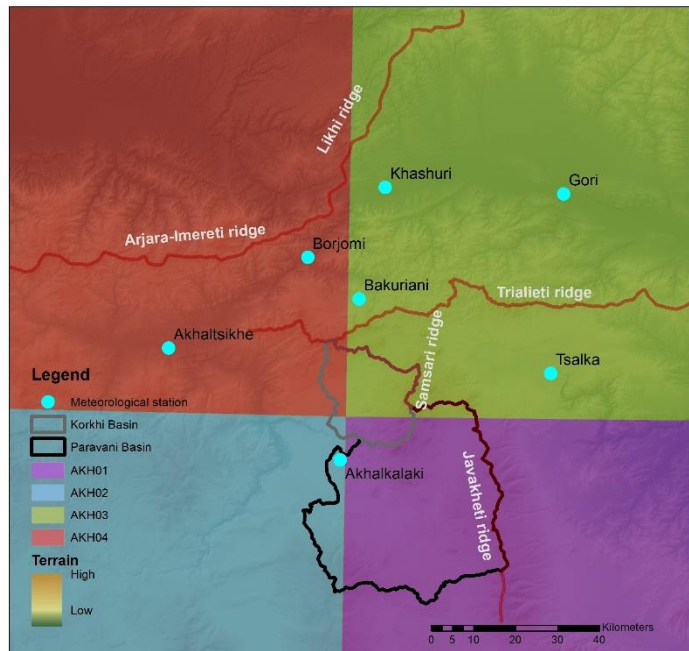
The first task is to define the exact location of the basin and then choose the most suitable CC forecast. Since CC projection is worldwide, and its grid size is big, during the selection proses, as an example, the satellite data has been used as well. Compared to CC projection, the pixel size and period of measurement is an advantage of the satellite data (figure 2).

Figure 2. Satellite annual precipitation data (1986-2005 yy)



¹ [climate knowledge portal](#)

Figure 3. WBG global grid spacing (1°x1°) Projection



Generally, the correlation between precipitation and water flow is different during the year, and without daily parameter, such as temperature, evapotranspiration, land use and precipitation it is impossible to define the rivers actual flow regime. Monthly based information of precipitation is given on the WBG website that has been downloaded, and multi-annual average flow has been calculated accordingly. In case of Paravani and Korkhi river, the targeted period for the CC forecast is 2040-2059 yy.

For now, based on the data given on the website, and as mentioned above, we can only calculate rivers multi-annual average water flow and distribute it according to the former Khertveisi gauging station or measured flows at the Paravani HPP.

The data source which has been used for calculation covers the region, and all data has a different range of time. However, between the data, there is an overlap, which is an excellent indicator to see their reliability. Below is listed available data for the project area.

- The hydrology of the project in the feasibility study is based on the old soviet flow measurement data (1936-1986 yy).
- Akhalkhalaki meteorological station's monthly measurement precipitation data (1981-2019 yy).
- Satellite information of precipitation is available from the USGS website, for the 1981-2019 yy period.
- CC scenario on the WBG website for the period 1986-2005 yy is based on precipitation and temperature data.
- Satelite evapotranspiration data is from the USGS website is available for 2003-2019 yy.
- Historical Soviet evapotranspiration data for the basin is available 1936-1968 yy.

Unfortunately, on the WBG website, there is no predicted evapotranspiration for the period 2040-2059. Due to this fact, during the hydrological calculation of river flow, as an assumption, historical data of evapotranspiration of the 1936-1968 yy and 2003-2019 yy period have been used (table 2).

Figure 4. Actual evapotranspiration in the watersheds (2003-2019)

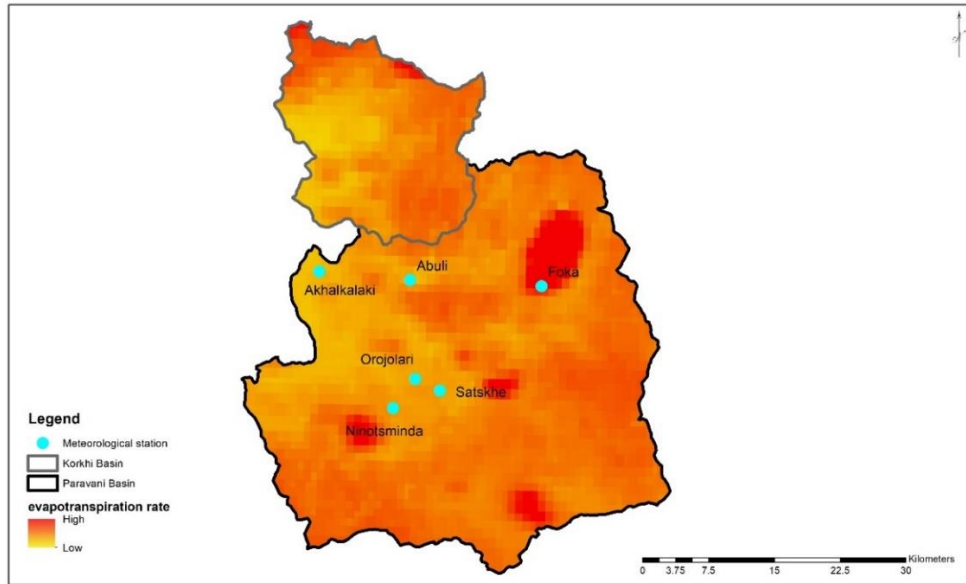


Table 2. Actual evapotranspiration rate in the watershed

River	USGS (2003/2019)	Historical data (1936-1968)
Paravani	387.40	454.19
Korkhi	361.60	445.30

It should be mentioned that in the Paravani watershed evapotranspiration rate is higher compared to Korkhi river watershed due to lakes and swamps, which are widely presented in the catchment area (see figure 4).

In the feasibility study precipitation and its distribution is given via different ground stations which were at various places in the basin. Above mentioned meteorological stations were located only in Paravani watershed (please see figure 5) and not in Khorkhi river catchment area. However, the hydrological calculation for Paravani and Korkhi river is based on Khertvisi and Arakvi gauging stations' water flow data only, and they are not linked with precipitation information and distribution. According to the meteorological stations' historical data from the Paravani watershed, multi-annual average precipitation varies from 607 mm up to 733 mm (see table 3). And multi-annual average flow for the river Paravani at intake is 13.4 m³/sec (see table 4).

