RT&A, Special Issue № 4 (70)
Volume 17, November 2022

METHODOLOGY FOR THE IMPLEMENTATION OF PROBLEMS CAUSED BY RESERVOIRS ON THE SEASHORE

Lia Matchavariani, Giorgi Metreveli

•

Ivane Javakhishvili Tbilisi State University, Georgia
lia.matchavariani@tsu.ge
giorgi.metreveli@tsu.ge

Abstract

Geological, demographic, climatic (present-day eustasy) and anthropogenic (reservoirs, urban loadings) factors play an active role in the formation of the coastal zone. The anthropogenic factor acts against the background of natural factors and depending on the direction of their vectors increases or decreases. In such circumstances, it is expedient to create a long-term forecast of coastal dynamics using proven methods. In contrast to them, in order to study the anthropogenic factor, i.e., the impact of the reservoir on the state of coastal beaches, a new method for studying the limiting volume of the silting prism of a reservoir has been proposed. Therefore, for the long-term prediction of the dynamics of a specific section of the seashore under the influence of the reservoir, a methodology should be used, that, together with it, combines the research methods of the factors operating in the region. Such a technique has been first tested on the eastern coast of the Black Sea, in the Chorokhi delta, where the sea threatened the city of Batumi with complete destruction after river sediments were blocked in recent years by a cascade of six reservoirs. According to the forecast made by this technique, the coast of the city will no longer receive beach-forming sediments within a millennium. Taking into consideration that the sea annually carries away a large amount of beach-building material from the delta, the city of Batumi and the entire delta are threatened with a complete abrasive collapse. The long-term forecast created using the new method makes it possible to determine timely the duration of the impact of reservoirs on the coast, the risks of natural disasters, and start permanent artificial backfilling of the coast with sediments and its strengthening with appropriate anti-abrasive structures.

Keywords: abrasion, beach, sediment quarry, silting prism, silting tail

I. Introduction

Delta at the confluence of the river with the sea is an area of unstable dynamic equilibrium between land and sea. Here, solid material carried down by the river, sediment, and runoff, interacts with the sea. Most of them sink into the sea passing through underwater valleys and canyons, and some are carried by waves along the coast. Such sediments form protective beaches, and runoff creates coastal and bottom currents that enhance sediment transport. Accordingly, the beach is a layer whose parameters, coastal protection, and other functions are determined by the amount and characteristics of sediments.

Urbanic and climatic processes are taking place in deltas, against the background of long-term (centuries long) movements of land and sea level. In the current century, due to their impact, the parameters of hydrometeorological events, storm waves, and currents more and more often reach catastrophic levels. In turn, both climatic and urban factors significantly increase the requirements for the complex use of rivers with reservoirs. Clearly, anthropogenic activity has a negative effect on the safety and social conditions of the settlements located in their deltas, since the reservoir blocks the flow of river sediment for many years, which leads to the destruction of coastal beaches [3, 10, 14, 17, 18, 19]. Finally, the abrasive effects of sea waves end up destroying the delta, settlements, infrastructure, and communications.

Reservoir silting processes have been satisfactorily studied [1, 2, 4-9, 11-13, 15, 16]. An exception is the study of the consequences and risks of the impact of the reservoir on the seashore. Therefore, the dynamics of the delta in the area of influence of the reservoir, the social conditions of the population, and the types of vulnerability should be studied with such a method that includes the processes of the dynamics of the prism of the reservoir (Fig. 1). Using this method, it becomes possible to create a long-term forecast of the impact of the reservoir on a particular delta.

Figure 1: *Fragments of the Silting Prism of Mountain Reservoirs (Zhinvali)*

Thus, the goal of the study is to create a methodology that includes methods for studying the main factors acting on the seashore, laws of the reservoir silting prism dynamics, and creates the conditions for preparing a long-term forecast of the dynamics, protection-adaptation, and development of the region affected by the reservoir. Using this method, it is possible to calculate the risks of a disaster in a timely manner and start the permanent artificial filling of the coast with sediment, as well as build coast protection structures according to a scheme corresponding to the litho-dynamic and other characteristics of the coast.

In the current century, the process of using rivers as water reservoirs have significantly intensified on the eastern coast of the Black Sea. In recent decades, a cascade comprised of six reservoirs was built on the Chorokhi River. In the coming decades, seven more should be added to them(Fig. 2). In addition, it is also planned to build two by two reservoirs on the Rioni and Enguri rivers. These actions have led to a significant deficit in sediment on most parts of the sea coast, starting the degradation of the beaches, which threatens the population living in the deltas, infrastructure, communications, and port complexes with catastrophic erosion.

