Study of anthropogenic and natural impacts on archaeological sites of the Volga Bulgaria period (Republic of Tatarstan) using remote sensing data

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ABSTRACT

In this paper we consider the possibility of using remote sensing data for determining various negative factors affecting archaeological objects condition on the territory of the Republic of Tatarstan. Fortified settlements, with the system of defensive fortifications, were selected as the objects of study, as they are easily identified by remote sensing data. In our view, the analysis of medieval Volga Bulgars (X-XIII centuries A.D.), the most common in the territory of the Republic of Tatarstan, has the highest priority. The first task by using remote sensing was to obtain actual data on the current condition of archaeological monuments located on the Kuibyshev reservoir shore, where the threat of destruction is maximized. Due to the fact, that most of the Volga-Bulgaria settlements, is located on the small rivers banks, the second task was geomorphological description of monuments placement in order to assess the risk of their destruction by natural processes. Third objective was to evaluate the role of the human factor in archaeological sites destruction. Ancient settlements under different types of negative impact were selected for the study. Deciphering of multitemporal remote sensing data allowed to assess the objects condition and to predict the risk of further damage. Additionally, it made able to correct the form of the Bulgars hillforts in comparison with existing plans, as well their size and location in the landscape, to restore the original appearance of destroyed fortified settlements, to determine precise coordinates for the further use of these data in the archaeological geographic information systems.

Keywords: Cultural heritage management, anthropogenic factor, exogenous factor, medieval hillfort, remote sensing, aerial image, GIS, archaeology

1. INTRODUCTION

The use of aerial photography by archaeologists goes back more than 100 years, since the beginning of Forum Romanum photofixation in 1899. First pictures of archaeological objects have been made from aerostats boards, photography from airplanes actively developed during the First World War. Soon, aerial photography becomes the main tool for obtaining remote sensing data and starts to be used in archaeological research ubiquitously [1]. Later, during the interwar period and especially after the Second World War, active use of aerial photography in Europe and America led to the discovery of dozens of thousands of archaeological sites. Cooperation of European archaeologists in this field led to the creation in 1981 of the international Aerial Archaeology Research Group, that holds annual sessions, specialized conferences and field schools [2].

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Today, more than a hundred years after the first applying of remote sensing in archeology, aerial and space imagery is successfully used during archeological investigations in Asia, Europe and America, distinguished by a variety of methods and resources.

A mandatory part of modern archaeological research is the aerospace monitoring of archaeological objects condition. For example, multitemporal aerial and satellite imagery are widely used in Historical and Cultural Heritage Preservation State Service of Bavaria (Germany) and Bavarian Archaeological Society for detection and study of as the groups of archaeological sites as well as individual objects. [3], [4] or in Cyprus, where remote sensing data using for cultural heritage management (CHM) and monitoring. Several natural and anthropogenic hazards have been mapped using different remote sensing data and methodologies. [5] In the UK, works on monitoring of archaeological monuments condition is carried out by English Heritage (EH) Aerial Survey team under the National Mapping Program (NMP) [6] - Combination of different remote sensing data, including optical multispectral, LiDAR and synthetic aperture radar (SAR), is widely used in modern archaeological research [7], [8].

For instance, air scanning used effectively in order to detect the archaeological sites at obtained digital elevation model. Increasingly, unmanned aerial vehicles (UAV), or as in case with "ICARUS" project (Cyprus) – remote controlled balloon [9], are used for remote survey of local archaeological objects and subsequent 3D-models creation [1], [10]. Despite the variety of modern methods, archived remote sensing data such as past years aerial photography or conversion space images (Corona, USA; Cometa, USSR) are using actively for detecting of new and monitoring of known objects of archaeological heritage [11], [12].

In this paper, aerial photos received in the last century (1950, 1970-80-ies.) used as the main source of information. Research potential in archaeology, which provides computer processing and deciphering of 40-50-year-old aerial and space imagery can hardly be overestimated. In fact, we can talk about their re-introduction into scientific process at a new level of research technologies. The range of scientific tasks solved with the help of computer processing of archive remote sensing data is very broad.

Special place in modern archaeological investigations belongs to the study of archaeological objects, that exposed by intense negative anthropogenic and/or exogenous influence. Analysis of multitemporal aerial and satellite imagery is a priority in assessing of the risk of archaeological sites damage, as well as for data updating and development of specific measures for historical and cultural heritage conservation.

