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Kuibyshev reservoir shore transformation as a factor of archaeological heritage objects destruction

I I Gainullin¹, B M Usmanov², D R Sharipova² and L N Bagautdinova³

¹Innopolis University, 1, Universitetskaya Str., Innopolis, 420500, Russia

²Institute of Environmental Sciences, Kazan Federal University, 18, Kremlevskaya str., 420008, Kazan, Russia

³Kazan National Research Technical University named after A.N. Tupolev–KAI, 10, K. Marx str., 420111, Kazan, Russia

gainullis@gmail.com

Abstract. The article presents the results of long-term research carried out in the shoreline zone of the Kuibyshev reservoir, at the location of the Izmer's complex of multitemporal archeological sites, territory the Republic of Tatarstan. "Beganchik" Paleolithic site and fortified settlement of Bolgar period "Devichiy Gorodok" were selected for detailed study. The assessment of the shoreline transformation has been carried out with the use of remote sensing data, advanced methods of field survey and geoinformation analysis. As a result the most dynamic areas have been identified. In the work, were used archival aerial images, high-resolution satellite images and results of field surveys.

1. Introduction

Cultural heritage is an expression of the way in which a community developed and lived, passed on to future generations, including customs, practices, places, objects, artistic expression, and values. [14] Historical and cultural processes in any specific geographical area are determined by the physical, geographical and climatic characteristics of the region. Information about these processes is preserved in historical and cultural objects and in the unique appearance of anthropogenic landscapes.

At present, all over the world there is a problem of preserving of destroying archaeological heritage objects, it is necessary to study the negative impact of natural and anthropogenic factors on archaeological sites state. Damages caused to cultural heritage sites are most of the times irreversible and data with significant cultural and archaeological value is being lost. Among various negative factors, coastal processes are stand out by the rate of destruction of ancient objects territory [1].

Coastal erosion is a result of the combination of different factors – both natural and human-induced – with different patterns in time and space and has different nature. Especially ones located in coastal areas, susceptible to floods, or that are under the direct effect of the backwater processes, the mechanic action of waves or aggradation.

A significant number of scientific works are devoted to the development of a strategy for the preservation of archaeological sites located in the coastal zone of seas and oceans [6-7, 14-15], however, very few studies concern the influence of large reservoirs [2, 8].

Since the Paleolithic era, large rivers and their fertile valleys have attracted people, since water is undoubtedly the most important resource and a decisive factor in the settlements placement. The creation of the water-storage reservoirs fundamentally changes the landscapes of the river valleys



flooding high-water bed and low terraces where cultural heritage sites are usually located [5]. Thus, many archaeological sites disappear during the creation of large reservoirs, and the rest are negatively affected during their further exploitation.

Given this fact, it is necessary to assess the intensity of archaeological sites destruction in the zone of large reservoirs impact by interdisciplinary approach. The most effective is the monitoring of the archaeological monuments state by methods for studying of exodynamic processes, analysis of archival data, multi-time remote sensing data, modern methods of field survey and assessing the risk of destruction of cultural heritage objects [10, 12].

Remote sensing methods are used in archeology for various kinds of research, including monitoring of archaeological heritage objects state, "new" objects identifying and predicting their possible location [3]. Archival aerial and space imagery is invaluable for predicting the state of monuments, since it is practically the only source of accurate spatial information about the initial state of cultural heritage objects, given the low accuracy of archival plans and text descriptions. Over the last years, multi-rotor unmanned aerial vehicles (UAVs) were used in modern archaeological research due to their low price and ease of operation. UAV used to obtain highly detailed aerial photographs which enable to produce orthophoto of study area, digital elevation models (DEMs) for detection and reconstruction of archaeological objects, as well as the monitoring of their current state.

These methods make it possible to obtain information about the change of the shore in archaeological sites location, values of the shoreline retreat rate and assess the risks of their further destruction [4].

This article presents the results of long-term field observations of archeological monuments in the zone of influence of the Kuibyshev reservoir using archival aerial and space imagery on the example of two observation sites.



