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Iskander I. Gainullin
Petr V. Khomyakov
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Iskander I. Gainullin ^{*a}, Petr V. Khomyakov ^b, Airat G. Sitdikov ^a, Bulat M. Usmanov ^b
^aKhalikov Institute of Archaeology, Butlerova st. 30, Russian Federation, 420012; ^bInstitute of Environmental Sciences, Kazan Federal University, Kazan, Tovarisheskaya st. 5, Russian Federation, 420097;

ABSTRACT

Archaeological monuments are an essential part of the cultural landscape. According to UNESCO directive, the "cultural landscape" is understood not simply as a result of joint creativity of man and nature, but as a purposefully formed natural and cultural territorial complex, which has structural, functional integrity, developing in specific physical and geographical, cultural and historical conditions. This article discusses the modern condition of the archaeological monuments of the Republic of Tatarstan, as a manmade part of the cultural landscape. Fortified settlements, with the system of defensive fortifications, were selected as the objects of study, as they are easily identified by remote sensing data. Identification and evaluation of monuments destruction risks is a priority in the study of medieval settlements. Due to the fact, that most of monuments is located on the small rivers banks, the first task of our study was to assess the risk of their destruction by natural processes. The second objective was to evaluate the role of the human factor in archaeological sites destruction. One of the main used methods is archival and modern remote sensing data analysis that also made able to correct the form of study settlements in comparison with existing plans, as well their size and location in the landscape. The results of research will help to identify trends in the monuments state and quantify the risks of their destruction.

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

1. INTRODUCTION

According to the situation at 2015 yr. 2751 objects of cultural heritage (historical and cultural monuments) are under the influence of negative natural and anthropogenic factors In Republic of Tatarstan (RT) [1]. As a result, not only the occupation layer of monument is affected, but also its shape is changing, and even, having a limited area of distribution, it can be destroyed [2]. Despite this, an integrated multi-disciplinary research of archaeological heritage objects state still has not been carried out. The last detailed study and mapping of archaeological monuments of Tatarstan were in the 70-ies of the last century. In addition, currently there is no evaluation system for anthropogenic and exogenous processes impact on the archaeological monuments, and there are no approved methodologies for quantitative assessment of monument state. This makes impossible to comply with the requirements of modern legislation for support and use of cultural heritage object. In this situation a unique evidence of Tatarstan peoples past disappear forever with archeological monuments destruction. To preserve the historical heritage on the territory of the Republic of Tatarstan, it is necessary to provide large-scale security and rescue works at destroying sites. Thus, the work on assessing of the risk of archaeological monuments destruction will help in priority areas selection for urgent archaeological research [3].

Worldwide, development of cultural heritage preservation strategy based on the analysis of the current monument state, forecasting and assessment of risks for archeological sites using advanced methods (analysis of remote sensing data, GNSS technologies and GIS) is an essential part of modern archaeological research [4]. For example, on the base of multi-method research, it is possible to identify and document landscape changes for improving understanding, protection and management of cultural heritage at all scales, from single monuments to entire landscapes [5]. In this, various methods of aerial photographs and satellite image processing are widely used: a comparative analysis of changes in the state of the monument [6], planning of targeted archaeological protection and rescue works [7], and reconstruction of ancient landscapes and initial appearance of archaeological objects of different historical epochs [8]. Thus, remote sensing data solves the following tasks in archaeology [9]:

1) best documentation and managing of rapidly disappearing ancient landscapes;

- 2) understanding of landscape formation processes;
- 3) identification and interpretation of economic, environmental, and social influences that result in long-term settlement and land use patterns;
- 4) recognize and contextualize the interplay between environment and human agency in the evolution of ancient economies and transformations in socio-organizational complexity.

In addition, the use and analysis of remote sensing data is an integral part of the non-destructive methods used in the study of archeological monuments, along with geophysical research aimed at objects identification and minimizing the destruction caused by archaeological excavations. Over the last years, multi-rotor unmanned aerial vehicles (UAVs) more widely used in modern archaeological research due to its low price and ease of operation [10]. Now they are widely used in various fields where it is necessary to obtain remote sensing data quickly and inexpensively from a short distance. 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 [11], [12], as well as the monitoring of their current state [13], [10]. The use of UAVs at the present stage also allows data combining for documentation and 3D visualization [14], [15].