In this context, in our view, the first priority of remote sensing is to provide both historical data and operational information about the current state of archaeological sites in the areas of intensive processes of coast transformation (sea, large water reservoir) and dangerous exogenous processes (landslides, debris, etc. .d.), where the threat of destruction is maximized.

Because always the main criteria for the selection of favorable place to settle was the closeness of the water and the presence of natural fortifications, most of the archaeological sites usually located on the banks and terraces of small rivers, where influence of fluvial and exogenous processes is possible. Therefore, the second task is geomorphological description of ancient settlements placement in order to assess the risk of their destruction by natural processes.

The main factor that increases the importance of historical remote sensing data in anthropogenic influence context, is widespread process of plowing, irrigation, active construction, etc., that starts at the middle of the XX century. Intensive territory development led to a significant change in exterior of monuments and often – to their complete disappearance. So, a third objective is to evaluate the role of the human factor in archaeological sites destruction.

In addition, the processing of remote sensing data allows in a great extent to specify the shape of the archaeological sites in comparison with existing plans, to correct their area and location in landscape, to restore original appearance of destroyed archaeological objects, to carry out an accurate coordinate referencing for further use of these data in archaeological geoinformation systems.

A large number of archaeological sites, exposed to various forms of impact determined the selection of the Tatarstan Republic territory for remote monitoring of cultural heritage objects. Republic of Tatarstan is situated in the eastern part of the East European Plain, near the confluence of Volga and Kama rivers (Fig. 1). The area of the republic is 68,000 square kilometers, and its surface is an undulating plain. With an average altitude 170 m above sea level, some parts of republic territory rise up to 300-350 m. East European Plain gradually rises from the Volga River to the spurs of the Ural Mountains, where the Bugulma-Belebey upland formed. At the same time, significant areas are the lowlands, where the height does not exceed the level of 100 m.

Forms of relief created by flowing water are widely distributed in Tatarstan, especially gullies and ravines, dissecting the slopes of uplands and river valleys. Besides the four large rivers –Volga, Kama and its confluents Belaya and Vyatka, approximately 500 small rivers over 10 km long flows on republic territory. reservoir filled in 1955-1957 is one of the biggest reservoirs in the world and the largest on Volga river. Its main purpose – Volga and Kama flow regulation and

Volga Hydroelectric Power Station support. Kuibyshev reservoir, stands out by almost all indicators with the highest values of bank transformation.