Table 3. Former meteorological stations and multi-annual average precipitation in the Paravani watershed based on a feasibility study (mm)

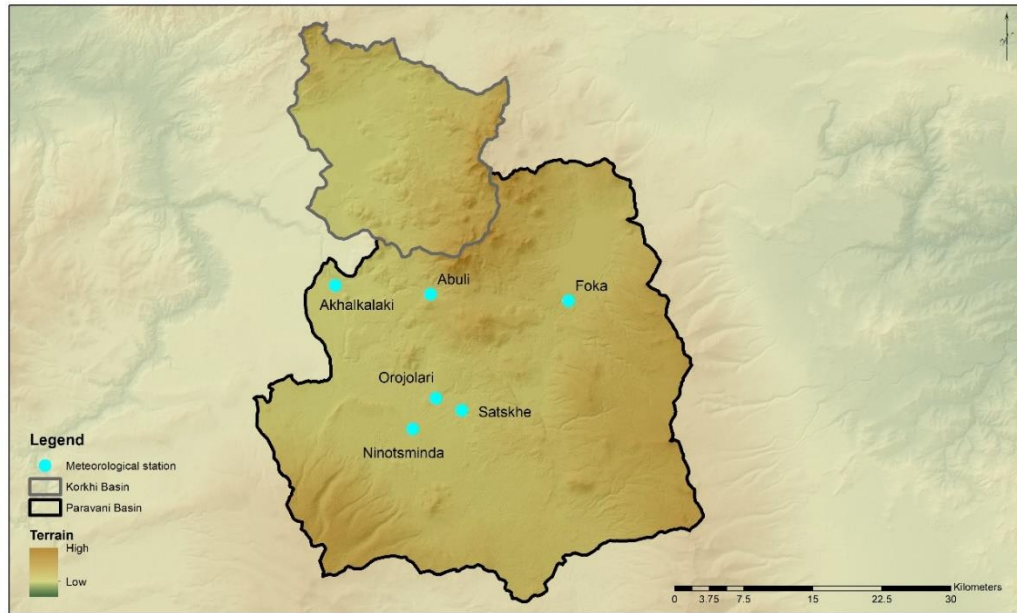
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Akhalkhalaki	30	39	40	57	86	93	67	54	44	41	41	29	621

Abuli	32	40	42	60	89	97	71	57	46	44	44	31	653
Ninotsminda	38	55	56	69	93	116	77	60	47	48	44	30	733
Foka	39	46	44	65	86	92	67	54	44	44	44	34	659
Satkhe	34	44	47	55	83	103	70	54	42	41	37	26	636
Orojolari	29	41	46	53	80	99	66	52	40	40	37	24	607
Average	33.7	44.2	45.8	59.8	86.2	100.0	69.7	55.2	43.8	43.0	41.2	29.0	651.5

Table 4. Paravani river multi-annual average flow at the proposed intake location based on a feasibility study (m³/sec)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Avg. at intake	9.1	9.6	12.0	24.2	27.8	21.7	11.6	9.2	8.7	8.9	9.1	8.9	13.4
Ecological flow	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Irrigation flow	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.9	0.3	0.0	0.0	0.0	0.2
Available flow	7.8	8.3	10.7	22.9	26.5	20.4	9.7	7.0	7.1	7.6	7.8	7.6	12.0

Figure 5. Meteorological station in Paravani watershed



In case of global grid projection (1°x1°), from the WBG website, each zone has a different precipitation value, and its share in the whole watershed has been foreseen for the average value calculation. For Paravani river, historical data given on the WBG website, multi-annual precipitation in the projected area (above the intake) for the 1986-2005 yy period was 648 mm, and watershed is divided into three different zones (figure 3 and 6).

As it is mentioned above, if Paravani river watershed is covered by three different zones, Korkhi river catchment area is covered by four zones (figure 3 and 6). To determine multiannual precipitation for both

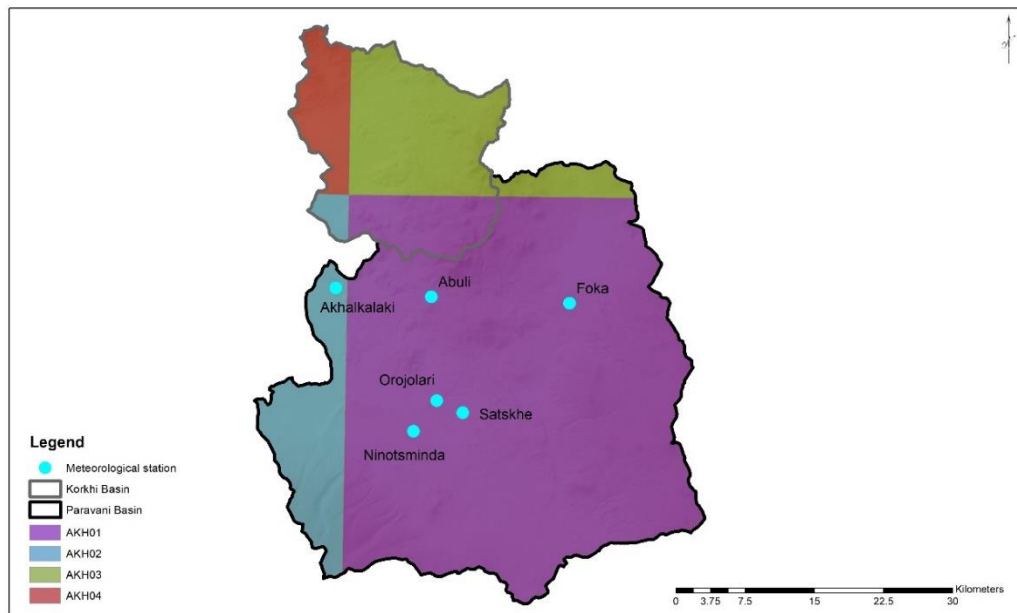
watersheds layer given on WBG website has been imported into the GIS system (figure 3), raster file has been created, and the average volume has been calculated.

Table 5. Observed precipitation data in mm for the Paravani and Korkhi watershed (WBG CC website 1986-2005)

Projection ID	Value (mm)
AKH01	640.13
AKH02	666.56
AKH03	795.4
AKH04	912.13

As it is mentioned above based on the data presented in table 5, the average multi-annual precipitation has been calculated considering shares of each zone in each watershed. In case of Paravani river catchment area multi-annual average rainfall has been defined 647.8 mm, while for Korkhi river basin is 781.50 mm. Due to the defined results, which are closed to the values presented in table 5, multi-annual precipitation and its distributions of AKH01 and AKH03 have been used for Paravani and Korkhi river basins relatively (see figure 6).

Figure 6. Meteorological station in the catchment area and global grid CC projection (1°x1°).