The use of high-precision geodetic equipment is now becoming common and essential for archaeological works. If before it was enough to build topographic plans in conventional coordinate system using traditional instruments, but now archaeological research involves both digital geodetic equipment and high-precision GNSS receivers. Currently, GNSS technology is primarily used for archaeological excavations, allowing archaeologists to get results in electronic form, helping to create an excavation grid and manage the overall organization process. In addition, satellite methods help to determine exact location of the find, its exact length and spatial orientation. When using UAVs, satellite methods are especially useful to justify the coordinates of ground reference points for more accurate positioning and aligning of aerial images [16]. Also GNSS technologies are effective for determining and studying the dynamics of dangerous exogenous processes that threaten the monument [2]. Thus, the use of GNSS technologies provides accurate data collection, helps to build complex multi-layer maps and form geodatabases on the object under study.

The data obtained with the use of modern technologies and methods make it possible to carry out risk assessments for historical and cultural monuments, which is a top priority in cultural heritage management, as the basis for decision-making and implementation of specific measures for archeology sites conservation [17], [18], [19].

In this paper, remote sensing data were used to describe the state of several archeological sites under the influence of negative natural and anthropogenic processes. This work is continuation of the research [20] aimed at developing of a system for analyzing of disturbance of cultural heritage site (archeological monument) territory using both archaeological research methods and geomorphological and geocological research practices. Methodology for risk assessment of cultural heritage objects destruction is being developed on the basis of modern instrumental and cartographic-geoinformation approaches within the territory of Predvolzhye of the Republic of Tatarstan (RT). This region characterized by very high level of agricultural development with 76,4 % of plowed and 40 % eroded lands [21].

2. METHODOLOGY

Archaeological monument is an object in appearance and internal structure of which we can see the presence and transforming activity of human as a carrier of a particular culture. In addition, archaeological sites are integral part of the landscape, so modern methods of their study are primarily related to the approaches used in ecology and geography [22]. Therefore, the problem solved in the study assume an interdisciplinary approach, which determines the use of the following methods: topographic-geodesic, cartographic, remote sensing, GIS, field expedition studies, modeling.

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 (hillforts), 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. 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.

The study of remote sensing data does not always make it possible to determine the actual situation on the sites under study, therefore, fieldwork is necessary to obtain operational data on the current state of settlements, determine the degree of their susceptibility to different types of impact, and justify the need for rescue activities.

Field surveys included:

- Specification of location and visual features of settlement.
- Organization of ground control points for referencing during repeated survey.
- Photofixation and photogrammetry of study sites, GNSS survey of reference points for 3D model georeferencing.

The reference points were organized on hillforts, where the danger of destruction as a result of modern exogenous processes or anthropogenic impact was identified. On completely destroyed fortifications, as well as in the absence of signs of impact, the installation of control points not carried out.

In addition to standard photography, photogrammetric survey was carried out in some areas, which makes it possible to create a 3D model of the destroyed sites of fortificate settlement.

3. RESULTS

During processing of approximately 130 aerial photos, 30 settlements have been found relating to the different cultures and most of them exposed to different forms of impact. Five monuments are destroyed, and their external appearance can be restored only on archival aerial photographs. As a result of analysis of multi-temporal archival aerial and actual satellite imagery 5 hillforts of Predvolzhye RT were selected for subsequent detail field survey aimed to describe their current state (Fig. 1, Tab. 1). Their configuration, as well as the dimensions, are very different. Besides the traditional for our region cape settlements, using natural fortifications and having a triangular shape, settlements with square, round, trapezoidal, semicircular or other forms can be found. The size of the settlements also differ. Within Tatarstan settlements generally occupy a relatively small area (within 10-20 thousand m²), but there are also very large, for example Bogdashkinskoe (center of the principality) and Khulashskoe hillforts, chosen for this study.