Figure 1. Study area. Location of Devichiy gorodok and Beganchik sites.

The Kuibyshev reservoir, the largest in the Volga-Kama cascade system, was created in 1957 as a result of the of the Zhigulevskaya hydroelectric station construction. It covers the territory of the Chuvash and Tatar republics, Ulyanovsk and Samara regions. The Kuibyshev reservoir has an area of 6450 km², water volume – 58 km³, length – 510 km, average depth – 9.3 m. 1289 cultural heritage sites have been identified around the Kuibyshev reservoir. Many of them have been lost or are under threat of destruction as a result of the reservoir organization and exploitation [2, 8].

A complex of archaeological object near the Izmeriy village, in the Spassky municipal district of the Republic of Tatarstan, was selected for study (figure 1). These are objects of different historical periods from Paleolithic sites to the Middle Ages. Two sites were selected for detailed study – 1. Beganchik Paleolithic site. 2. The shoreline in the area of now destroyed hillfort of Bolgar period of Middle Ages the "Devichiy Gorodok". Both sites are located in the zone of influence of the Kuybyshev reservoir and lose their area as a result of the banks transformation.

2. Methods

To assess the intensity of bank transformation various sources of information were used:

1) Archaeological plans, archival 1958 and 1980 aerial images used to study shoreline retreat in the early stages of the reservoir's existence;

2) Field survey results. The main task was the shoreline mapping. In 2012, 2013 and 2014 the survey was carried out using a Trimble M3 total station, in 2015 – the Trimble Geoexplorer 6000 Geo XR GNSS receiver. Since 2017, field works includes shooting with the DJI Phantom 4 drone;

Next step was office analysis of field observation results, including the construction of the coastline for different periods based on the results of archive images interpretation, topographic survey and UAV data in order to study of the bank transformation rate. Thematic maps construction and quantitative indicators analysis was held in MapInfo and ArcGIS;

One of the priority tasks that can be solved using the methods under consideration is the assessment of the intensity of archaeological sites elimination due to the Kuybyshev reservoir banks transformation. The main measure of transformation danger is its destructive power, which is quite fully characterized by the intensity of the process in the form of average long-term linear, areal or volumetric rates of bank destruction (m/year, ha/year, m³/m.year, etc.) [9].

To quantify coastal transformation at the Maiden Town site, the ArcGIS Digital Shoreline Analysis System (DSAS) plug-in was used to collate various sources of data relating to processes of erosion over time along the Kuybyshev reservoir shore. The main application of DSAS is to use polyline layers as a representation of a specific shoreline feature at a specific point in time. Based on the comparison of coastline positions, a number of statistical indicators of its changes are compiled: Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR), Linear Regression Rate (LRR) and Weighted Linear Regression Rate (WLR). This module is effective for simplifying the analysis of changes in the position of the shoreline.

3. Results and discussion

3.1. Beganchik

The Paleolithic site "Beganchik" is located on the left bank of the confluence of the Kama and Volga rivers, at the mouth of the Aktai River on the isolated hill of a second terrace, which turns into an island at a high water level (figure 2). The height above sea level is 54-60 m. The northern part of the site is represented by a very steep cliff which is continually eroding. Previous preliminary studies have revealed that the erosion rate is about 2-3 m/year [8]. Field survey was conducted by the authors in 2017.