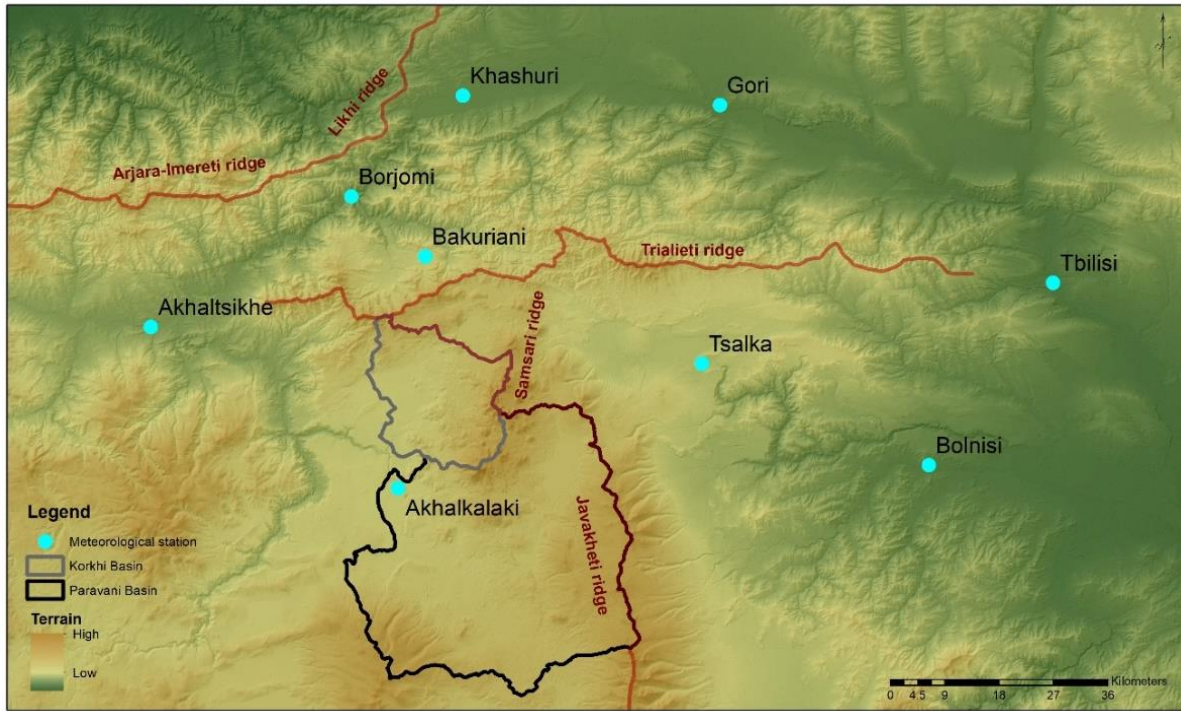
Additionally, for the calibration, the meteorological station from different places has been used to see how the weather is changing and which morphological barrier is most influencer regarding the weather and precipitation in the region. For this, the correlation coefficient between those meteorological stations has been determined (Tsalka, Akhalkhalaki, Bakuriani, Khashuri, Gori, Tbilisi, etc.). This information gives us a clear view of the weather condition and geography of the region. Based on the above mentioned meteorological stations precipitation data and its distribution during the year, Akhalkhalaki has the best correlation (table 6) with Akhaltsike, then it is Tbilisi, Tsalka and Bakuriani. Due to this, the main barrier in

the region is Lesser Caucasus (Ajara-Imereti, Trialeti, Samsari and Javakheti ridge) and Likhi ridge (figure 7).

Table 6. Correlation coefficient between the Meteorological stations compare to Akhalkalaki

Station	Bakuriani	Borjomi	Akhalsikhe	Tsalka	Tbilisi	Bolnisi	Gori	Khashuri
correlation	0.88	0.77	0.97	0.88	0.89	0.78	0.78	0.61

Figure 7. Existing meteorological Statins in the neighboring area and morphology of the region

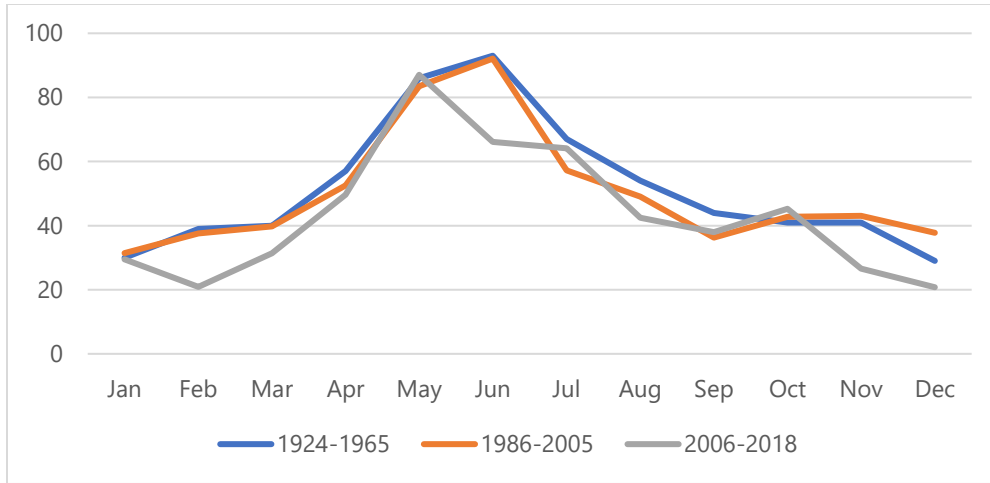


Regarding the WBG projection in the Paravani river watershed, three different sources' data have been used and compared to see the difference. Nowadays in the selected area, only one Meteorological station Akhalkhalaki exists, which has a long observation history and it is an excellent indicator to see how climate has changed in the neighbouring area and see how accurate CC projection and satellite measurements are. Based on the information given below, we can say that the precipitation had changed rapidly. If before in the Akhalkhalaki city multi-annual average precipitation was 621 mm, for the referenced period (1986-2005 yy) it dropped by 3% and nowadays it is 16% lower (table 7).

