Quality report review of the hydrogeological and natural hazards ESIA studies for Nenskra HPP, Georgia.

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Summary

Hydropower plants are widely considered as a low emission of greenhouse gasses investments and less harmful for the environment than coal or nuclear power plants. That is true in general, but it also depends on the scale and location of such an investment. The object of interest in this review is a 280 Megawatt planned hydropower plant on the Nenskra River in the Caucasus Mountains, Georgia. Main components of the investment are (Buffin, Bukowski 2017):

- the dam – 130 meters high and 870 meters long with asphalt face and filled with rocks;
- the reservoir – area of 2,67 square kilometres and capacity of 176 million cubic meters;
- the Nakra water intake – additional Nenskra water supply (45 m^3/s) of the Nenskra Hydropower Plant and a 12,25-kilometer long tunnel to transfer the water;
- the power waterway – a 15,5-kilometer long headrace tunnel, a pressure shaft and undergoing penstock of 1790 meter length.

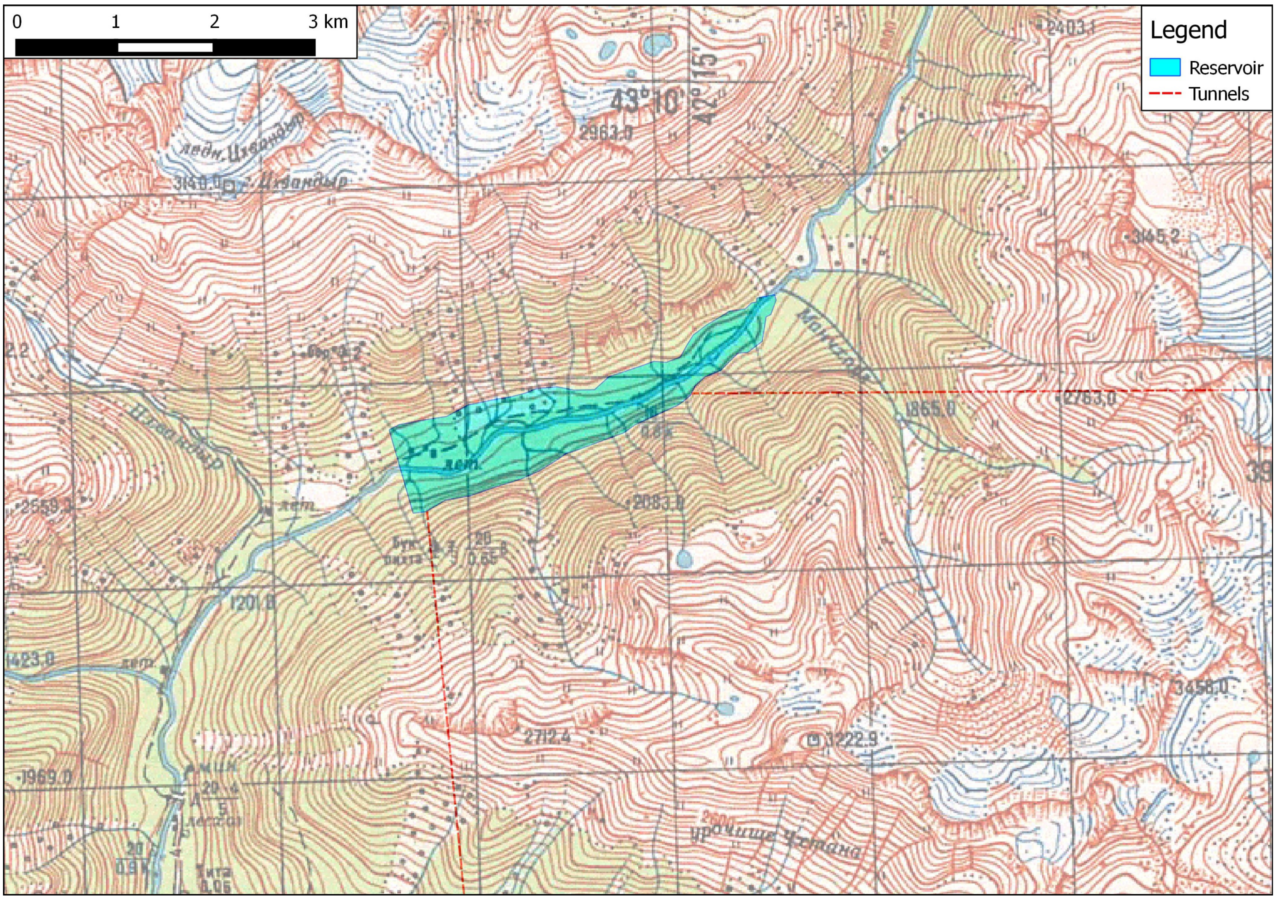

Fig. 1. Topographic Map of the HPP Nenskra.