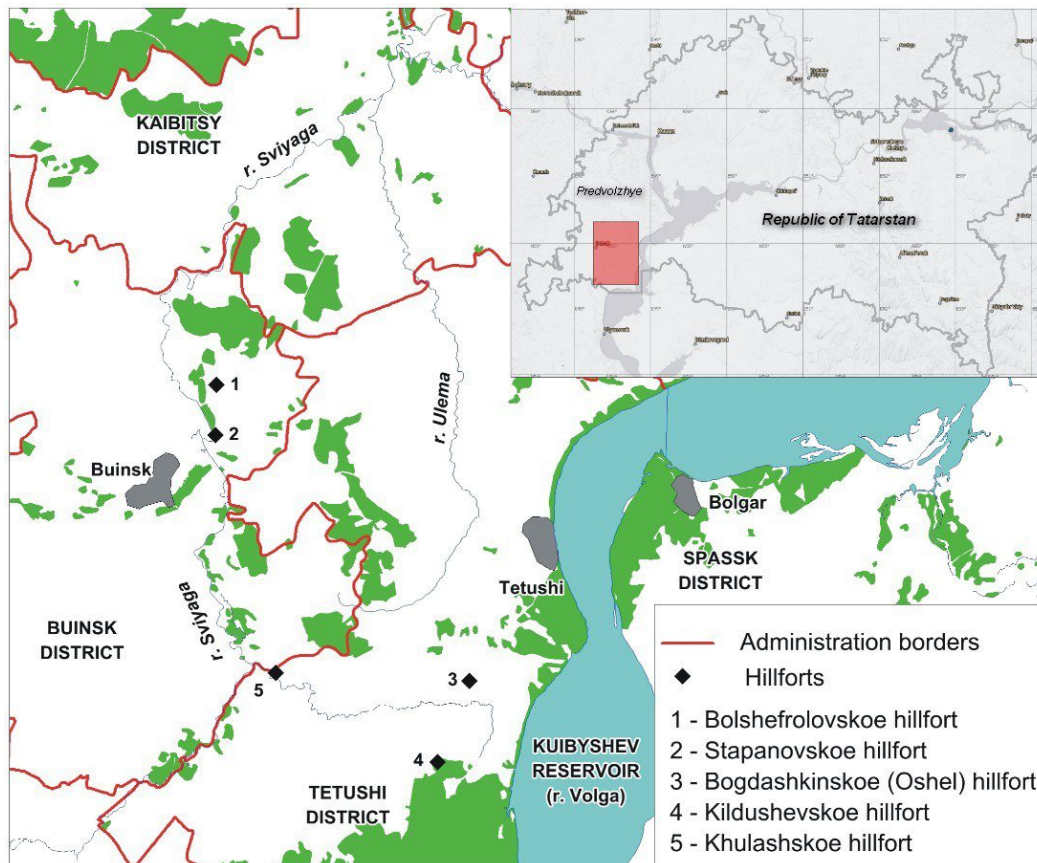


Figure 1. The location of studied settlements (Predvolzhye RT).

Table 1. Characteristics of studied fortified settlements.

№№	Name	Dating	Culture affiliation	Aerial survey, year /number of images		
1.	Bogdashkinskoe settlement	X-XIII cent.	Volga-Bolgar culture		1969/1	1980/2
2.	Kildyushevskoye settlement	X-XIII cent.	Volga-Bolgar culture	1958/2	1969/2	1980/2
3.	Hulashskoe settlement	X-XIII cent.	Volga-Bolgar culture		1969/1	1980/2
4.	Bolshetrolovskoe settlement	IV-VII cent.	Imenkov culture	1956/2		1980/2
5.	Stepanovskoe settlement	IV-VII cent.	Imenkov culture	1956/1		1980/1

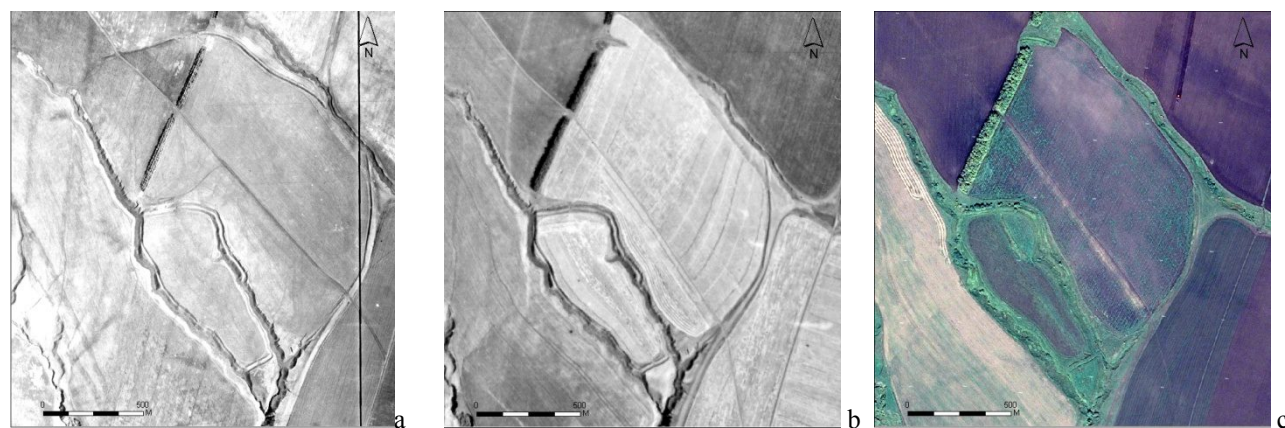


Figure 2. Bogdashkinskoe settlement on multi-temporal images (a – 1969, b – 1980, c – 2015).