Table 7. Multi-annual average precipitation and its distribution in town Akhalkhalaki (mm)

Observed years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1924-1965	30.0	39.0	40.0	57.0	86.0	93.0	67.0	54.0	44.0	41.0	41.0	29.0	621.0
1986-2005	31.4	37.6	39.8	52.5	83.5	92.1	57.2	49.0	36.2	42.7	43.0	37.8	602.9
2006-2018	29.5	20.9	31.3	49.7	87.1	66.1	64.1	42.4	37.9	45.2	26.6	20.8	521.6

Figure 8. Multi-annual average precipitation and its distribution in town Akhalkhalaki (mm)

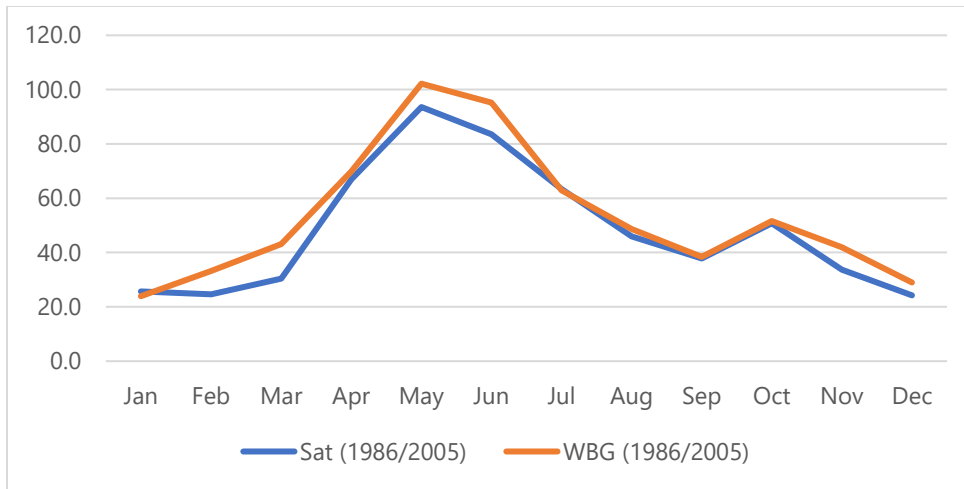


Second sources which can be used for comparative analyses is satellite data from the USGS website and CC projection. Those data have overlap, and they are observed at the same time for the period 1986-2005 yy. Satellite measurement data show that the multi-annual average precipitation in the Paravai watershed was 580.8 mm, while data given on the WBG website says that multi-annual average precipitation in the catchment area was 640.1 mm (table 8). The difference between satellite measurement and CC projection could be due to the resolution of the data. The satellite measurement has better resolution, and its pixel size is 22 km² (see figure 2), while the pixel size for CC projection is 9000 km² (figure 3). Also, satellite data has its problems and to rely on this data it needs additional calibration and hydrological modelling. However, it is a good source for comparative analyses. The difference between them and reliable data form meteorological station is not too high, and this difference could be explained due to the morphology and the size of the basin.

Table 8. Multi-annual precipitation and its distribution in the basin (mm)

Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Akhalkhalaki (1986-05)	31.4	37.6	39.8	52.5	83.5	92.1	57.2	49.0	36.2	42.7	43.0	37.8	602.9
USGS (1986-05)	25.7	24.7	30.4	67.0	93.6	83.6	63.4	45.9	37.8	50.8	33.7	24.2	580.8
WBG (1986-05)	23.9	33.3	43.2	69.9	102.2	95.2	62.9	48.7	38.4	51.6	41.9	29.0	640.1

Figure 9. Multi-annual precipitation and its distribution in the watershed (mm)



Climate change

In the CC scenario compared to the referenced period (1986-2005 yy), multi-annual precipitation will drop for the targeted period 2040-2059, and the difference depends on the emission. However, in some month precipitation are increasing (please see table 9). For the predicted rainfall calculation, the information given on the website has been merely downloaded and changed accordingly. For calculation out of three different scenarios, a pixel which was more close to the overall situation has been used. And in case of Paravani basin, this one is AKH01, and for Korkhi river it is AKH03. According to the WBG, observed precipitation for the selected catchment area is 640.1 mm (table 5).

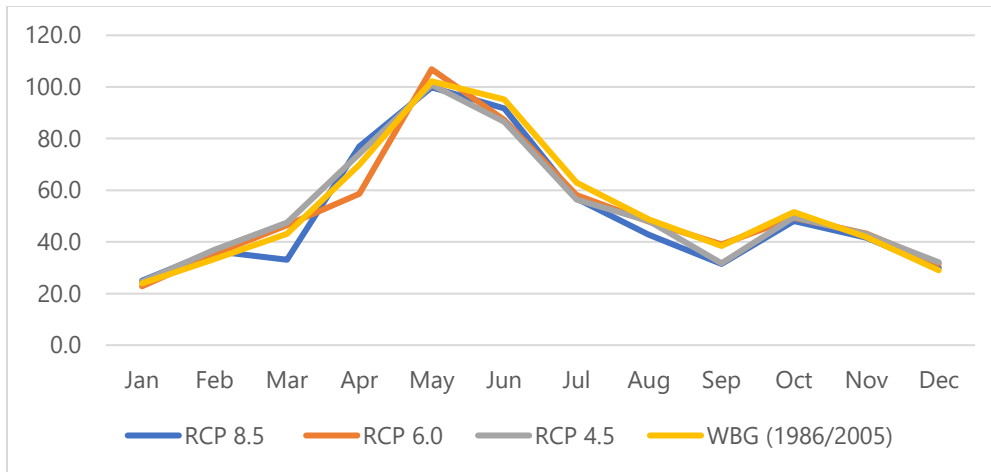
Table 9. Predicted change of precipitation in the Paravani watershed (mm) for 2040-2059 yy

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	1.0	3.2	-10.1	7.2	-2.3	-3.5	-6.2	-6.0	-6.9	-3.6	-0.3	0.9	-26.6
RCP 6.0	-1.1	2.1	3.3	-11.2	4.7	-8.0	-4.8	-0.8	0.6	-2.3	1.3	2.5	-13.7
RCP 4.5	0.6	3.6	4.3	4.2	-1.3	-8.8	-6.5	-0.5	-6.7	-2.0	1.1	3.0	-8.9

Table 10. Predicted precipitation distribution in the Paravani watershed (mm) for 2040-2059 yy

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	25.0	36.5	33.1	77.0	99.9	91.7	56.7	42.7	31.5	48.0	41.6	29.9	613.5
RCP 6.0	22.8	35.4	46.4	58.6	106.9	87.3	58.2	47.9	39.0	49.3	43.2	31.6	626.4
RCP 4.5	24.6	36.9	47.5	74.0	100.9	86.5	56.4	48.1	31.8	49.6	43.0	32.1	631.3
WBG (1986-05)	23.9	33.3	43.2	69.9	102.2	95.2	62.9	48.7	38.4	51.6	41.9	29.0	640.1

Figure 10. Predicted precipitation distribution in the Paravani watershed (mm) for 2040-2059 yy



According to the data given on the WBGs' CC projection, compared to the referenced period precipitation will be lower, depending on the emission rate and forecast. Same will be for the multi-annual average flow, and it will drop at least 11%, compared to the feasibility study (table 11). Also, it should be noted that, satellite data of the period 2003-2019 yy has been used for evapotranspiration amount.