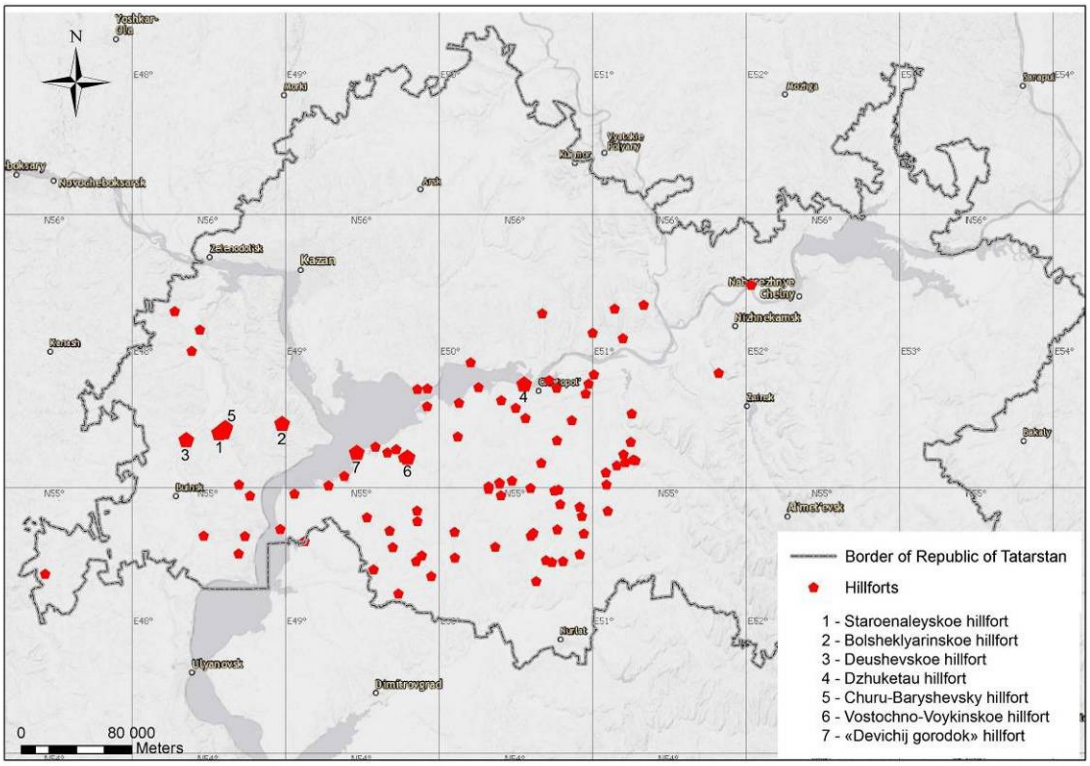

Figure 1. Bolgar hillforts detected on remote sensing data

The main part of the territory of Tatarstan is represented by agricultural lands - 46301 km2 (68.2%), forest areas occupy only 16.8%. The high degree of plowing at low forest coverage are prerequisites of active erosion processes. As a result, the area of erosion-hazardous agricultural lands in republic is 21689 km^2, or 47% (2014 yr). High economic development of territory and the large proportion of erosion areas raise the risk of damage and destruction of monuments and associated historical environment. Now in Tatarstan actually identified 4278 objects of archeology, 2758 of them are exposed to destruction [13]. Hillforts, most often with the system of defensive fortifications (shafts, ditches), selected as objects of this research, because they are easily identified by aerial survey data. At this stage, information is gathered about the medieval fortified settlements of Bulgarian culture (X-XIII centuries), the most common in the territory Tatarstan – 161 settlement of this period.

2. METHODOLOGY

In the middle of the XX century, continuous aerial survey for the purpose of topographic mapping and study of the transformation of the coast of Kuibyshev reservoir was held on the territory of the Republic of Tatarstan. The main number of images related to the 50-th and 80-th years of the last century. Thus, remote sensing data of maximum possible time spectrum over the past 60 years were selected to obtain information about archaeological monuments condition. Old aerial imagery (1: 17000 scale) from special fund of Kazan Federal University library and modern high-resolution satellite imagery from public resources were taken. Fortified settlements, with the system of defensive fortifications, were selected as the objects of study, as they are easily identified by remote sensing data.

Search for fortified settlements on aerial photographs carried out with the help of descriptions based on the results of field survey of past years. Further overlapping aerial images were scanned and georeferenced in ArcGIS to align it with the space imagery data.

The next step was to estimate the fortified settlements condition. Monuments exposed by anthropogenic (plowing, construction, quarrying, etc.) and natural (gully erosion, landslides, rockslides, rivers meandering, etc.) processes were

subsumed to separate categories. Fortified settlements without visible effects of impact and completely destroyed monuments of archeology, with a description of possible causes of extinction, stands apart in this classification.
In addition, comparison of the existing fortifications schemes with their image on remote sensing data carried out, for further correction of monuments plans.

3. RESULTS

Currently our team found 95 Bulgarian period (X-XIII ct) fortified settlements by using remote sensing data (Fig. 1) and most of them exposed to different forms of impact. Considering the large number of examined archaeological sites, this article describes the most typical objects affected by various negative factors.

3.1. Kuibyshev reservoir abrasia

The archaeological sites location near water bodies causes their exposure to geodynamic and hydrological processes. One of the factors which changes ancient settlements appearance and their condition most intensively is the coastline movement [14, 15]. Reservoir changed the whole landscape shape of the valley bottom in the Middle Volga fundamentally. After reservoir inception Volga and Kama floodplain and low floodplain terraces below its mouth disappeared under water. Also considerable amount of historical and cultural objects, including archaeological sites was destroyed and sunk. So the monitoring and gathering of information about the status and trends of exogenous processes at reservoir bank its an urgent task.

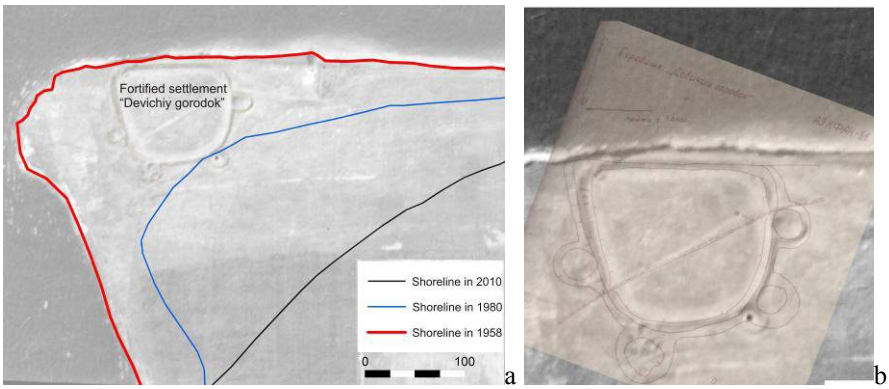

Figure 2. Dynamics of coastline in the location of hillfort "Devichy gorodok" (a) and comparison of its configuration with official plan (b)