The quality review analyses mostly hydrogeologic impact of the Nenskra HPP on water resources. The most problematic consequence is triggering mass wasting during construction works and filling the reservoir. They can be dangerous for the dam and be devastating for valuable habitats on the slopes of Nenskra valley. Another negative impact is a change of sedimentary aquifer upstream the projected dam, which can lead to suffosion and pose a threat to its construction. According to the author's opinion, all the aspects of hydrogeological and hydrological consequences connected with the HPP Nenskra should be a subject of a numerical hydrogeological model.

Methodology

The main goal of this quality review is to do a critical analysis of hydrogeological and hydrological aspects connected with the Nenskra Hydropower Plant. To achieve the goal three main tasks were done. First of them is the analysis of geological, hydrological and hydrogeological settings of the projected investment site.

The second task is the GIS analysis. The Geographic Information System (GIS) analysis is widely applied to illustrate different issues on maps. In this review the analysis concentrated on overlaying layers with different sorts of information: topography with geomorphology (landslides), geology (types of rocks, faults, cross section line), hydrology (rivers, springs, watershed, glaciers) and projected investment (reservoir, dam, tunnels). The overlaying helped to make different maps showed in a separate paragraph and to measure distances, areas and to assess the scale of different phenomena and impacts between the projected investment and different components of the environment (water resources, relief).

The last task is the critical analysis of the Environmental and Social Impact Assessment aspects concerning hydrogeology, hydrology and natural hazards. There are described in the last chapter problems which were ignored or insufficiently analysed in the original ESIA report.

Geologic and hydrogeologic settings

The oldest rocks of Nenskra catchment area occur in the northern part. This belongs to the Fold System of the Greater Caucasus, Main Range zone. Prevailing rock type is Macera metamorphic complex, that consists of crystalline schists, plagio-gneiss, granite-gneiss, plagio-migmatites, granite-migmatites, metagranites and amphibolites. This rock complex belongs to the series of Greater Caucasus, Main Range zone, and its age is Proterozoic and Lower Paleozoic. In other stratigraphic classifications, it is divided into Nakra formation and Dolrini formation and the latter one is bedrock also of the dam location site. Within this rock complex, there are intrusions of plutonic rocks. They are upper Paleozoic microcline granites, granodiorites and plagiogranites and their gneissic varieties. There are two distinctive dislocations of NW-SE direction illustrated on Fig. 2.