Table 11. Precipitation and Runoff according to the Climate change scenarios in Paravani river

	Pres (mm/year)	ETp (mm/year)	Runoff (mm/year)	Q m ³ /sec	Diff (%)
Feasibility study data	712.0	452.6	259.3	13.4	-
RCP 8.5	613.5	387.4	226.1	11.0	-17.7
RCP 6.0	626.4	387.4	239.0	11.7	-13.0
RCP 4.5	631.3	387.4	243.9	11.9	-11.2

Unfortunately, unlike the Paravani river basin in the Korkhi catchment area, there were no meteorological stations, and due to this, we are not able to calibrate satellite data accordingly. However, due to the above-explained situation, AKH03 has been selected for CC calculation (figure 6 and table 5), and predicted changes determined accordingly (table 12 and 13).

Table 12. Predicted change of precipitation in the Korkhi watershed (mm) for 2040/2059

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	2.1	3.2	4.5	3.8	-2.1	-2.0	-6.6	-6.2	-6.0	-4.4	-0.9	1.2	-13.3
RCP 6.0	-0.1	3.2	4.4	1.0	6.2	-4.2	-4.4	-1.3	0.6	-3.3	2.0	2.3	6.7
RCP 4.5	1.7	5.3	4.5	3.2	-0.5	-9.1	-5.1	-0.4	-3.0	-4.0	0.7	4.5	-2.3

Table 13. Predicted precipitation distribution in the Paravani watershed (mm) for 2040/2059

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	46.3	44.1	56.6	79.0	108.3	124.0	67.8	60.7	37.6	57.8	51.5	48.6	782.1

RCP 6.0	44.2	44.1	56.5	76.2	116.6	121.8	70.0	65.6	44.1	58.9	54.4	49.7	802.1
RCP 4.5	46.0	46.1	56.5	78.3	109.9	116.9	69.3	66.5	40.5	58.2	53.1	51.9	793.1
WBG (86/05)	44.3	40.9	52.1	75.2	110.4	126.0	74.4	66.8	43.5	62.2	52.4	47.4	795.4

Figure 11. Predicted precipitation distribution in the Korkhi watershed (mm) for 2040/2059

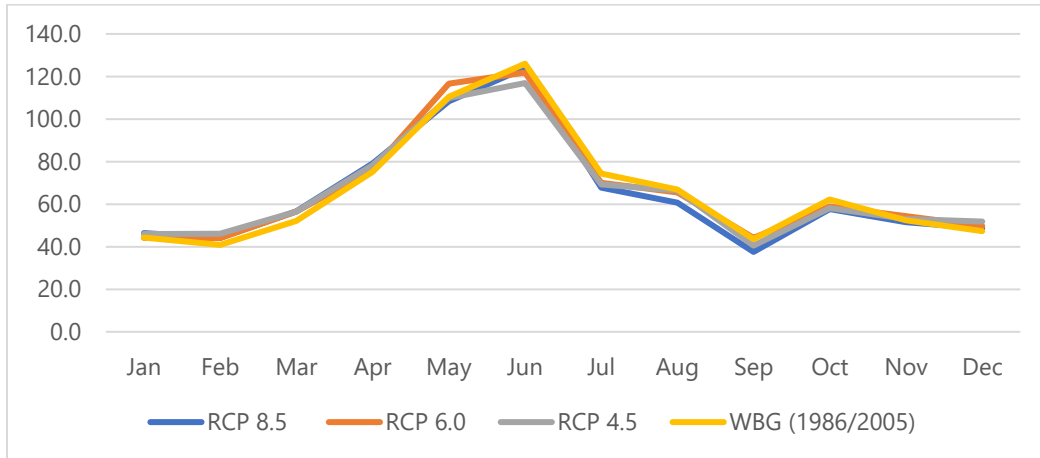


Table 14. Precipitation and Runoff according to the Climate change scenarios in Korkhi river

	Pres (mm/year)	ETp (mm/year)	Runoff (mm/year)	Q m ³ /sec	Diff (%)
Feasibility study data	681.19	445.73	246.76	3.01	-
RCP 8.5	782.14	361.61	420.53	5.38	78.60
RCP 6.0	802.07	361.61	440.46	5.63	87.07
RCP 4.5	793.11	361.61	431.50	5.52	83.26

In case of Korkhi river calculation result seems unrealistic. Somehow WBG historical data indicates higher numbers than it is recorded by the nearest meteorological station and satellite measurement. The reason for it could be due to the size of the pixel for AKH03 (figure 3). Regarding CC projection, AKH03 covers half of Shida Kartli region till the Great Caucasus and small part of it are presented in west Georgia (West Georgia is the wettest region in Georgia) and Lower Kartli as well (figure 3). Due to the reason above explained, AKH01 has been used for Korkhi river as well (table 9 and 10).

Table 15. Precipitation and Runoff according to the Climate change scenarios AKH01 in Korkhi basin

	Pres (mm/year)	ETp (mm/year)	Runoff (mm/year)	Q m ³ /sec	Diff (%)
Feasibility study data	681.2	445.7	246.8	3.0	-
RCP 8.5	613.5	361.6	251.9	3.2	1.6
RCP 6.0	626.4	361.6	264.8	3.4	2.8
RCP 4.5	631.3	361.6	269.7	3.4	3.3

According to the date given on the WBGs' CC projection, compared to the referenced period precipitation will be lower, depending on the emission rate and forecast. However, water discharge will not change significantly. Even more, it may be increased depending on the evapotranspiration rate (table 15).

Annual rainfall range

The second scenario which is linked with baseflow is annual rainfall range, which indicates the difference between driest and wettest year (table 16). Regarding the yearly rainfall range following changes are predicted.