Bogdashkinskoe fortified settlement (X-XIII cent. A.D.), known since 1909. The planning, fortifications, cultural relics indicate the urban character of the settlement. Presumably, the ancient settlement is associated with the chronicle city Ochel, destroyed in 1220 [23]. The settlement has a complex form of fortification structures – the site is divided into two parts: 1) citadel (3.4 ha) in the southwestern part of the site, surrounded by two rows of ramparts and ditches; 2) trading quarter, protected by one row of fortifications. The complex shape is clearly visible from the picture of 1969 (Fig. 2. a). Even at that time, both the outer and inner territory were plowed, but almost all the ramparts were preserved, except several fragments in the north-eastern and north-western top ends of the outer platform. The defensive system of the outer, and mostly of the inner settlement, was already partially destroyed by 1969 due to landslide processes on the slopes of ravines that developed along the ditches. Only according to the photographs of 1969 it is possible to restore the shape of the settlement, because by 1980 most of the fortifications bordering the trading quarter part were destroyed as a result of intensive plowing (Fig. 2. b). Currently it can be argued that about 95% of ancient settlement area, including the defensive system, is under negative anthropogenic and natural impact. The area of the untouched cultural layer (170 hectares), which are determined at earliest photo taken in 1969, has now shrunk to 3.4 hectares, limited only to the citadel. From the original length of the outer shafts of 1,784 m, at present, 165 m are still intact.

Kildyushevskoye fortified settlement (X-XIII cent. A.D.), known since 1957. Based on the results of the interpretation of remote sensing data, information on the monument location and area has been essentially refined. In addition, we found out that the settlement covers an area not 200x200 m, as stated in the description of 1957, but 350 x 350 m and it can be seen that the ramparts surrounds settlement not from two but from all four sides. According to the multitemporal images, the area of tree vegetation is decreasing from 2.5 ha to 0.6 ha in the northern and southeastern parts of the site. (Fig. 3. a-d). We can see ravine, that destroyed the 50 meters of rampart on the western side of the monument as well as slope processes, partially destroyed the ramparts in the south by 1958.

The maximum damage to the site was inflicted in the last 30 years. From the southern and eastern sides of the monument, the rampart was destroyed by road (50 m), in the south-western part of the ancient settlement a pond was created. During land works, the part of the ancient settlement with an area of 4388 m² was cut off and the cultural layer was destroyed. In the center of the settlement there is an orchard (?) (3 ha), a country road 490-meter long passes through the ancient settlement (Fig. 3. d). Thus, currently, about 50% of ancient settlement area, including the defensive system, is under negative anthropogenic and natural impact. With a total area of an ancient settlement of 12.5 hectares, the area of the untouched cultural layer is 6 hectares.