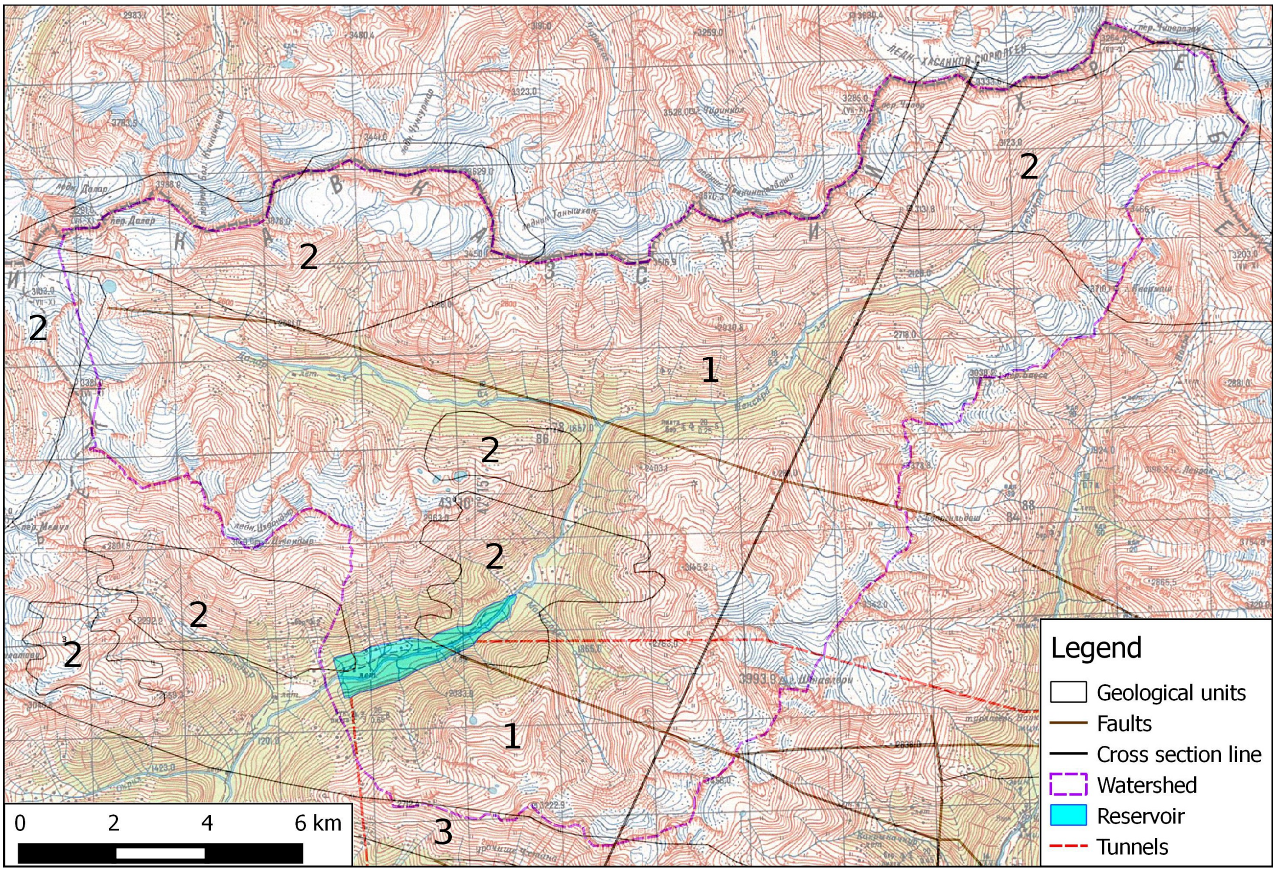

Fig. 2. Geological map of HPP Nenskra on topographic background. Types of rocks: 1 – Macera metamorphic complex (crystalline schists, gneisses, migmatites); 2 – plutonic rocks intrusions (granitoids, granodiorites); 3 – quartz-diorites.

The Nakra catchment area adjacent to the Nenskra catchment from the east. This area is built also of the Macera metamorphic complex and plutonic rocks intrusions within. The same two dislocations cut the Nakra valley (Gudjabidze, Gamkrelidze 2003, Gamkrelidze et al. 2009, Gvakharia 2015).

Metamorphic and plutonic rocks in the area of interest are covered by different Quaternary (Pleistocene and Holocene) sediments (Gvakharia 2015):

- glacier deposits – gravel, sand and silt (thickness up to 60 m) covered by younger sediments;

- fluvial channel deposits – mostly blocks, gravel and sand, which thickness ranges from 20 m to 40 m;
- alluvial fan deposits – blocks, gravel, sand, and silt, which thickness is up to 80 m;
- slope debris – blocks, sand and silt created by rock material movement downward, which thickness ranges from 10 m to 45 m;
- alluvial deposits – occurring along Nenskra River channel and consisting of gravel, blocks, sand and clay, which thickness is up to 120 m.

According to the data from 8 boreholes located at the projected dam site the bedrock Dolrini formation is covered by Quaternary deposits. Their thickness ranges from 20 m to 127 m. These are permeable sediments divided by impermeable layers of silt and clay. Even the upper part of Dolrini formation rocks is permeable because of fractures (vertical and horizontal) and weathered parts of bedrock.