Table 16. Predicted Changes in the watershed according to WBG (2040-2059 yy)

projection		mm/y	Korkhi			Paravani		
			rainfall	ETp	area	rainfall	ETp	area
			640.13	361.607	403.3	640.13	387.401	1538.67
			Rainfall mm/y	Runoff mm/y	Flow m ³ /sec	Rainfall mm/y	Runoff mm/y	Flow m ³ /sec
RCP 8.5	Wettest	606.96	1247.09	885.48	11.32	1247.09	859.69	41.94
	Median	49.65	689.78	328.17	4.20	689.78	302.38	14.75
	Driest	-54.02	586.11	224.50	2.87	586.11	198.71	9.70
RCP 6.0	Wettest	878.4	1518.53	1156.92	14.80	1518.53	1131.13	55.19
	Median	85.2	725.33	363.72	4.65	725.33	337.93	16.49
	Driest	-80.78	559.35	197.74	2.53	559.35	171.95	8.39
RCP 4.5	Wettest	353.66	993.79	632.18	8.08	993.79	606.39	29.59
	Median	40.91	681.04	319.43	4.09	681.04	293.64	14.33
	Driest	-67.44	572.69	211.08	2.70	572.69	185.29	9.04

Temperature impact on extreme flows

In case of temperature change in the projected area temperature will rise. However, rising of temperature is different and depends on the emission trends for example in case of high emission (RCP 8.5) annual temperature in the catchment area will increase by 2.39 C⁰, while for medium-high (RCP 6.0) and medium-low emission it will be 1.51 C⁰ and for RCP 4.5 it will be 1.73 C⁰. If we consider the fact that air temperature raising by degree Celsius, flood peak will increase by 7%. According to the hydrological data given in the feasibility study, peak flow for Paravani intake is 170 m³/sec, and for Korkhi river it is 65 (100-year return period)

Table 17. Estimated peak discharge (m³/sec) affected by temperature change (2040-2059 yy)

Projection	C ⁰	Probability (return period, years)						
		0.5 (200)	1 (100)	2 (50)	3 (33)	5 (20)	10 (10)	20 (5)
Paravani river								
RCP 8.6	2.39	239.3	198.4	175.1	157.6	134.2	110.9	73.5
RCP 6.0	1.51	226.7	188.0	165.9	149.3	127.2	105.1	69.7

RCP 4.5	1.73	229.8	190.6	168.2	151.3	128.9	106.5	70.6
Korkhi river								
RCP 8.5	2.39	87.5	75.9	64.0	60.0	50.0	39.9	32.4
RCP 6.0	1.51	82.9	71.9	60.6	56.8	47.3	37.8	30.7
RCP 4.5	1.73	84.1	72.9	61.4	57.6	48.0	38.3	31.2

Average monthly flow distribution for the period 2040-2059 yy

Average monthly flow distribution for the Akhalkalaki 1 HPP has been done according to the existing Paravani HPP hydrological data of the period January 2015 including May 2020.

Table 18. Akhalkalaki 1 HPP monthly flow distribution at intake

Paravani river													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	8.89	9.20	10.76	15.18	19.36	14.05	9.93	8.20	9.05	9.25	8.98	9.16	11.00
RCP 6.0	9.45	9.78	11.44	16.15	20.59	14.94	10.56	8.72	9.63	9.84	9.55	9.75	11.70
RCP 4.5	9.61	9.95	11.64	16.42	20.94	15.20	10.74	8.87	9.79	10.00	9.72	9.91	11.90

In case of Akhalkalaki 2 HPP average monthly flow distribution has been done according to the existing Paravani HPP and the former gauging station data on the Khorkhi river. Monthly distribution has been adjusted slightly to the climate conditions in the watershed.

Table 19. Akhalkalaki 2 HPP monthly flow distribution at intake

Korkhi river													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	2.80	2.89	3.54	6.37	4.84	3.15	2.33	1.59	2.42	3.06	2.85	2.78	3.22
RCP 6.0	2.95	3.04	3.73	6.71	5.09	3.32	2.45	1.68	2.55	3.22	3.00	2.93	3.39
RCP 4.5	3.00	3.10	3.79	6.83	5.18	3.38	2.50	1.71	2.60	3.28	3.06	2.98	3.45

Projected energy generation distribution

As mentioned above the daily flow projections in both Paravani and Khorkhi rivers is not possible and only monthly river flows could be defined based on the methodology and assumption provided in this report.

Consequently, monthly energy generations have been calculated for different scenarios for both HPP schemes.

Table 20. Akhalkalaki 1 HPP monthly generation distribution in GWh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	2.79	2.61	3.37	4.91	5.36	4.52	3.28	2.46	2.75	2.91	2.73	2.88	40.55
RCP 6.0	3.04	2.91	3.59	5.19	5.36	4.84	3.31	2.73	3.07	3.24	3.04	3.21	43.52
RCP 4.5	3.16	2.96	3.66	5.18	5.36	4.92	3.37	2.78	3.12	3.30	3.10	3.27	44.17

Table 21. Akhalkalaki 2 HPP monthly generation distribution in GWh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP 8.5	1.06	0.99	1.16	1.12	1.16	1.12	0.86	0.48	0.87	1.16	1.05	1.05	12.08
RCP 6.0	1.12	1.04	1.16	1.12	1.16	1.12	0.91	0.51	0.94	1.16	1.10	1.11	12.45
RCP 4.5	1.14	1.05	1.16	1.12	1.16	1.12	0.93	0.57	0.95	1.16	1.12	1.13	12.60

Same energy calculations have been done for actual monthly river flows of Paravani and Korkhi rivers to be compared to different energy projections presented in Table 20 and Table 21.

Table 22. Akhalkalaki 1 HPP monthly generation distribution according actual river flows

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Paravani river flow, m ³ /sec	9.13	9.6	11.98	24.2	27.76	21.74	11.62	9.19	8.72	8.93	9.12	8.94	
Generation, GWh	2.87	2.85	3.92	5.18	5.36	5.18	3.65	2.89	2.64	2.80	2.77	2.80	42.91

Table 23. Akhalkalaki 2 HPP monthly generation distribution according actual river flows

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Korkhi river flow, m ³ /sec	3.39	2.39	2.94	6.17	5.07	3.01	2.01	1.71	2.28	2.39	2.38	2.36	
Generation, GWh	1.16	0.80	1.12	1.12	1.16	1.10	0.71	0.57	0.82	0.89	0.85	0.87	11.17

In total Akhalkalaki HPP annual generation based on the actual monthly river flows has been calculated 54.1 GWh, while annual generations for different climate change scenarios for the 2040-2059 years period vary between 52.6 – 56.8 GWh.

The energy generation calculations of Akhalkalaki HPP show that annual generation for the 2040-2059 years period will vary between minus 5% and plus 3% from its planned generation depending on the different scenarios of the GHG emissions, which seems quite in a reasonable range.