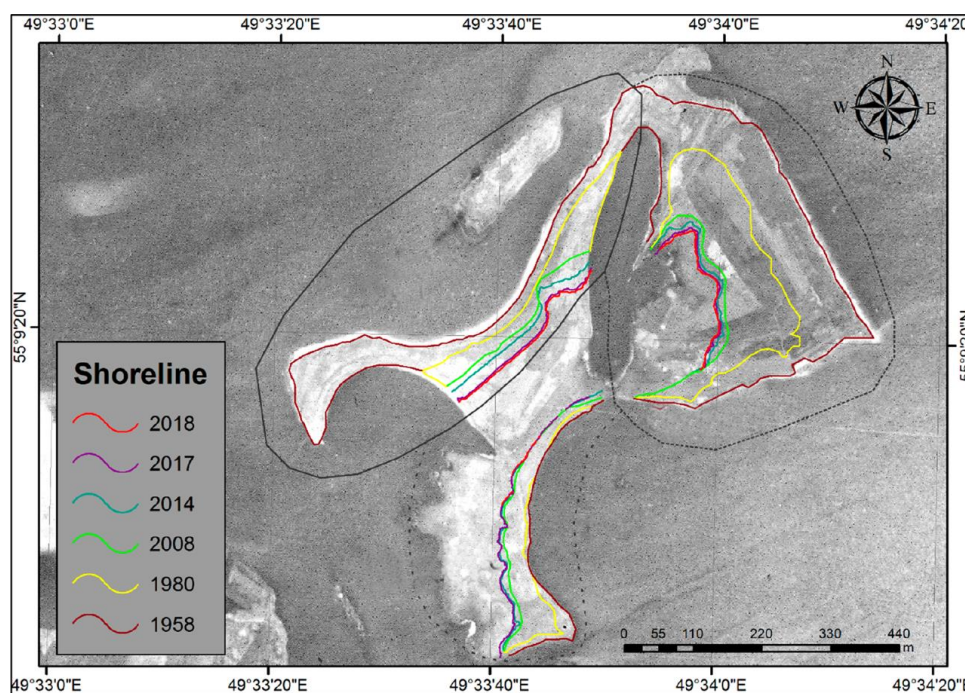


Figure 2. Bank transformation at Beganchik site [7].

Table 1. Shoreline retreat at Beganchik paleolithic site for different observation periods.

| Observation period | Years | Shoreline retreat north-west sector | | Shoreline retreat east sector | | Shoreline retreat south sector | |
|--------------------|-------|-------------------------------------|--------|-------------------------------|--------|--------------------------------|--------|
| | | m | m/year | m | m/year | m | m/year |
| 1958-1980 | 22 | 32.84 | 1.5 | 44.85 | 2.04 | 5.59 | 0.25 |
| 1980-2008 | 28 | 33.88 | 1.21 | 64.81 | 2.31 | 13.85 | 0.49 |
| 2008-2014 | 6 | 11.57 | 1.93 | 9.61 | 1.6 | 7.37 | 1.23 |
| 2014-2017 | 3 | 17.03 | 5.68 | 4.76 | 1.59 | 1.53 | 0.51 |
| 2017-2018 | 1 | 3.23 | 3.23 | 2.8 | 2.8 | 1.53 | 0.31 |

As a result of the of archival aerial photography (1958-1980) and space imagery analysis (2008-2014) it was revealed, that north-west part was not actively eroded between 1958 and 2014 because it was protected by another island (60–90 m north-west), as indicated by the relatively low values of the shoreline retreat – 1.5-1.9 m/year (table 1). Erosion has considerably increased after the island disappeared, as we can see by specific land loss and volume rates. Field studies have shown that the shoreline retreat reached maximum values in the period 2014-2017 – 5.68 m/year. In 2017-2018 the speed is lower, but still high (3.23 m/year). The bank transformation values in this area can currently be characterized as extremely hazardous.

Unlike north-west part, eastern was and still is under the direct exposure of the Kama River flow and currents. As we can see at Figure 2, the main changes at this site occurred at 1958-2008 period. This is typical for the initial stage of lowland reservoir development. Approximately 70% of the eastern part of the site was eroded. Following that, part of the river’s current’s strength was redistributed along the north-western part, which also explains the sudden decrease in land loss. As a result, this sector can be classified as moderately dangerous.

Southern sector of the Beganchik site shoreline is the most stable because it located in the close proximity to the Aktai River mouth and protected from the mechanical action of waves and Kama River strong currents. The most intensive processes of reservoir bank transformation in the study area

were observed in north-west and east sectors, due to currents and waves destructive effect. The erosion intensity varies from year to year, depending on the reservoir water level oscillations.