Figure 2: *Borchka, Deriner,and Yusufeli Reservoirs, Turkey*

Most of these factors are characterized by a long period of action, low inertia, and the irreversibility of results. Therefore, to adapt-neutralize their results, appropriate projects are needed, which must be created ahead of time.

The research area includes the eastern coast of the Black Sea - the coastal strip of Georgia, the basins of the rivers Rioni, Enguri, and Chorokhi where separate reservoirs and their cascades operate; also, Kodori and Bzibi gorges, because they are promising in terms of creating integrated reservoirs. Batumi (1882-2021) and Poti (1873-2021) marine and hydro-meteorological monitoring (1870-2021) stations operating in the region. The assessment of geological and geodesic processes was performed with the data of repeated geodetic plans (1902-1952), the results of the active geodetic network, and special geodetic measurements [17].

II. Methods

This study uses traditional statistical (least squares, mathematical expectation) and analog methods in the research process. During the implementation of research work on the impact of reservoirs on the environment and population, the methods of "estimating the regional parameters of the background of current climate variability" and "determining the limiting volume of the reservoir's silting prism" were created[16]. In their implementation, the results of natural experiments for the study of water reservoirs were used [12].

III. Results and Discussion

At the beginning of the current century, when the Muratli Reservoir was built (2005) on the Chorokhi, the reality of catastrophic coastal erosion of the region became obvious. The commissioning of the next reservoirs of the cascade – Borchka (2007), Deriner (2012), Artvini (2020), and Yusuflu (2021) confirmed that if in the current decade the source-ore to fill the degradable beaches was not selected, and the sediment conveyor "ore– shore" was not put into operation, storm waves shortly (2030-2050) will damage the runway of Batumi airport and the nearest residential buildings.

The aforementioned technique was used (tried) for the first time on the eastern coast of the Black Sea, in the delta of the Chorokhi River, where the multifunctional city of Batumi with a population of 150 thousand people is situated. A significant share of the oil transported by the Baku-Ceyhan pipeline passes through the Batumi port to many countries. The city is located on the southern part of the Colchis plain, the so-called Kakhaberi plain, which is built of the Chorokhi sediments. Due to the constant lack of sediment, the Kakhaberi plain, as well as Batumi with its surrounding settlements, infrastructure, and communications, will inevitably become a victim of marine erosion as the cascade of the Chorokhi reservoir blocked the sediment flow that filled the beaches for a long time (Table 1).

Table 1: *The years of reservoirs operation on the Chorokhi, morphometric parameters, and terms of maximum silting (the construction of 7 additional reservoirs is scheduled which will increase the mentioned period to 2260)*

River	Reservoir	Year of operation	Volume of reservoir, km^3	Marginal volume of silting prism tail, km^3	Marginal volume of silting prism$(W + W_{tail})$,km^3	Term of marginal silting of water reservoirs, year
Chorokhi	Muratli	2005	0.04	0.01	0.05	6.0
	Borchka	2010	0.45	0.16	0.61	73.0
	Deriner	2012	2.10	0.75	2.85	339
	Artvin	2016	2.13	0.76	2.89	344
	Yusufeli	2024	2.13	0.76	2.89	344
Adjaristskali	Shuakhevi	2015	0.15	0.05	0.20	24
		Total:	7.0	2.49	9.49	1130

Obviously, it is necessary to determine the period during which the coast will remain in the mode of sediment deficit. Calculating its duration is also necessary because the sea takes 80-100 thousand m^3 of beach-building material from the delta every year, and if it was compensated by river sediment before the cascade was activated, during the cascade's operation, it will be necessary to artificially fill the sediment deficit following the relevant principles.

Determination of the indicated period (T yr.) is possible using the method of the threshold value of the silting prism of each reservoir. Its essence is that the sediment accumulates in the reservoir until the sediment completely fills it, i.e., it creates an accumulation body – the silting prism. At the same time, the tail/train of this prism will be formed synchronously above it (Fig.3). Such tail starts from the dam, completely covers the reservoir, and extends into the tributaries to the intersection, where the river can transport the full spectrum of sediments to the lower basin. The length and width of such a tail significantly exceed the parameters of the reservoir mirror, and the volume reaches 20-30% of the reservoir size (W).