Hydraulic calculation for increased peak flows

Akhalkalaki 1 HPP headwork calculation

Akhalkalaki 1 HPP headwork was calculated on $Q_{1\%} = 170 \text{ m}^3/\text{sec}$ and so-called checking discharge $Q_{0,5\%} = 200 \text{ m}^3/\text{sec}$.

Considering the effect of climate changes, the headwork should be recalculated for increased discharges $Q_{1\%} = 198,4 \text{ m}^3/\text{sec}$ and $Q_{0,5\%} = 239,3 \text{ m}^3/\text{sec}$ as a result of the worst scenario RCP 8.5.

The calculations for these increased discharges, were provided by the same methodic and formulas as initial calculations and are provided below.

During providing of maximum discharges, the flooding gates of the flushing orifices should be in fully open position. In this case the water discharge provided through the flushing sluice orifice should be calculated as water discharge through the spillway.

For calculating the water discharge over the spillway, at first, it should be defined, is this water flow over the flushing sluice, submerged or unsubmerged.

The spillway is unsubmerged, when:

$$P + h_{kr} \geq h_b$$

where:

P – is the height of the spillway crest from the river channel bed

h_b – is a water depth in the lower pool of the headwork, for the given discharge

h_{kr} – is the established water depth on the spillway crest and it is calculated by the formula:

$$h_{kr} = k \times H_0$$

where H – is the geometric water head on the spillway crest

Here k – is the coefficient. Its value depends on the form of the inlet part of the spillway crest. This value will be $k=0,76$

H_0 – is the water head on the spillway crest, considering the water inflow velocity:

$$H_0 = H + \frac{v_0^2}{2g}$$

Where H is the geometric water head on the spillway crest and v_0 is the river water flow velocity for a given water discharge.

Water discharge should be calculated by the formula

$$Q = mb\sqrt{2g} \times H_0^{3/2}$$

m – is so called discharge coefficient. Its value depends on the width (length in parallel of the water flow) of the spillway. When the width of the spillway $\delta > (2 - 3)H$ we have the so-called broad spillway. For broad spillway, the value of the discharge coefficient should be $m=0,32$

If $\delta < 0,67H$, in this case we have the spillway with sharps crest, and the discharge coefficient will be $m=0,48 \div 0,49$, according to the shape of the spillway crest.

When $0,57 H < \delta < (2 - 3)H$, we have the so called practical profile spillway and the discharge coefficient for such a spillway depends: on the spillway height, the ratio of the water head over the spillway and the spillway width, the configuration of the spillway, and is in boundaries $m=0,35 \div 0,44$. The data for the discharge coefficient for the practical configuration spillways are presented in a hydraulic manuals, in special tables.

b-is the width of the flushing sluice orifice $b=6,0$ m. But we should also consider the contraction of the water flow through the flushing orifice. In this case, $b_{contr}=e \times b$, where $b=6,0$ m. is the width of the flushing sluice orifice and e is the so-called contraction coefficient, that is calculated by the following formula:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b}$$

where n-is the quantity of the contractions. For Akhalkalaki 1 HPP with three flushing sluice orifices, $n=6$.

ξ is the coefficient, that depends on the form of abutments and for half circular abutments its value is $\xi=0,7$

The calculations for the Akhalkalaki 1 HPP headwork for increased water discharges are provided in the following way considering the different water levels in the upper pond of the headwork, and calculating the provided water discharges through the headwork orifices, until the provided water discharge for the given water elevation, will be equal to the increased rated maximum discharge $Q_{1\%}=198,4 \text{ m}^3/\text{sec}$. Below is provided the final calculation, when a water level in the upper pond, corresponds to the design discharge of $198,4 \text{ m}^3/\text{sec}$.

Water level in the upper pond – 1616,45 m.

For this elevation, the water head over the spillway crest will be $1616,45-1612,70=3,75 \text{ m}$.

Initially is was calculated the water discharge over the spillway, according to assumption that it is the unsubmerged spillway.

The water contraction coefficient will be:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b} = 1 - 0,1 \times 6 \times 0,7 \times \frac{3,75}{18,0} = 1 - 0,0875 = 0,9125$$

The total width of the flushing sluice orifices, considering the calculated contraction coefficient will be $3 \times 6 \times 0,9125 = 16,42 \text{ m}$.

The discharge coefficient, for practical spillways, according to special tables, when spillway height $P < 2,0 \text{ m}$ and $H/\delta = 4,10:3,0 = 1,37$ will be $m = 0,35$

$$H_0 = H + \frac{v_0^2}{2g} = 3,75 + \frac{2,1^2}{19,62} = 3,97 \text{ m}.$$

$$Q = mb\sqrt{2g} \times H_0^{3/2} = 0,35 \times 16,42 \times \sqrt{19,62} \times 3,97^{3/2} = 201,3 \text{ m}^3/\text{sec}.$$

For discharge $201,3 \text{ m}^3/\text{sec}$ the water level in the lower pond of the headwork will be $1611,80+2,10=1613,9 \text{ m}$.

For this discharge:

$$h_{kr} = k \times H_0 = 0,76 \times 3,97 = 3,02$$

$$P + h_{kr} = 1,1 + 3,02 = 4,12 \geq h_b = 2,2$$

It means that we have the unsubmerged spillway, and the calculations provided according to the formulas of unponded spillway, are valid.

So, when the elevation in the upper pond of the Akhalkalaki 1 HPP headwork is 1616,45 m., the water discharge through the headwork gates will be $201,3 \text{ m}^3/\text{sec} > Q_{1\%} = 198,4 \text{ m}^3/\text{sec}$.

For this water elevation, with some reserve, the elevation of the side walls and intermediary piers of the headwork, from the upper pond side, should be $1616,45+0,4=1616,85 \text{ m}$.

According to headwork design, the elevation of the side wall and piers of the Akhalkalaki 1 HPP headwork is 1617,20 m. So the headwork can provide the increased $Q_{1\%} = 198,4 \text{ m}^3/\text{sec}$ water discharge. It also can provide the $Q_{0,5\%} = 239,3 \text{ m}^3/\text{sec}$ water discharge, according to following calculation:

Water level in the upper pond – 1617, 0 m.

For this elevation, the water head over the spillway crest will be 1617,00-1612,70=4,30 m.

The water contraction coefficient will be:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b} = 1 - 0,1 \times 6 \times 0,7 \times \frac{4,30}{18,0} = 0,90$$

The effective width of the flushing sluice orifices, considering the calculated contraction coefficient will be $3 \times 6 \times 0,9 = 16,2$ m.