3.2. *Devichiy gorogok*

This complex of archaeological sites (settlements and burial grounds) is located 1.5 km north-west of the Izmeri village (figure 1). Earlier, there was a unique archaeological site related to the Bulgar culture (X-XIII centuries), the hillfort "Devichiy gorogok". As a result of the Kuibyshev reservoir creation this archaeological site was constantly destroyed and disappeared by 1980. The medieval settlement "Devichiy gorogok I", as well Izmeri ancient settlements and burial grounds are still located here. Comprehensive studies of intensive bank transformation in order to obtain data on the current state of archaeological objects have been carried out in this area since 2012.

The length of the observation site is 600 m. The coast is strongly rugged, has a cliff scarp with a steepness of up to 90° and a height of up to 7-9 m. The shore of abrasion-landslide type is composed of blocky structure loess-like loams, with numerous vertical cracks that appear in the process of swelling and shrinkage.

Since it is assumed that at the initial stage of development, reservoirs have maximum values of bank transformation shoreline retreat analysis was carried out for 3 periods: initial period – 22 years (1958-1980), 2 period – 32 years (1980-2012), period of modern field study – 5 years (2012-2017). The reservoir bank at study area was conditionally divided into 2 sites – cape, on the western part of the bank and the remaining shore due to different transformation rates.

Based on statistical data from the DSAS module, a table of average transformation rates was built (table 2). To assess the intensity of the bank transformation at the study area, the classification of the bank transformation development danger, proposed by A.L. Ragozin [9], were used.

Table 2. Shoreline retreat at Devichiy gorogok site for different observation periods.

| Observation period | Years in period | Shoreline part | Shoreline retreat, m/year | Shoreline retreat by reservoir existence stages, m/year | |
|--------------------|-----------------|------------------|---------------------------|---|---------|
| | | | | 1 stage | 2 stage |
| 1958-1980 | 22 | cape shore | 2.7 | 3.7 | – |
| | | | | 1.7 | – |
| 1980-2012 | 32 | cape shore | 2.3 | – | 3.5 |
| | | | | – | 1.2 |
| 2012-2017 | 5 | cape shore | 3.8 | – | 5 |
| | | | | – | 2.8 |
| 1958-2017 | 59 | entire shoreline | 2.6 | – | – |

Linear retreat in the cape part in each period remain constantly high, and in the shore part of the study area, increase with each period. In general the maximum transformation values are observed in the cape part (figure 3) – the shoreline retreat is 347.42 m, and the average speed is 5.9 m/year. The minimum – noted between the cape and the shore part with 70.66 m retreat, and average speed – 1.2 m/year.