The Nenskra River Basin covers an area of 614 square kilometres and the Nenskra River catchment upstream the projected dam site covers 222 square kilometres. This catchment average elevation is 2650 m. a. s. l. and mean annual discharge 16,2 cubic meters per second that give 74 litres per second from each 1 square kilometre. The Nakra catchment area upstream the projected intake is 87 square kilometres and its average elevation is 2750 m. a. s. l. Mean annual discharge is 9,2 cubic meters per second that give 113 litres per second from each 1 square kilometre (Bukowski, Cazaillet 2017).

Chemical analyses of Nenskra and Nakra river water samples showed that the composition of the water is typical for such rivers low electrical conductivity (50-91 µS/cm) suggests low values of Total Dissolved Solids. In fact, concentrations of main ions are low: Calcium (0,36-0,69 meq/l), Magnesium (0,16-0,25 meq/l), Chlorides (<0,3 mg/l) and Sulphates (8,7-10,0 mg/l). The higher values of Calcium and electrical conductivity were found only in Nakra river water samples. Lack of sodium, potassium and bicarbonate ion does not let us assess the chemical type of water and Total Dissolved Solids, but even from these incomplete data we can notice that the Nenskra and Nakra river water samples represent lower values of electrical conductivity and most of the analysed ions from sample taken from a site where the reservoir or weir is projected than the other sampling locations located downstream. This can be caused both by an anthropogenic and geogenic factor (Bukowski, Cazaillet 2017).

Besides the river water also spring water was analysed and two types of spring water were analysed: drinking water and mineral water. Potable spring water in Nenskra valley had higher electrical conductivity (190 µS/cm) than river water but still it is low value, while mineral spring water represented much higher electrical conductivity (1733 μS/cm) and some specific ion were detected in the chemical analysis like Arsenic, Beryllium, Boron, Lead, Manganese, Selenium, Iron and Fluorides (Bukowski, Cazaillet 2017).

Analysis of the hydrogeology and natural hazards raised in the ESIA of the Nenskra Hydropower

Mass wasting. Hydrologic research with some hydrogeological problems described in the Environmental and Social Impact Assessment concentrates on the part of the Nenskra River catchment downstream from the projected dam site, but it does not analyse the impact on groundwater around the projected reservoir. When the water level rises in the projected reservoir, so will do groundwater table in the area adjacent to the reservoir shores (Domenico, Schwartz 1990, Bukowski, Cazaillet 2017). This will lead to develop the saturation zone and to extend the aquifer on the Nenskra River valley slopes which are very steep (up to 40 degrees). Parts of the slopes now located in the unsaturated zone will be saturated with groundwater. This will result in friction decrease, slope stability disturbance and it will lead to developing landslides and stone avalanches both under water and near the reservoir shores. Such a phenomena can be observed now in the Nenskra Valley, but after building the projected hydropower they will be more frequent and their extent will become larger. These phenomena can be also triggered by earthquakes which happen in this area and the earthquakes will be more often due to induced seismicity caused by the mass of the dam and water stored in the reservoir. When lower parts of the Nenskra valley slopes are undercut by landslides and avalanches, a domino effect may start and higher parts of the slopes will be taken up by these phenomena, which will destroy many valuable habitats on the slopes of the Nenskra valley. The dam also can be damaged by such artificially induced landslides. Landslides and avalanches may rapidly put a lot of rocks and other material into the projected reservoir. This will result in the rapid rise of water level in the reservoir and in some cases it may cause unexpected water spillage over the dam. This will lead to unexpected floods in the Nenskra valley downstream the projected dam. All the described phenomena should an object of numerical hydrogeological model and slope stability model. The phenomena described in this paragraph were insufficiently described in different chapters of the ESIA, vol. 5.

In the ESIA, vol. 6 there is described a slope stability assessment based on satellite radar interferometry. This is a proper monitoring method for existing mass wasting, but this is insufficient for predictions because there are other factors, like the described in this chapter, resulting in triggering new landslides. Landslides and other types of mass wasting risk can be rated as very high, while the risk of water spillage over the dam can be rated as low. Only some of the mass wasting will start above the water level of the reservoir and move into the water body during the highest water stage.