The discharge coefficient, for practical spillways, according to special tables, when spillway height $P < 2,0$ m and $H/\delta = 4,10/3,0 = 1,37$ will be $m = 0,35$

$$H_0 = H + \frac{v_0^2}{2g} = 4,3 + \frac{2,2^2}{19,62} = 4,54 \text{ m.}$$

$$Q = m b_e \sqrt{2g} \times H_0^{3/2} = 0,35 \times 16,2 \times \sqrt{19,62} \times 4,54^{3/2} = 243 \text{ m}^3/\text{sec.}$$

It means, that when water elevation in the upper pond is 1617,0 m, the headwork can provide $Q_{0,5\%} = 239,3 \text{ m}^3/\text{sec}$ water discharge.

The wall crest elevation, according to design is 1617,2 m. So, the design headwork of Akhalkalaki 1 HPP is reliable also for increased check discharge.

Akhalkalaki 2 HPP headwork calculation

The Akhalkalaki 2 HPP headwork, originally was calculated for the discharges: $Q_{1\%} = 65 \text{ m}^3/\text{sec}$ and $Q_{0,5\%} = 75 \text{ m}^3/\text{sec}$.

Due to climatic changes projections, the headwork calculations should be checked for increased discharges: $Q_{1\%} = 75,9 \text{ m}^3/\text{sec}$ and $Q_{0,5\%} = 87,5 \text{ m}^3/\text{sec}$.

The calculation methodology and the formulas are the same, that was used for initial calculations.

The designed Akhalkalaki 2 HPP headwork consists of:

6 m long spillway with Tyrolean type water intake orifices. Spillway crest elevation 1627,5 m.

2,5 m wide flushing sluice – elevation 1626,0 m.

8,6 m wide spillway weir – elevation 1628,0 m.

Rated water intake discharge – $2,8 \text{ m}^3/\text{sec}$.

The spillway is submerged, when:

$$P + h_{kr} \geq h_b$$

where:

P – is the height of the spillway crest from the river channel bed.

h_b – is a water depth in the lower pool (tailwater) of the headwork, for the given discharge.

h_{kr} – is the established water depth on the spillway crest and it is calculated by the formula:

$$h_{kr} = k \times H$$

For non-submerged flow, the provided water discharge should be calculated by the formula

$$Q = m b_e \sqrt{2g} \times H_0^{3/2}$$

m is discharge coefficient. For Akhalkalaki 2 HPP, based on spillway crest form and size, the discharge coefficient for spillway weir section will be $m=0,48$ and for water intake section of the weir $m=0,40$.

b_e is the total effective width of the spillway weir sections: 6,0 m for water intake section and 8,6 m for spillway sections.

e is a contraction coefficient, which is calculated by the following formula:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b}$$

where n is the number of contractions. For each sections of the weir, $n=2$;

ξ is a coefficient that depends on the form of abutments and for half circular abutments its value is $\xi=0,7$

The calculations for the Akhalkalaki 2 HPP headwork are provided in a similar manner as calculations for the Akhalkalaki 1 HPP headwork. Different water levels in the upper pond of the headwork are considered, and water discharges through the spillway weir orifices are calculated, until the water discharge for the given water elevation is equal to the increased design discharge $Q_{1\%}=75,9 \text{ m}^3/\text{sec}$.

According to prepared design, the wall crest elevations of the headwork, from the upper pond side is 1630,5 m. It means, that a water level in the upper pond can be 1630,2 m. Below are provided the calculation of the water discharge through the headwork, when water level in the upper pond is 1630,2 m.

Water level in the upper pond – 1630, 2 m.

For this elevation:

The water head over the spillway crest will be $1630,20-1628,00=2,20$ m.

The water head over the water intake weir section crest $1630,20-1627,50=2,70$ m.

The water head over the flushing sluice orifice threshold $1630,20-1626,0=4,2$ m.

The water contraction coefficients for each section of the headwork, will be:

For spillway weir:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b} = 1 - 0,1 \times 2 \times 0,7 \times \frac{2,20}{8,60} = 0,96$$

$$b_e = 0,96 \times 8,60 = 8,26 \text{ m.}$$

For water intake section of the weir:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b} = 1 - 0,1 \times 2 \times 0,7 \times \frac{2,70}{6,00} = 0,94$$

$$b_e = 0,94 \times 6,00 = 5,64 \text{ m.}$$

For flushing sluice:

$$e = 1 - 0,1 \times n \times \xi \times \frac{H}{b} = 1 - 0,1 \times 2 \times 0,7 \times \frac{4,20}{2,5} = 0,76$$

$$b=0,76 \times 2,5=1,9 \text{ m.}$$

Accordingly, for the different sections of the weir, the discharge will be

By spillway weir:

$$Q = mb_e \sqrt{2g} \times H_0^{3/2} = 0,48 \times 8,26 \times \sqrt{19,62} \times (2,20 + 0,2)^{3/2} = 65,3 \text{ m}^3/\text{sec.}$$

By water intake section of the weir:

$$Q = mb_e \sqrt{2g} \times H_0^{3/2} = 0,40 \times 5,64 \times \sqrt{19,62} \times (2,70 + 0,2)^{3/2} = 49,3 \text{ m}^3/\text{sec.}$$

By flushing sluice:

$$Q = mb_e \sqrt{2g} \times H_0^{3/2} = 0,35 \times 1,90 \times \sqrt{19,62} \times (4,2 + 0,2)^{3/2} = 27,2 \text{ m}^3/\text{sec.}$$

In total, the discharge will be $65,3+49,3+27,2=141,8 \text{ m}^3/\text{sec}$ which is more than the design discharge $Q_{1\%}=75,9 \text{ m}^3/\text{sec}$. and checking discharge $Q_{0,5\%}= 87,5 \text{ m}^3/\text{sec}$.

With closed flushing sluice gate, the headwork can provide $65,3+49,3=114,8 \text{ m}^3/\text{sec}$, that is also more than the increased discharges of climate change projections $Q_{1\%}=75,9 \text{ m}^3/\text{sec}$ and $Q_{0,5\%}= 87,5 \text{ m}^3/\text{sec}$.

So, we can conclude that designed headwork of Akhalkalaki 2 HPP will be reliable in conditions of increased projected discharges for the worst-case scenario of climate change.

Conclusion

As a conclusion it should be noted that Akhalkalaki HPP project generation will not be affected even by the climate change worst-case scenario and the project's current characteristics will not be significantly changed.

Both headworks of Akhalkalaki 1 HPP and Akhalkalaki 2 HPP can be reliable for the increased water flow discharges projected by the climate change worst-case scenario and no additional prevention measures need to be conducted in the design of the Akhalkalaki HPP project.