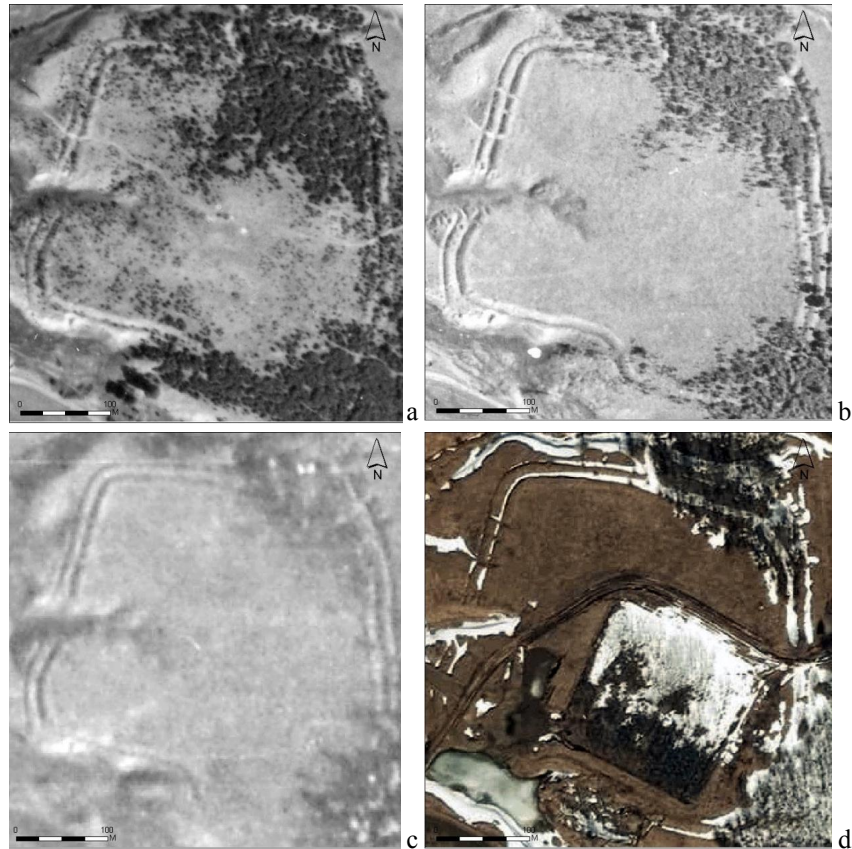


Figure 3. Kildyushevskoye fortified settlement on multi-temporal images (a – 1958; b – 1969; c – 1980; d – 2015).

Hulashkoe fortified settlement (X-XIII cent. A.D.), known from the middle of the 19th century, is located on a wide, sloping cape between the river bank and an ancient ravine (Fig. 4). As can be seen on modern images (Fig. 4 c), the territory of ancient settlement is actively plowed, so the ramparts of trading quarter are fully and of the inner city is partly destroyed. From total length of the inner city ramparts (1,8 km) visible in the 1969 image, remains only 600 m. With a total area of an ancient settlement of 180 hectares, the area of the untouched cultural layer is 8.5 hectares. Steep slope complicated by a complex of exogenous processes limits the monument from the southwest. Field studies have confirmed the situation observed in the images. The system of fortifications preserved only in the southern and north-western parts of the settlement, in the eastern part the remains of the ramparts are covered by forest vegetation.

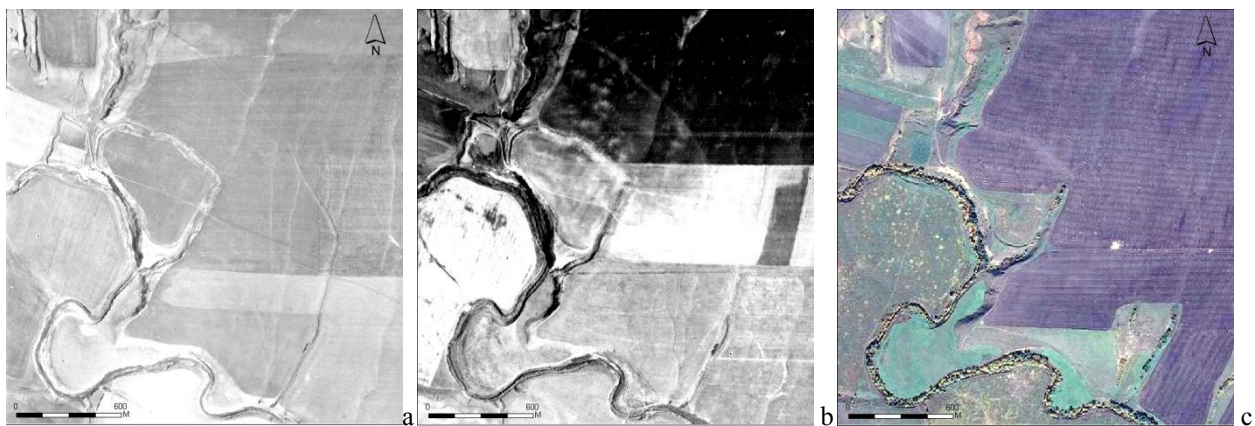


Figure 4. Hulashkoe fortified settlement on multi-temporal images (a – 1961; b – 1980; c – 2015).

Bolshefrolovskoe fortified settlement (IV-VII cent. A.D.), known since 1949. The settlement is located on a cape-shaped brow, bounded from the south by a high terraces ledge, and from the north by a gulch with a digging secondary ravine, which can cause dangerous exodynamic processes on the slopes (Fig. 5). From outside (east) two embowed ramparts and two embowed ditches strengthen it. Field studies have shown that human impact on this archaeological site is minimal. Since the settlement is located at remote place there is no plowing and grazing on its territory. At 30 m to the east from the first rampart there is an unauthorized limestone quarry, which almost completely destroyed the outside settlement. Bolshefrolovskoe settlement is under the strong influence of exogenous processes. Weak plant cover and soddy soils lying on a thin layer of loam on thr bedrock, represented by fine limestone (Urzhum stage of Upper Permian), are easily destroyed. Stress relief fractures are observed in the upper part of the slopes. Both in the north and in the south there is intensive destruction of the slopes, soil slips, the settlement boundaries are steep. From the south, on the slope of the river valley talus processes are observed.

