Working hypotheses on the hydropower resources’ involvement in the structure of the mountainous areas’ economic framework

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Abstract. The hydropower resources of the Kabardino-Balkarian Republic (Kabardino-Balkaria (KBR)) are estimated at 3 thousand MW, however, the total generation of the functioning hydroelectric power stations does not exceed 160 MW, or only 5.3% of the potential river capacity [1]. Neither the presence of a series of the programs for hydropower development, nor the favorable conditions for the technologies’ import, nor the economic feasibility studies for the projects have improved the situation. The persistently not decreasing imbalance in the electric power industry structure in the mountain zone became the motive for a new attempt to actualize the indicated problem. The implementation of the idea will be an important step in “embedding” the Russian research in the field of mining hydropower in the international context of the transition to the renewable energy sources.

The purpose of the article is to publicly discuss the most important agenda for the republic - the overdue optimization of the electric power industry structure, the understanding of the possible options for involving the mountain rivers with slightly changed hydrological parameters. The objectives of the publication are:

– the suitability study of the small tributaries supplying the main mountain rivers for generating electricity;
– identification of the river sections, in the first approximation, possessing the favorable technical and economic indicators, for involvement in the electric power industry;
– study of the necessity and possibilities of regulating the mountain rivers’ flow;
– formulation of the hydropower units’ relative position working hypothesis.

The authors consider the underestimated hydropower potential of high mountain small tributaries of the rivers, which have high water pressure (from 25 to 100 m). The relevance of their involvement is also due to the steady growth of point energy consumers in the mountains, for which the autonomous power plants are the optimal source of energy supply. Such suppliers of energy resources can be small and ultra-small hydropower plants, the technological characteristics of which adequately fit into the natural specifics of the mountain valleys [2].

The article does not share the widespread opinion about the categorical inadmissibility of the water-accumulating structures’ creation in the mountains. Without denying the presence of limiting environmental and technological factors for the water-regulating objects’ construction in the mountain zone, the article draws attention to the fact that they are not critical and are
completely solvable by searching for compromises, including the choice of the optimal alignment for placing the hydraulic units.

Introduction

Despite the relatively good knowledge of the main mountain rivers’ hydrology, the available data are not enough to expand the natural base of the hydropower economy and bring it into line with the forecast resource requirements of the ambitious “Strategy for the Social and Economic Development of the KBR until 2035”. The largest mountain river Malka of has not found any application in the electric power industry in the Republic. Involving the underestimated potential of the high-altitude “sheaf” of small tributaries, which are maximally adapted to the global trend towards the autonomy of high-altitude energy consumers, can also be a constructive step in solving this problem.

The publication was based on the stock materials from the previous hydropower studies. During several expeditions, the authors assessed the geomorphological conditions of the rivers’ upper reaches and studied their ecological situation. In formulating the working hypotheses for involving the hydropower resources, the KBR territorial planning scheme and cartographic materials of a scale of 1:25000 were used. Such hydropower characteristics of the rivers as the process of determining the flow rate of watercourses that do not have hydrometric observations; the calculation of the hydropower current size, are not considered in the article, assuming that these issues have been considered earlier (Kalov, 2016, 2018, 2019).

Results

Based on the updated materials on the nutrition nature, the structure of the basins, the characteristics of the rivers’ longitudinal profile, the hydrographic network of the mountainous areas is conditionally divided into 3 zones [3]:

1. The zone of alpine runoff, representing a “sheaf” of small tributaries that nourish the main rivers of various orders of predominantly glacial nutrition.
2. The zone of the main mountain valleys collecting the tributaries waters of all types and diverting them outside the mountainous regions.
3. The zone of minor rivers (Nalchik, Shalushka, etc.) ice-free (snow, rain, ground) nourishment.

In the framework of this approach, as a first approximation, 16 river sections were identified as convenient for the construction of various types of hydraulic units. Three sections of them are located on the river Malka (Kichmalkinsky, Lakhransky, Kamennomostsky), four - in the main valley of the river Baksan (Itkolsky, Gizhghtsky, Bymymsky, Zhanhoteksky), one - on the river Cherek (Lake Cherek-Köl), one - on the river Cherek-Khulamsky, two - on the river Chegem (Verkhnechegegskoe and Su-Auzu) and five - on the small tributaries of the Baksan river (Donguz-Orun, Adyr-Su, Yusungi, Syltran-su, Kyrtyk).