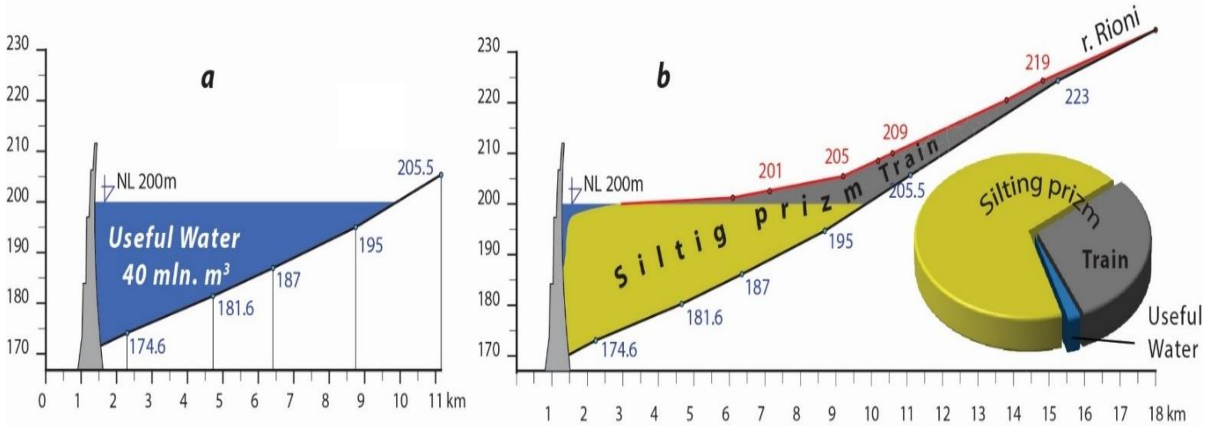

Figure 3: *Gumati Reservoir longitudinal sections in initial (a) and finishing phases (b) of operation*

Finally, the silting of the reservoir ends when a body with a volume of ~1.3Wj forms in it. And its surface is an accumulative plain inclined towards the dam, which starts from the dam and extends to an imaginary intersection of tributaries, from where they can transport sediment to the lower basin. Taking into account this regulation, the complete silting volume (R) of the Chorokhi cascade can be determined with acceptable accuracy using the following expression:

$$R = 1{,}3 \sum_j^n Wj, \quad n=1,2,....,6$$

In the expression, 1.3Wj denotes silting limit value of each water reservoir (Fig. 2).

According to long-term monitoring data of the hydrological station Erge, the annual sediment volume of the Chorokhi reached 8.4 mln m^3 until 2005, or 0.0084 km^3. Of this volume of sediments, 2.5 mln m^3 were large beach-forming sediments. Of these, ~0.2 mln m^3 was used to fill and restore coastal beaches, the rest was lost in the underwater canyon of the river.

The long-range forecast produced by this method makes it possible to calculate disaster risks in time and proceed to the constant artificial filling of the coast with sediment, as well as to strengthen the coast with structures that correspond to the characteristics of a particular land area.

The catastrophe can be avoided if the following procedures are performed by the proposed method: determine the dominant factors that define the regime of the beaches along the studied coast; select methods for analyzing these factors; establish the duration of the impact of reservoirs on the delta; identify detect an alternative source of Chorokhi deposits (ore).

On the coast of the region under study, during historical time, the activity of geological (tectonics, sedimentation-consolidation) and oceanographic (abrasion, eustasy) factors was a priority. Since the 1900s, the climatic factor has intensified in the Black Sea basin and the eustasy provoked by it – the rise in sea level, which is the result of thermal expansion of water. This process began in the 1960s and accelerated dramatically in the 2010s. Accordingly, the urban factor has intensified – subsidence caused by the weight of the underlying buildings, the vector of which is opposite to the geological factor in this region. Under the influence of the geological factor, the coast was rising at a rate of ~10 cm/yr. until the 1960s. In subsequent decades, the urban load created by constructions on the coast increased so much that this component almost neutralized the influence of the geological relief, and the coast, composed of alluvial layers, began to subside. This is confirmed by the results of the standard geodetic network and sea level monitoring. This is a negative fact since the subsidence of the coast brings the collapse of coastal erosion closer.

To determine the parameters of modern eustasy, the long series of sea levels constructed based on the monitoring results of the Batumi Oceanographic Station is used. It is possible to determine the parameters of the secular coastal movements using repeated data of geodetic planning. The parameters of modern climate change can be determined from monitoring data of the main meteorological elements of the regional climate background [air temperature (t), precipitation (p), wind (w), and air humidity (h)]. The variational parameters of these elements are also determined: trend (τ), average values for characteristic time intervals (M[t,p,w,h]), and the main statistical characteristics – a polynomial equation and a correlation coefficient.