"Devichy gorodok" hillfort. Was referred to the Imen′kovskaya archaeological culture (IV-VI centuries A.D.); later, the area used by the Volga Bulgars (X-XIII centuries A.D.). Analysis of remote sensing data for different dates, allowed determining the exact location of the site and revealing the dynamics of the retreat of the coastline in its location (Fig. 2a). Photo-interpretation results showed that the location of the settlement on the cape shaped ledge caused greater coast destruction rate (7 m/year from the images 1958-1980 yrs.) in comparison to the nearby coastline. During this time, the monument was destroyed almost completely. Despite the fact that in the period 1980-2010 yrs. coastal destruction rate drops to 5 m/year, it still remains very high. [16]

3.2. Dangerous exogenic processes

Slopes very often surround ancient settlements. This fact makes possible their destruction by modern exogenous processes, many of which may occur with catastrophic speed. Therefore, different erosion forms and processes study in the area of archeological monument location is necessary to prevent its destruction.

Figure 3. Churu-Baryshevsky hillfort in 1958 (a), 2014 (b) and on official plan (c).

Churu-Baryshevsky hillfort, has a circular shape and has been known since the XIX century. Natural barriers provides by breakages to the river and gully, artificial – by double system of ramparts and moats to the north-west and single from the southeast. The findings typical for the period of X-XIII centuries have been collected in 1949. It's hard enough to restore external view of archaeological site, because of damage by whole set of exogenous processes due to its location on high cape shaped ledge. Settlement destroyed by landslides in the western and north-eastern part. It also intersects by gully running along the bottom of ancient beam. The further growth of gully was luckily stopped due to the underlying bedrock. For a detailed description of site condition it is necessary to carry out field survey.

Figure 4. Vostochno-Voykinskoe hillfort in 1958 (a), 2014 (b) and on official plan (c).

Vostochno-Voykinskoe hillfort, known since the XIX century. Shape rectangular with rounded corners. Strengthened by two shafts and two moats on three sides. The eastern part of ancient settlement is separated from the western by rampart and moat. It is limited by gully from the west and by the river – in the southern part. From aerial photographs it is clear that there was a risk of bank caving on the south side by river meander (Fig 4a). At present, as can be seen by space images, active exogenous processes is not observed on the territory of the hillfort, exactly like the anthropogenic impact – buildings have disappeared as clearly recognizable on aerial data (Fig. 4b).

3.3 Anthropogenic factors

Intensive ***agricultural development***, which began at the territory of the Republic of Tatarstan in 1970-1980 years, endanger the existence of many archaeological monuments, including the fortified settlements of Middle Ages. As a result of plowing monuments lose their external features that complicates detection of fortifications remains on modern satellite images. Old aerial pictures deciphering helps in this situation to restore the exact fortifications shape of hardly recognized and completely destroyed sites and to estimate their area.

Figure 5. Staroenaleyskoe hillfort in 1958 (a), 2014 (b).

Staroenaleyskoe hillfort. Known since the XIX century. Shape is round, occupied area – 24316 m^2. The defensive line consists of one shaft and outer moat. As can be seen on space image, currently hillfort is completely plowed (Fig.5b). Part of the fortifications destroyed in the north-western part by gully and unpaved road extends through settlement. It can be assumed that at this moment archaeological site is destroyed due to anthropogenic impacts. It's possible reconstruct the shape ancient settlement and its defensive system by 50th years images (Fig. 5a), as well to estimate the anthropogenic damage. Field studies are necessary for more detail assessment of archaeological site condition.