The most pronounced sheaf system of tributaries was formed by the river Baksan. The use of the upper tributaries can be associated not only with zonal differences, but also with a significant differentiation of the intrazonal natural parameters: the underlying surface, the exposure of the slopes, etc. [4]. The indicated diversity is reflected in the formation of the runoff on the Baksan tributaries, in their spatial and temporal variability. An extensive network of tributaries, in turn, based on altitude differences, can be divided into 3 subsystems.

Small rivers of the upper “sheaf” are located in the nival-glacial zone, the basin of which is localized within 1800–1900 m, flowing into the main watercourse approximately to the village Tegenekli (Table 1).

**Table 1. High-altitude systems of the river Baksan tributaries**

| No. | High altitude tributary systems | Distance from the river source [km] | Area catchment area [km²] | Average catchment height |
|-----|---------------------------------|-----------------------------------|--------------------------|-------------------------|


In addition to zonal natural factors, the nature of the runoff spatiotemporal variability of this group of small tributaries is also due to azonal factors (exposure of the slopes, specifics of the underlying surface, etc.). A consequence of the steady decline in glacial landscapes is the episodic hollow-like expansion of valleys (Yusengi River, Donguz-Orun, Terskol). Glacial erosion processes also led to the longitudinal river profiles’ stepping: mudflows from slopes and side gorges, mountain landslides cluttered the gorges, creating high water drops and increased specific power in the short valleys (tracts Tyubele and Kamyk), being a favorable condition for the small hydropower plants’ installation.

From this group of small rivers, the Donguz-Orunsky target (below the confluence of the Azau and Donguz-Orun rivers) can become the highest high-altitude development zone. Its head position in relation to other waterworks makes it possible to assign a certain stock-regulating function to it. The geographical proximity to the steadily expanding resort sector of the Elbrus region actualizes the potential demand for the power unit. With a specific power of the river up to 3.5 MW, a hydropower plant can provide a minimum of the reduced costs and the cost of electricity [5].

Table 2. Hydropower characteristics of higher pressure small tributaries of Baksan in its middle course

| River name | Pool area [km²] | Average long-term water consumption [m³/sec] | Specific pressure [m] | Power density per 1 km of derivation [MW] |
|------------|----------------|---------------------------------------------|----------------------|---------------------------------------|
| Adyl-su    | 90.0           | 2.2                                         | 80                   | 1.40                                  |
| Irik       | 85.0           | 1.7                                         | 170                  | 2.35                                  |
| Adyr-su    | 120.0          | 5.8                                         | 115                  | 5.40                                  |
| Kirtyk     | 130.0          | 1.3                                         | 160                  | 1.68                                  |

It is easy to notice that the specific power of most high-mountain rivers exceeds 2 MW, which predisposes to the deployment of a wide range of hydraulic installations on them, characterized by the simplicity of construction, operation and maintenance (Table 2) [1]. The choice of a specific unit should be determined by the technical parameters of the alignment, taking into account the prospective aggregate demand for electricity in the area.

Particularly high favorable for hydropower construction in this tributaries group is characterized by the river Adyr-Su (right-bank tributary of the Baksan River). As an alignment, it is possible to take its 5-kilometer section with a specific pressure of 115m. The laying of a 4-kilometer derivational tunnel (about 500 m of which is underground) in the area of its transition to the Baksan Valley will make it possible to count on a rather high power of 25 MW [6].
Below Tyrnyauz, the specific power of the Baksan tributaries is noticeably reduced. The riverbeds, broken into the river arms, with a thick layer of sediment, will not allow for high water pressures. Therefore, the involvement of tributaries up to the village Zayukovo can be caused only by socially significant socio-economic demand for electricity in a specific area.

Thus, a number of free investment sites are visible in the upper reaches of Baksan. To activate the private capital in the study area, it is advisable to send clear signals to the hydropower business about the desired goal of the republican authorities and a transparent project support system. The attractiveness of investing in the hydropower sector can somewhat increase the steady trend of glacier degradation, as a result of which the water content of various elements in the nourishing high-altitude “sheafs” has increased from 2 to 10% [5].

A slightly different approach will require the use of hydropower reserves of the main Baksan valley, where the waters of the various regimes’ tributaries are collected. Current conditions and possible runoff levels of the river Baksan are characterized in Figure 1.