Hydrogeological interactions change. A Large mass of the dam and the water in the reservoir induce additional seismicity and this will lead to a change of hydrogeological interactions between groundwater and surface water and between shallower and deeper aquifers. Construction of the dam will divide sedimentary aquifer into two parts of different hydrogeological properties. While the upstream part of laying under the reservoir will be under high hydraulic pressure, the downstream part will have far lower hydraulic pressure and under the dam, there will be a high hydraulic gradient. When the reservoir operates at the highest water stage the hydraulic gradient will be as high as 30%. This means that groundwater will flow downstream with the highest velocity under the dam both in the sedimentary and crystalline aquifer. This will lead to suffosion and may be dangerous for the dam construction, especially due to land subsidence and seismic activity of this area. In the author's opinion, construction of the diaphragm wall in the alluvial deposits is insufficient because fluvioglacial deposits are also very permeable and there are usually many hydraulic contacts between them. So grouting some parts of sediments or building the wall will not eliminate the risk of suffosion and land subsidence. This risk was ignored in the ESIA, vol. 5., but it can be rated as high.

The impact on local climate. The projected reservoir will influence also on local climate within a distance of a few kilometres from the shores. Due to water evaporation, such large water bodies decrease air temperature amplitudes and rise relative air humidity. After filling the Jhvari reservoir an increase of air humidity was observed (UNDP 2014). The first phenomena will lead to higher air temperatures in winters and lower ones in summers. However, higher air humidity may cause higher water content in the ground. This can play as an additional factor leading to happen landslides and rock avalanches more frequent. These phenomena were described in the ESIA, vol. 5, section 8.3. It is difficult to classify the above-described risk because it will be dominated by hydrogeologic factors described previously.

Melting glaciers impact. The area of interest is a catchment of Nenskra above the dam location. Besides geological and tectonic settings it is also needed to determine climate conditions and its predicted changes in the future. General information about mean annual air temperature ranges from +2ºC to +4 ºC in the valley but drops below zero on the Caucasus Ridge. Annual mean precipitation in Lakhami is 1267 mm, but it rises along with altitude and reaches 3200 mm per year on the highest mountain ranges. Low air temperatures and high precipitation are the main cause of glaciers presence in the highest parts of Nenskra catchment (Gvakharia 2015). In 2014 there were 67 glaciers in the Nenskra Basin and they covered 25,58 square kilometres. But in 1960 there were 75 glaciers and they covered 48,62 square kilometres (Tielidze et al. 2015). This means that climate change causes rapid melting of the glaciers. If the glaciers melting rate in the Nenskra Basin were constant, the last glacier in this area would disappear until 2075. Rapid melting of the glaciers results in water retention decrease and a general change of Nenskra flow regime, especially in the upper part of its basin. Flash floods may become more rapid and water stages during these phenomena may be higher. All the hydrological phenomena related to climate change should be modelled and their impact on the projected hydropower plant should be predicted, the especially influence of more rapid flash floods on the dam and water spill over the dam. Hydrologic consequences of climate change and glaciers melting were described in the ESIA, vol. 5, section 8. The climate change risks described in this paragraph can be rated as high.