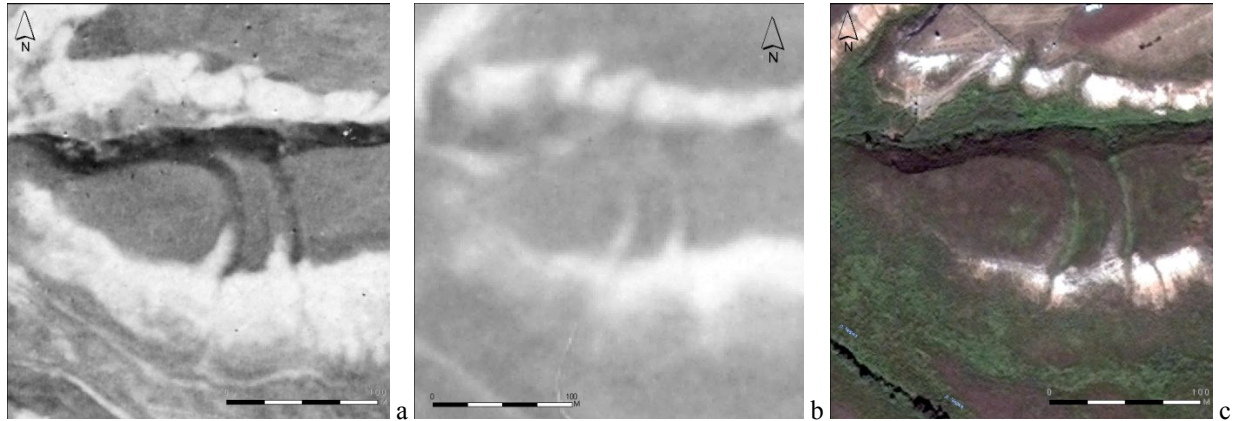


Figure 5. Bolshefrolovskoe fortified settlement on multi-temporal images (a – 1958; b – 1980; c – 2015).

Stepanovskoe fortified settlement (IV-VII cent. A.D.), known since 1949. The settlement has a triangular shape, from outside (east) it is strengthened by rampart and embowed ditch. In the 1970s the rampart was completed with two parallel mounds for the construction of a shooting range which is currently not functioning. (Fig. 6 b-c). A gulch with grassy slopes rounds the site from the southwest, west and northwest and indicates a low intensity of exogenous processes. A ravine, the right slope of which is composed of bedrock (Fig. 7) with talus processes and the left side is made of loam and cut by a ravine-gulch net, bound the site from southeast. Over the 60-year period the settlement area in the south-eastern part start to destroy because of talus processes, an average edge retreat is 12 m (0,2 m/year). The destruction of the settlement area leads to the destruction of the cultural layer.

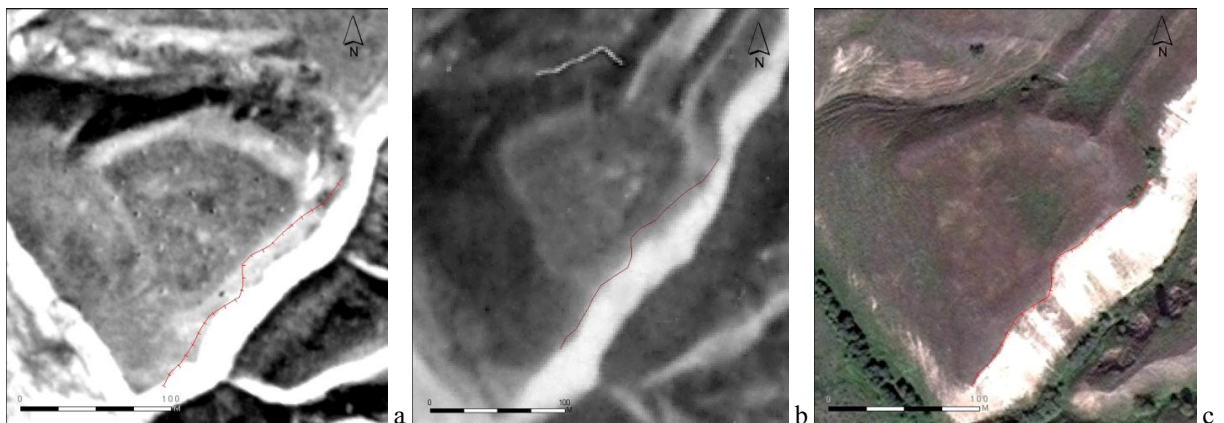


Figure 6. Stepanovskoe fortified settlement on multi-temporal images (a – 1958; b – 1980; c – 2015).