![Figure 1. Conditions and possible levels of runoff use on the river Baksan (according to data for 1970–2010)](image)

Explanations for Figure 1: 1 - average monthly water expenditures; 2 - security of monthly water consumption; 3 - security of average daily water consumption; 4 - integral drain curve; 5 - average annual water consumption; 6 - level of runoff use at various power plants; 7 - level of power use as a percentage of annual runoff.

Figure 1 indicates that its average winter, mid-summer and high-water discharge vary widely, due to the seasonal specifics of the formation and circulation of water in the basin. The runoff dynamics is characterized by a stretched spring maximum and a winter minimum. Therefore, under the conditions of a pronounced variable water supply, the Baksan hydroelectric station with an installed capacity of 30 MW in fact produces no more than 27 MW, decreasing to 6 MW in winter [8].

Consequently, in relation to the river Baksan once again updated the issue of the regulating flow appropriateness. Of course, the authors adequately perceive the often-logical objections of the construction hydro-storage facilities’ opponents in the mountains. Nevertheless, as applied to the Baksan energy system, no less than arguments can be made in favor of the technical way feasibility to increase the runoff stability [3].
As a first approximation, water can be accumulated in Lake Syltran-Kel, increasing its useful volume by a dam up to 30 m high. In the lymno-system at an altitude of 1700 m, it is possible to accumulate the river Kirtyk runoff and its tributary river Syltran-Su, the flow rate of which can be collected using the drainage channels and thrown into the lake with a tunnel (about 1 km). If the idea is implemented, there will be a chance to get an effective regulatory system for the potential downstream power units within the Verkhnebaksansky, Tyrnyauzsky, Bilymsky, Zhanhoteksky sections and the existing Baksansky hydroelectric power station. The designated hydropower facility will simultaneously reduce the high channel turbulence. The hydro-accumulative structure itself can become an independent energy producer (up to 30 MW), which will accelerate the return on costs.

The sum of the active capacities of all the proposed cascade power plants will depend on the capacity of the regulated Baksan river and the role of the hydroelectric power station in the energy complex of the river. Based on the available hydrological data, we have constructed a runoff utilization curve and a forecasted utilization curve of the installed river capacity (Figure 2).

**Figure 2.** Characterization of the conditions of the Baksan river use with different flow provision and installed capacity

Explanations for Figure 2: 1 - installed capacity utilization curve; 2 - runoff utilization curve for various levels of the hydroelectric power stations’ installed capacity.

Figure 2 indicates that the monthly level of installed capacity utilization will be characterized by high dynamism, which necessitates the search for the ways to systematically increase the level of installed capacity utilization.

Of course, a cascading approach to hydropower development of the Baksan Valley may have a number of limiting factors, among which the limestone-slate composition of the root valley, abundant in karst processes, for example, in the areas of the proposed sections (Bymynsky, Zhanhoteksky gorges) is already obvious. So, on the right bank of the latter, Jurassic limestones became widespread, which in the case of the energy project’s implementation, will require the capital-intensive techniques to strengthen the gorge base and its right slope. The creation of an open distribution device in the structure of the Zhanhotek hydroelectric complex, which can be placed closer to the mouth of the Gundelen river, can somewhat reduce the severity of the problem. This technique will also allow to involve an additional runoff volume into the production process [5].
Unlike Baksan, the alpine tributaries of the Malki did not form a pronounced sheaf structure, although they play an important role in shaping the nature of its annual water discharge. Consequently, it is more expedient to place potential power units in its main valley. This means that in the conditions of seasonal fluctuations in runoff, the entire chain of potential hydroelectric power stations will consistently experience water shortages in winter. Therefore, an attempt to find an acceptable option to reduce the amplitude of water flow has been made. The sections within the tributaries of Kichmalka and Bolshoy Lahran previously possess as a flow regulator, the properties of the latter being more favorable for the pumped storage facility construction. This is evidenced by the constructed diagram of the volumetric characteristic of the alignment (transverse profile). Using it, it is possible first to formulate a working hypothesis of the potential useful volume of the reservoir (Figure 3).

![Diagram of the volumetric characteristic (transverse profile)](image)

**Figure 3.** Diagram of the volumetric characteristic (transverse profile)  
Bolshoy Lahran Valley

Explanations for Figure 3: P – defines the transverse profile of the gorge at the site of the proposed dam; V is the volume of a possible reservoir bowl (mln.m³).