In the 2010s, the activation of the lower reservoir of the Chorokhi cascade (Muratli) intensified erosion processes in the delta so much that it became necessary to carry out special research works to make a forecast of the expected erosion of the delta and the Batumi seashore. According to research results, shortly (2030-2040), sea waves will directly attack airport runways and nearby residential buildings (Fig. 4). After making new forecasts for the impact of the silting prism of reservoirs [13, 16] on the sea coast in 2020-2022, it will become obvious that the Cascade threatens the area surrounding Batumi with complete abrasion collapse (Fig. 5). According to the same studies, a disaster can be avoided by selecting a full-fledged deposit substituting the Churokhi R. sediments. Most likely, such an object is the Rioni River sediments forming a silting prism of the Gumati reservoir.

Figure 4: *Expected erosion of the Chorokhi River delta and the Batumi coastline under conditions of permanent sediment deficit*

IV. Conclusions

The impact of the reservoir on the sea coast is extremely negative. It blocks the flow of sediments that fill the beaches for a long time, and the permanent deficit of sediments caused by their cascade reaches many centuries in some places and ends with the collapse of the coastal erosion. Such negativity can be avoided by the methodology which combines all the rules and methods that form the multifactorial regime of the coast and determines the terms for the maximum silting of the reservoir silting prism. Its advantage is that it determines the duration of a particular water reservoir or cascade with reasonable accuracy and allows early identification of means to prevent abrasive collapse in due time.

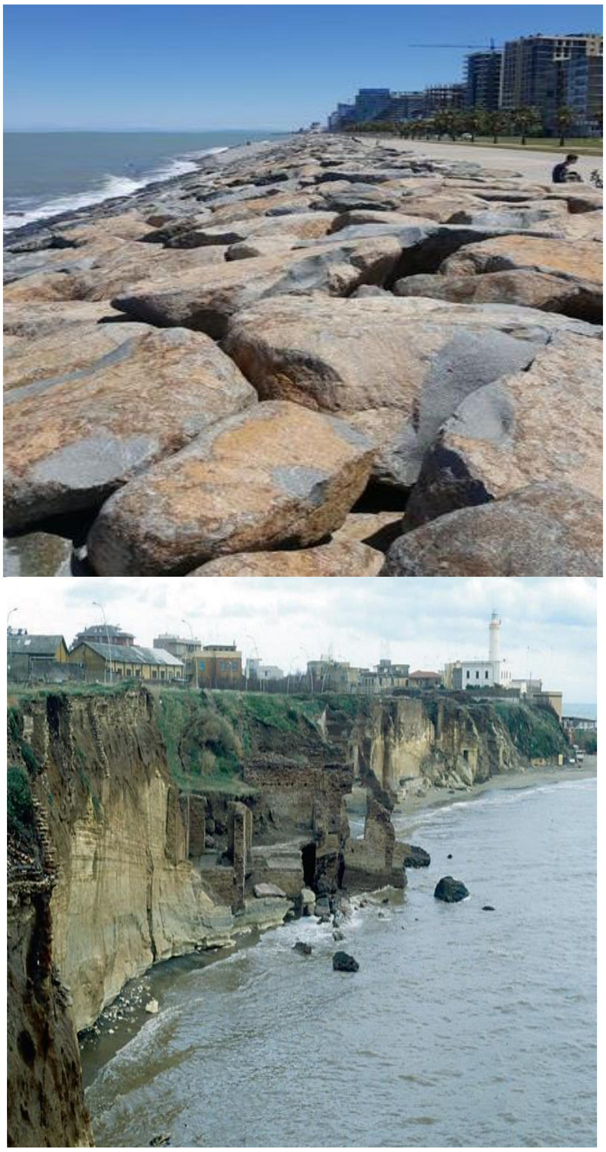

Figure 5:*Covering massive boulders, protecting against the abrasive effects of waves (A); Result of the abrasive collapse of sea waves (B)*

References

[1] Andredaki, M., Georgoulas, A., Hrissanthou, V., Kotsovinos N. (2014). Assessment of reservoir sedimentation effect on coastal erosion in the case of Nestos River, Greece. *Intern. Journal of Sediment Research*, 29(1), 34-48.