Figure 7. Talus processes in the south-eastern slope of the Stepanovskoe fortified settlement.

CONCLUSION

Anthropogenic impact. As a result of the analysis of remote sensing data and field studies, the most vulnerable to the negative anthropogenic processes are Bogdashkinskoe and Hulashskoe fortified settlements (Tab. 2). Most of their territory is in the zone of intensive agricultural activities. To a large extent, but not so intensely, there is a destruction of the cultural layer and changes in the external appearance of the Kildyushevskoye hillfort. With the overall integrity of the ramparts, the cultural layer is disturbed by orchard and pond creation. The Stepanovskoye fortified settlement is least affected by anthropogenic negative processes. The creation of the shooting range has led to a change in a hillfort appearance. Bolshefrolovskoye ancient settlement is not under the influence of anthropogenic processes, but the territory of nearby settlement possibly destroyed by a limestone quarry and requires a separate study.

Table 2. Natural and anthropogenic negative impact on studied fortified settlements.

№№	Object name	Negative processes Damage (%)		Recommendations
		Anthropogenic	Exogenous	
1.	Bogdashkinskoe settlement	ploughing 80%	Slope processes 15%	Instrumental high precision surveying of the settlement, the definition of the boundaries of the monument, land use study
2.	Kildyushevskoye settlement	Construction, agriculture? 40%	Slope processes, forested 10%	Instrumental high precision surveying of the settlement, land use study, rescue archaeological work in areas of exposure of the cultural layer.
3.	Hulashskoe settlement	ploughing 85%	Slope processes 10%	Instrumental high precision surveying of the settlement, definition of monument boundaries, land use study.
4.	Bolshefrolovskoe settlement	—	Slope processes 10%	Rescue works on nearby settlement, monitoring of slope processes.
5.	Stepanovskoe settlement	Construction 10%	Slope processes, 20%	Organization of annual monitoring observations of landslide processes

Exogenous processes. The most intensive exogenous processes were found at Stepanovskoye fortified settlement (talus on a steep slope). The remaining sites under study are also under influence of exodynamic processes; this led to partial destruction of the defensive system of Bogdashkinsky, Kildyushevsky and Khulashsky hillforts. Despite the observed slope processes, only Bolshefrolovskoye fortified settlement retained its original appearance.

Thus, for the first time for the study region, works were carried out to determine the fortifications transformation, to study dynamics of monuments destruction, to restore the shape of the lost cultural heritage objects. The actual data about fortified settlements state obtained with the use of modern technologies and methods make it possible to carry out system for historical and cultural monuments territory disturbance analysis. At the same time, the results of research will help to identify trends in the monuments state and quantify the risks of their destruction.

The conducted studies determine the work of the team in the future. During the field works a new and original, not only for our country but also abroad, a comprehensive risk assessment method of archaeological monuments destruction will be developed using unmanned aerial vehicles, photogrammetry, 3D-modeling, GNSS technologies.