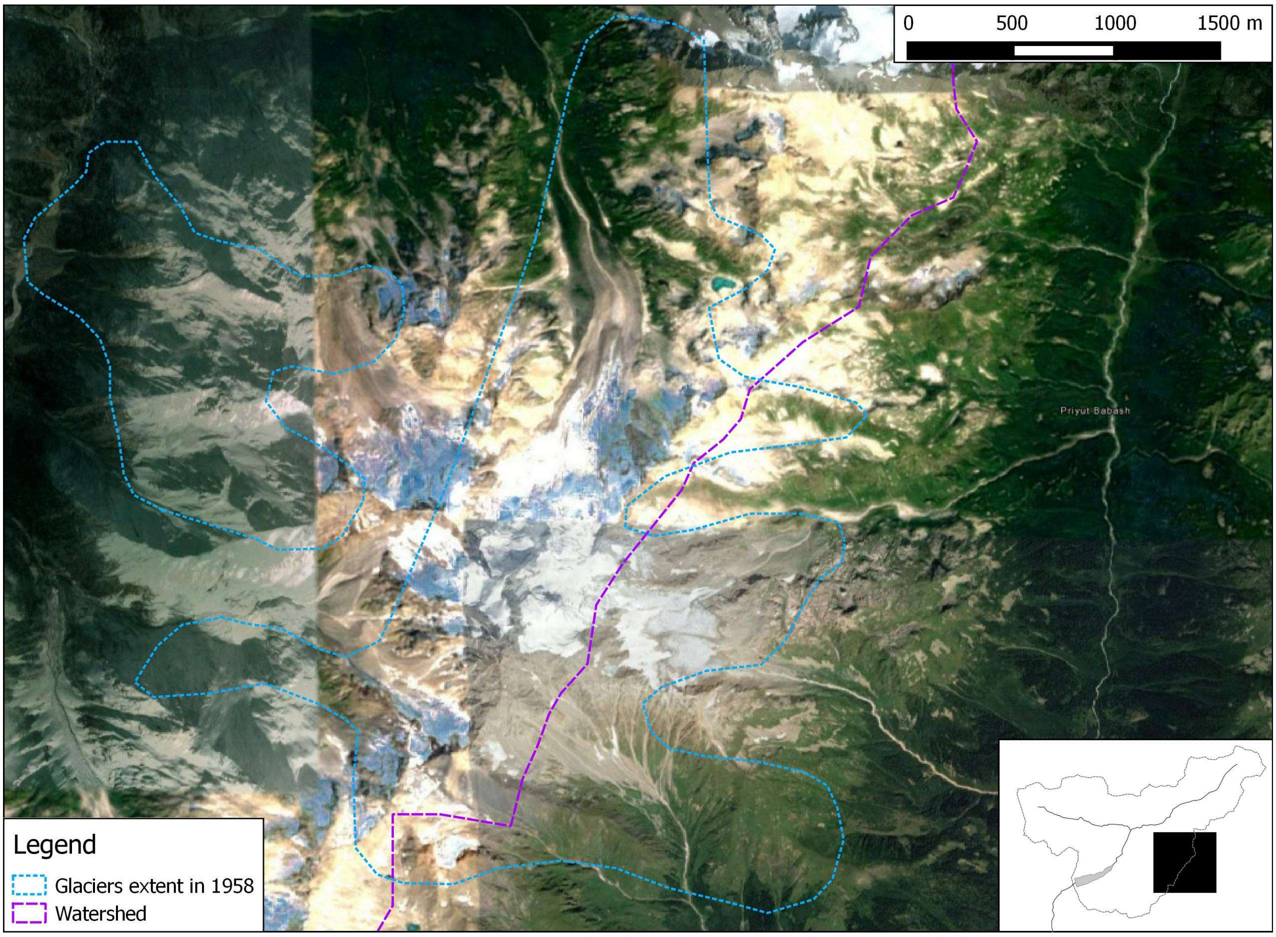

Fig. 3. Melting of Shdavleri Glacier compared to its previous extent in 1958.

During analysis of Nenskra watershed in Dalari Glacier area, a controversy appeared. According to the authors of the ESIA (Bukowski, Cazaillet 2017), the watershed runs partially across the Dalari Glacier Valley as a straight line with only two points where the watershed changes direction. In a terrain of such a complicated topography (mountain range), it is not sufficient. The watershed should be conducted more carefully because this area is mostly glaciated and relatively large area of Nenskra catchment may be excluded – up to 3 square kilometres which are 12% of all glaciated area (Fig. 4). The glaciated area difference of this magnitude can lead to wrong conclusions about Nenskra flow regime predictions during climate change described in the previous paragraph and may result in similar consequences. The risk can be rated as high.