The coefficient of natural regulation in the Malka river (that is, the volume of the reservoir required for full annual regulation as a percentage of the river flow per year) varies from 0.4–0.55 [3]. Based on this, it is possible to calculate the size of the reservoir useful capacity, and therefore the height of the dam, sufficient to equalize the flow.

Instead of a dam, the option with a derivational tunnel should be considered. But in the absence of any noticeable progress in technologies providing a height difference between the water receiving device and the engine room, it will be necessary to create a height difference of up to 500 m, which in geomorphological conditions of the upper Malki will provide only a tunnel of 14-15 km. Moreover, this expensive scheme will be effective in relation only to the lower located hydroelectric station [6].

The option with a reservoir will provide an acceptable dynamics of water flow within the main river Malka valley simultaneously for several potential targets, for example, Khabazsky, Kamennomostsky, Sarmakovskiy. In addition, a decrease in river turbulence will allow the funds annually released for bank protection to be directed to increase the safety margin of the proposed dam.
The colleagues’ concerns regarding the environmental consequences and seismic threats, of course, has a right to exist. So, the field studies have shown that the implementation of the idea will be associated with the removal from the circulation of 120 hectares of farmland and more than 200 hectares of the forest land. Unfortunately, there is no environmental management option that provides maximum economic efficiency and at the same time the optimal results in environmental protection. Therefore, it is necessary to look at the compromises’ possibilities behind the problems, for example, by comparing the alternative energy productivity of the territory withdrawn by the hydropower complex (forest productivity, total agricultural potential, size of unused solar energy, refusal to use wind energy, etc.). In relation to seismic risks, it can be noted that over the years of the hydroelectric power stations’ Kashkhatau cascade operation (10 different hydroelectric power stations located at a distance of 10 to 70 km from the dam), not a single case of deviation from the stable seismic situation was recorded.

Other tributaries of the Malki river are mostly cluttered with clastic material, and therefore their specific power is minuscule. An exception may be inflows, the flow rate of which is sufficient for micro-hydro units in a period of high water. They will solve the power supply problem to the dispersed livestock complexes, climbing camps, rescue structures, tourist facilities, research stations using the principle of “short networks”, which is important, since the capital costs of laying and maintaining the power grid in the cost structure often reach 70–80 % [1].

The question of the runoff using possibility in the river Chegem is not clear. Its average winter water discharges are minimal (0.5–5 m³/sec) at potential pressures do not exceed 20 m. Only the river section above the mouth of the river Basmaly-su can have applied value (between the Su-Auzu gorge and the village of Nizhny Chegem), which requires an additional study. It is necessary to significantly expand the existing truncated water energy cadaster of the river, starting from which other options for the safe and cost-effective river water resources use can be substantively discussed. According to the expert assessment of RusHydro, Chegem’s total hydropower resources amount to 1.5 billion kWh per year [6].

The authors do not consider the Cherek river basin with its powerful hydropower potential due to the fact that it is the most studied and involved in the hydroelectric energy water system of the KBR: 10 hydropower units of various capacities operate on the river.

Summary

The main energy base of the socio-economic development in the republic should remain the hydroelectric stations. At the same time, the formation of the small and ultra-small hydroelectric power stations system should be thoroughly forced. Wellhead sections of small tributaries of the main mountain rivers are most favorable for providing an autonomous energy supply system for energy consumers dispersed in the mountains according to the principle of “short grids”.

The developed working hypotheses and preliminary schemes for using the energy of the Baksan and Malka rivers indicate the possibility of erecting pumped storage facilities on the Syrtran-Kel and Bolshoy Lahran lake basis. The latter will allow regulating the cascade of 3–4 power plants within the Khabaz, Kichmalkinsky, Kamennomostsky and Sarmakovskiy sections.

The emergence of sustainable energy sources in the recreational and grazing zones of the upper rivers’ reaches will create the preconditions for the local nature management enterprises’ formation, and the reduction of the energy press on the mountain villages’ socio-economic situation. The theses presented in the article can become supportive in discussing the alternatives for the industry development and making decisions. The final choice of the hydraulic units’ construction order should be the subject of public scientific public discussion.

Increased attention to hydropower does not mean that it should be the only form of renewable electricity in the mountains. The directions of the industry modernization can be manifested in different combinations (geothermal, solar, wind, etc.). The emphasis made in the article is related to the fact that of the underestimated local energy resources, hydropower is the most obvious and
traditional in the mountains, the involvement of which can become a stable basis for the optimistic scenario’s implementation of the country’s socio-economic development in the medium term.

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