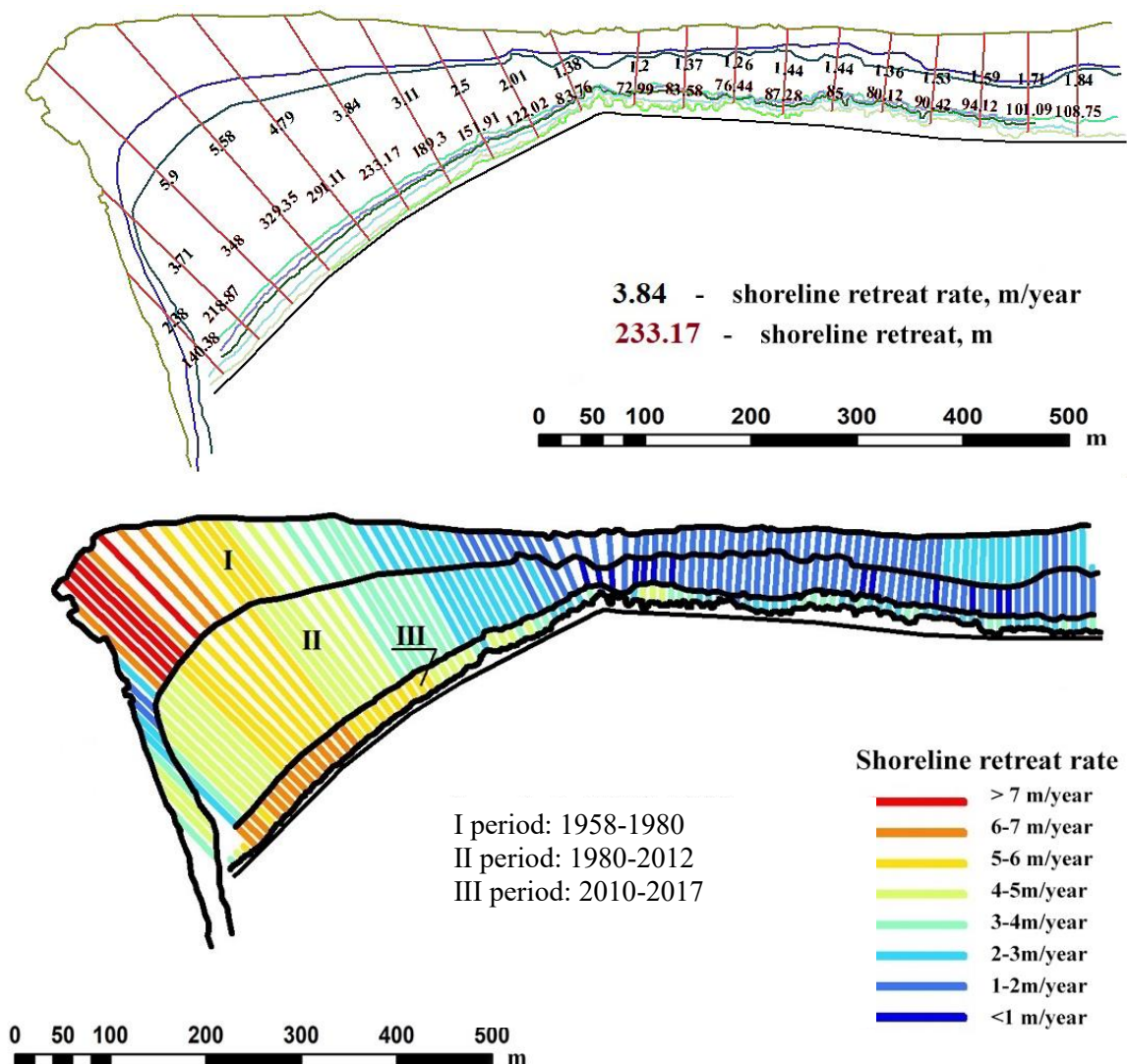


Figure 3. Bank transformation at Devichiy gorogok archaeological site.

4. Conclusion

The results of long-term observations have shown high rates of shoreline retreat in the studied areas. Although it was expected that the maximum intensity of bank transformation will be observed only in the first years after the Kuybyshev reservoir creation, reservoir level regime, wind waves, currents and other factors determine the high intensity of abrasion processes. This is especially typical for the mouth of the Kama River with a large water area, where the investigated archaeological monuments are located. A significant factor contributing to the archaeological objects destruction is the easily eroded loams that form the bank and the large height of the scarp. The block structure of loam and a large number of swallow nests also contribute to the collapse of the coast.

Long-term studies have shown that combining archival data with the field survey results allows to determine with high accuracy the rate of destruction of archaeological sites located on the large reservoirs banks. Results of the study can be expanded and adapted for use elsewhere in prioritizing sites according to rates of destruction.

To monitor the archaeological objects located in the zone of large reservoirs influence, it is advisable to use software for transformation rate automatic calculations to quickly and efficiently update information on the state of cultural heritage sites and inform involved governmental agencies.

The ongoing research can become part of a program to assess the risks of destruction of cultural heritage sites with state agencies for cultural heritage protection support and developed system of cultural heritage management.

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