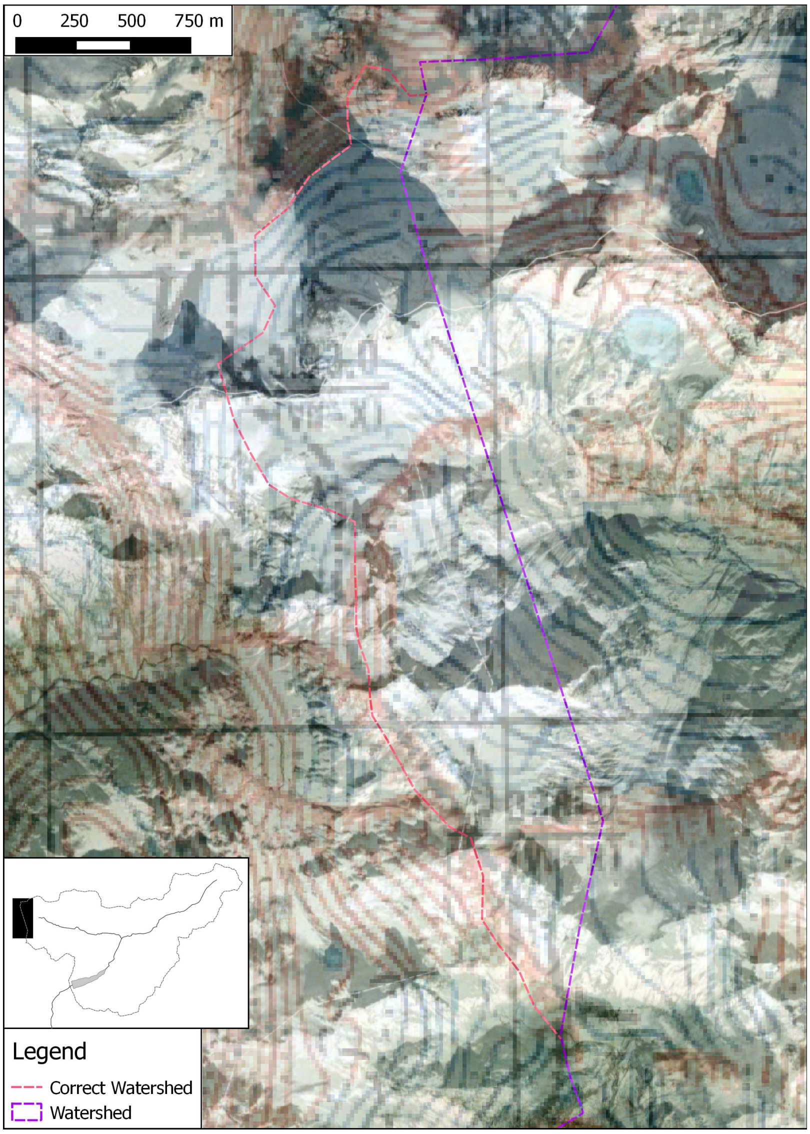

Fig. 4. The corrected watershed of Nenskra in Dalari Glacier area.

Insufficient hydrogeological information. The ESIA gives very little information about groundwater and hydrogeological conditions of the area of interest. For example, the older report (Gvakharia 2015) in spite of analysing the borehole data does not give any information about the groundwater present in the projected dam site except an enigmatic information about the lack of groundwater table. According to the state of the art in hydrogeology, permanent rivers in temperate climate zone drain groundwater from aquifers. The aquifer in the Nenskra valley is mostly the cover of Quaternary deposits described above: alluvial, fluvial and glacial ones. The aquifer lithology (blocks, gravel and sand) suggests very good permeability of the sediments. Moreover, described fractures and weathered parts of bedrock (Dolrini formation) can be another type of aquifer, probably in hydraulic connection with the overlying sedimentary aquifer. Therefore, it is almost impossible that there is no groundwater in the Quaternary sediments mentioned above. If it were, the Nenskra River would be periodic instead of permanent as it can be observed in arid climate areas like deserts. In the ESIA, vol. 5 there is no information about hydrogeological characteristics of the rock formations such as thickness or filtration coefficient of the aquifers.

Impact on the springs and water intakes. In the ESIA report (Bukowski, Cazaillet 2017) on page 67, it is written that springs discharge are little affected by river water levels. Actually, the river water level influences on the springs discharge depending on the scale and duration of river water level change. Especially during filling the projected reservoir with water when mandatory ecological flow would be 0,85 cubic meters per second. This is about 20 times less than the average annual flow of the Nenskra River at the projected dam site and an average water stage would be lower too. Lowered Nenskra water stage will result in lowering of groundwater table and this will affect on springs and groundwater intakes which yield decrease. Similarly, in the Nakra Valley such a flow reduction to an average 1,2 cubic meters per second, will be observed. This will also decrease the yield of springs and groundwater intakes. The risk was described in the ESIA, vol. 5, section 5, but it can be rated as medium because it strongly depends on the distance from the dam and the river flow regime.