[2] Bennett, S.J., Dunbar, J.A., Rhoton, F.E., Allen, P.M., Bigham, J.M., Davidson, G.R., Wren, D.G. (2013). Assessing sedimentation issues within aging flood-control reservoirs. *Reviews in Engineering Geology*, 21, 25-44.

[3] Burova V.N. (2020). Abrasion Risk Assessment on the Coasts of Seas and Water

Reservoirs. *Geodetski list*, 74(2), 185-98.

[4] Caputo, M. and Carcione, J.M. (2013). A memory model of sedimentation in water reservoirs. *Journal of Hydrology*, Elsevier, 476, 426-432

[5] Detering, M. and Schuettrumpf, H. (2014). Reservoir Siltation and Ecological Life Span of Dams. *Wasser Wirtschaft,* Springer,104 (1-2), 30-33.

[6] Garg, V., Jothiprakash, V. (2013). Evaluation of reservoir sedimentation using data driven techniques. *Applied Soft Computing*, Elsevier, 13(8), 3567-3581.

[7] Gopinath, G., Ashitha, M.K., Jayakumar, K.V. (2014). Sedimentation assessment in a multipurpose reservoir in Central Kerala, India. *Environmental Earth Sciences*, 72(11), 4441-4449.

[8] Hajji, O., Abidi, S., Habaieb, H., Mahjoub, M.R. (2014). Regionalization and contribution to the study of reservoir sedimentary: Lakes of Cape Bon and the Tunisia Central. Proceeding of the 11th Intern. Conference on Hydroscience & Engineering "Hydro-Engineering for Environmental Challenges", Germany, 575-582.

[9] Hosseinjanzadeh, H., Hosseini K., Kaveh, K., Mousavi, S.F. (2015). New proposed method for prediction of reservoir sedimentation distribution. *International Journal of Sediment Research*, 30(3), 235-240

[10] LoucksDaniel, P., Eelco van Beek (2017). Water Resource Systems Planning and Management: An Introduction to Methods Models and Applications. Springer, 624 p.

[11] Mansikkamäki, H. (2013). Monthly sedimentation in some reservoirs of hydroelectric stations in Finland. *Fennia-International Journal of Geography*, 2013, 143(1).

[12] Matchavariani, L., Metreveli, G., Alaverdashvili M., Lagidze L., Svanadze D., Gulashvili Z., Bregvadze G. (2016). Results of Field Experiments of Reservoirs' Siltation for Harmonious Realization of Hydropower and Coastline Problems. 2nd Intern. Conference on Science, Engineering & Environment, SEE-Osaka, Japan, 639-644.

[13] Matchavariani, L., Metreveli, G., Lagidze, L., Svanadze, D., Gulashvili Z. (2017). Solution of Reservoirs' Siltation Problem for Hydropower Development and Coastal Protection. *Intern. Journal of GEOMATE*, Japan, 206-212.

[14] Matchavariani, L., Metreveli, G., Gulashvili, Z. (2021). Role of Water Reservoirs in the Seashore Dynamics. Proceedings of the 21th Intern. Multidisciplinary Scientific GeoConference SGEM2021, 3(3.1), Albena, Bulgaria, 285-292.

[15] Metreveli, G., Matchavariani, L. (2016). Research Method of Silting the Mountain Reservoirs under the Current Climate Change. *Journal of Water Resources and Ocean Science. Science Publishing* Group, 5(2), 22-27.

[16] Metreveli, G., Matchavariani, L., Gulashvili, Z. (2019). Method for Hydrological Parameters Definition of Silting Prism and Equilibrium Bed in Water Reservoirs. Proceedings of the 19th Intern. Multidisciplinary Scientific GeoConference SGEM2019, 19(3.1), Albena, Bulgaria, 363-368.

[17] Metreveli, G., Matchavariani, L., Gulashvili, Z. (2022). Positives and Negatives of Water Reservoirs. Samshoblo, ISBN: 978-9941-9784-6-3, 200 p. (in Georgian).

[18] Patriadi, A., Soemitro R., Warnana D.D., Wardoyo, W., Mukunoki, T., Tsujimoto, G. (2021). The Influence of Sembayat Weir on Sediment Transport Rate in the Estuary of Bengavan Solo River, Indonesia. *Intern. Journal of GEOMATE*, vol. 20, Issue 81, 35-43.

[19] Starodubtsev, V.M., Bogdanets, V.A. (2016). Dynamics of the Tsimlyansk Reservoir Coastline. *SWorldJournal*, 1102, 7-15.