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REFERENCES

- [1] State Report. [On the state and environmental protection of the Republic of Tatarstan in 2015], 505 (2016).
- [2] Gaynullin, I., Sitdikov, A., Usmanov, B., "Destructive abrasion processes study in archaeological sites placement (Kuibyshev and Nizhnekamsk reservoirs, Russia)," Proc. International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM2014 3(1), 339-346 (2014).
- [3] Gaynullin, I., Kasimov, A., Khomyakov, P., Usmanov, B., "An integrated approach for medieval hillforts study (Republic of Tatarstan, Russia)," Proc. 3rd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM2016 3(2), 247-254 (2016).
- [4] Wang, J.-J., "Flood risk maps to cultural heritage: Measures and process," Journal of Cultural Heritage 16(2), 210-220 (2015).
- [5] Risbol, O., Briese, C., Doneus, M., Nesbakken, A., "Monitoring cultural heritage by comparing DEMs derived from historical aerial photographs and airborne laser scanning," Journal of Cultural Heritage 16(2), 202-209 (2015).
- [6] Lasaponara, R., Masini, N., Holmgren, R., Backe, Forsberg, Y., "Integration of aerial and satellite remote sensing for archaeological investigations: a case study of the Etruscan site of San Giovenale," Journal Of Geophysics And Engineering 9(4), S26-S39 (2012).
- [7] Banerjee, R., Srivastava, P. K., "Reconstruction of contested landscape: Detecting land cover transformation hosting cultural heritage sites from Central India using remote sensing," Land Use Policy 34, 193-203 (2013).
- [8] Reinhold, S., Belinskiy, A., Korobov, D., "Caucasia top-down: Remote sensing data for survey in a high altitude mountain landscape," Quaternary International 402, 46-60 (2016).
- [9] Hritz, C., "Contributions of GIS and Satellite-based Remote Sensing to Landscape Archaeology in the Middle East," Archaeol. Res., 22(3), 229-276 (2014).
- [10] Esposito, S., Fallavollita, P., Melis, M. G., Balsi, M., Jankowski, S., "UAS imaging for archaeological survey and documentation," Proc. SPIE 8903, 89030K (2013).
- [11] Stek, T. D., "Drones over Mediterranean landscapes. The potential of small UAV's (drones) for site detection and heritage management in archaeological survey projects: A case study from Le Piane in the Tappino Valley, Molise (Italy)," Journal of Cultural Heritage 22, 1066-1071 (2016).
- [12] Fernandez-Hernandez, J., Gonzalez-Aguilera, D., Rodriguez-Gonzalez, P., Mancera-Maboada, J., "Image-based modelling from unmanned aerial vehicle (UAV) photogrammetry: an effective, low-cost tool for archaeological applications," Archaeometry 57(1), 128-145 (2015).
- [13] Asăndulesci, A., "Inside a Cucuteni Settlement: Remote Sensing Techniques for Documenting an Unexplored Eneolithic Site from Northeastern Romania," Remote Sensing 1(17), 41 (2017).
- [14] Balletti, C., Guerra, F., Scocca, V., Gottardi, C., "3d integrated methodologies for the documentation and the virtual reconstruction of an archaeological site," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5(W4), 215-222 (2015).
- [15] Tscharf, A., Rumpler, M., Fraundorfer, F., Mayer, G., Bischof, H., "On the use of UAVs in mining and archaeology – geo-accurate 3d reconstructions using various platforms and terrestrial views," ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences II-1(W1), 15-22 (2015).
- [16] Dubbini, M., Curzio, L. I., Campedelli, A., "Digital elevation models from unmanned aerial vehicle surveys for archaeological interpretation of terrain anomalies: Case study of the Roman castrum of Burnum (Croatia)," Journal of Archaeological Science: Reports 8, 121-134 (2016).
- [17] Wu, P.-S., Hsieh, C.-M., Hsu, M.-F., "Using heritage risk maps as an approach to estimating the threat to materials of traditional buildings in Tainan (Taiwan)," Journal of Cultural Heritage 15(4), 441-447 (2014).
- [18] Romanescu, G., Nicu, I. C., "Risk maps for gully erosion processes affecting archaeological sites in Moldavia, Romania," Zeitschrift für Geomorphologie NF 58(4), 509-523 (2014).
- [19] Del Lungo, S., Sabia, C. A., Pacella, C., "Landscape and cultural heritage: best practices for planning and local development: an example from Southern Italy," Procedia - Social and Behavioral Sciences, 188, 95-102 (2015).

- [20] Gainullin, I. I., Khomyakov, P. V., Sitdikov, A. G., Usmanov, B. M., "Study of anthropogenic and natural impacts on archaeological sites of the Volga Bulgaria period (Republic of Tatarstan) using remote sensing data," Proc. SPIE 9688, 96880Z (2016).
- [21] Yermolaev, O. P., Usmanov, B. M., Muharamova, S. S., "The basin approach and mapping to the anthropogenic impact assessment on the east of the Russian Plain," International Journal of Applied Engineering Research 10(20), 41178-41184 (2015).
- [22] Gaynullin, I. I., Sitdikov, A. G., Usmanov, B. M., "Abrasion processes of Kuibyshev Reservoir as a factor of destruction of archaeological site Ostolopovo (Tatarstan, Russia)," Advances in Environmental Biology 8(4), 1027-1030 (2014).
- [23] [A set of archaeological monuments of the Republic of Tatarstan], Kazan, Russia, Vol. 3, 528 (2007).