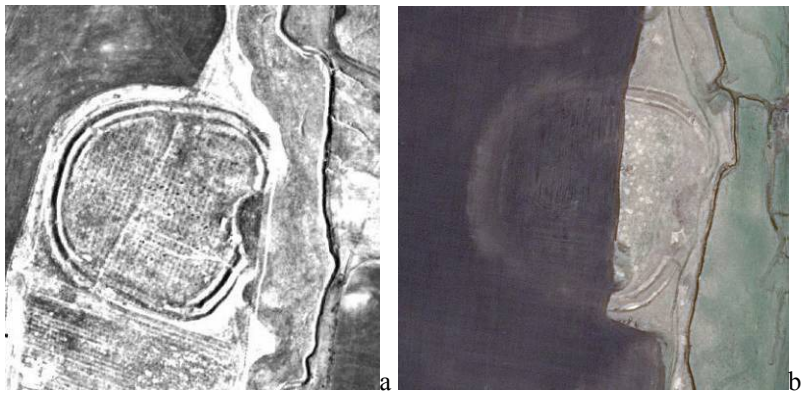

Figure 6. Bolsheklyarinskoe hillfort in 1958 (a), in 2014 (b).

Bolsheklyarinskoe hillfort, relates to the X-XIII centuries, known since the XIX century. Shape is round, occupied area – 3 300 $м^2$. It is surrounded on all sides by a line of fortifications consisting of ramparts and moats. As can be seen from aerial image (Fig. 6a), settlement area has been used for fruit and berry crops cultivation at the middle of last century. It has intensively plowed since the 1980s, now as a result about 70% of ancient settlement occupied by arable land. In the eastern part, fortifications are partially destroyed by old river channel. Today the form of destroyed ancient settlement can be restored through old aerial images (Fig. 6b).

Another negative anthropogenic factor, destroying archaeological sites, is the ***construction of industrial and residential buildings*** since the 1970s. Thus fortified settlements, getting under construction, often almost completely destroyed, including cultural layer, which makes their further study impossible.

Figure 7. Deushevskoe hillfort in 1958 (a), in 2014 (b)

Deushevskoe hillfort. Ancient settlement dates back to the X-XIII century and known by the end of the XIX century descriptions, according to which it had a rounded shape and cover 35 000-38 000 m^2. Today Deushevskoe fortified settlement is completely destroyed as a result of two negative anthropogenic factors combination – plowing and building (Fig. 7b). A small part of fortifications remained intact only in the garden of nearby house. According stories of local residents, during agricultural works a lot archaeological findings were discovered. As a result of anthropogenic impact only 1958 aerial image (Fig. 7a) makes possible to restore the configuration of the fortifications and determine the exact area of the archaeological site.

Figure 8. Dzhuketau hillfort in 1958 (a), in 2014 (b) and 3D model, view from southwest (c)

Dzhuketau hillfort. The monument is known from the beginning of the XIX century. As a result of numerous explorations (1928, 1952, 1960) and 1970-1972 excavation, identified the occurrence of ancient settlement to X century and its existence to the XV century. The territory of the site is currently occupied by an elevator and heavily damaged. Analysis of the stereo pair of aerial images allowed us to determine original appearance of fortifications, as well as to build a 3D model used to establish the height of the ramparts in the destroyed part.

4. CONCLUSIONS

As a result of archaeological sites study based on the analysis of multi-temporal aerial and satellite images three main directions revealed for remote sensing data use in the study of cultural heritage objects located on the territory of the Republic of Tatarstan.

1. Archaeological monitoring. Analysis of remote sensing data showed a high level of anthropogenic and exogenous factors load on archaeological sites located on the territory the Republic of Tatarstan. For example, in the last 50 years almost completely destroyed Staroenaleyskoe, Bolsheklyarinskoe and Deushevskoe hillforts as a result of total plowing and building. In this case, the use of multi-temporal images allows to estimate the damage caused both during economic activities, as well as under influence of natural processes, make an accurate mapping of sites and their separate elements that do not have precise georeference or currently disappeared.
2. Hillfort shape reconstruction. It is possible to create 3D models from aerial stereopair of the 1950s using software that implement automated photogrammetric algorithms, such as Agisoft Photoscan, VisualSFM, Autodesk 123Catch etc. Created in this way models of destroyed monuments such as the Dzhuketau hillfort (Fig. 8c) allows, in further post processing, to restore not only the shape of fortifications but also the actual size of ramparts and moats, currently known only from descriptions of past years.
3. Inclusion of remote sensing data processing results in archaeological GIS. This will allow not only to describe the morphometric characteristics of hillforts, to analyze spatial and attribute information but also to carry out an effective CHM. In case of human impact - removal of the monument area from land use zone and establishment of conservation boundaries. In case of identifying sites under negative exogenous processes - definition of local areas for urgent protection and rescue operations.

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