Impact on mineral springs. The projected investment will affect the local system of faults and fractures. Some of them can be tightened while the other ones can be widened and this will result in different paths of groundwater flow in the crystalline aquifer (Dolrini formation), that in turn can affect on the mineral spring located about 4 kilometres downstream from the projected dam site. Medical (Balneological) properties of the water from this kind of spring depend both on its discharge and on chemical composition and other chemical properties. The properties of such springs strongly depend on groundwater flow paths and regime and very little is known about them in this area. Another threat for mineral springs are the tunnel construction works. The Tunnel

Boring Machine will cut many fractures and faults on its way. Both mineral and freshwater springs drain the water flowing through such fractures and faults and if they are cut they will be drained by the tunnel instead by the spring. This will cause yield decrease of such a nearby spring until it dries out. In some cases, tunnel construction works may lead to groundwater pollution or significant change of chemical composition of the mineral spring water. For example, when rocks containing sulphide ore minerals are cut and exposed to atmospheric oxygen and water, sulphur oxidises to sulfuric acid and dissolves minerals of the rock complex. This leads to a growth of general water hardness, sulphate concentration and a presence of heavy metals and radionuclides in water and changes significantly chemical properties of spring water and may lead to its pollution or loss of its balneological properties. The above-described negative impacts on springs usually last many years after the tunnel construction. In the Nakra Valley, there is a mineral spring discovered during the construction works near the projected water intake and tunnel. For this spring this threat is particularly high due to the reasons described above. The issues described in this paragraph should be also subjects of the numerical hydrogeological model for this investment. Some of the impacts described in this paragraph were described in the ESIA, vol. 5, section 5.4. The risk can be classified as medium and strongly dependent on topographic, geologic and hydrogeologic conditions and relations between a spring and in investment infrastructure.

Oil spill risk. Specific kind of groundwater pollution will appear during the construction phase of this investment. An oil spill from the working machines during building the projected dam or the tunnels is a real threat to water resources because 1 litre of this liquid can pollute up to 5000 cubic meters of water (volume ratio 1: 5 000 000). Even if the oil spill happens not directly to the water, but into the ground, it is still a threat because groundwater vulnerability for pollution in this area is very high. The rocks building the unsaturated zone represent mostly good and very good permeability (sand and gravel) and the groundwater recharge is high due to relatively low mean air temperature and high annual precipitation. Due to the scale of investment and a number of machines used to build the dam and the tunnels overall probability of oil spill is high and therefore this is a real threat to water resources. In the ESIA, vol. 5 this risk was mentioned in Table 47.

Conclusions

The problems described in this review lead to the following conclusions:

1. Water level rise in the projected reservoir will result in the occurrence of new landslides and stone avalanches both underwater and in the area adjacent to the reservoir shore. Higher air humidity caused by the reservoir may cause the mass wasting more frequent.
2. Induced seismicity by the infrastructure will cause landslides and avalanches more frequent.
3. Building the projected dam will divide the sedimentary aquifer into two parts of different hydrogeological properties.
4. High hydraulic gradient will be the cause of intense groundwater flow and can lead to suffosion and land subsidence under the dam.
5. Glaciers melting in the Nenskra valley will result in a change of Nenskra flow regime. Overall retention capacity of the catchment will decrease and it may be expected water levels getting higher during floods.
6. Watershed in the Dalari Glacier area needs to be corrected and assessed more carefully in order to avoid wrong data of the water balance of the Nenskra River Basin.
7. Information about the lack of groundwater table in the boreholes made on the site of the projected dam is the most likely incorrect and needs to be verified.
8. During filling the projected reservoir with water both the Nenskra River average water stages and groundwater table will be lowered and this affects on lower yields of springs and water intakes.
9. The weight of the dam and the reservoir will affect on underlying aquifers and will change groundwater flow paths. This can lead to the change of spring properties: discharge and water chemical composition.
10. Oil spill is a serious threat of groundwater pollution not only directly to water but also to the ground, because of high groundwater vulnerability.

Annexes

1. Buffin D., Bukowski N., 2017, Project definition. [in:] Nenskra Hydropower Project. Supplementary Environmental & Social Studies. SLR Consulting.

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