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Study of medieval fortified settlements destruction under natural and anthropogenic factors using remote sensing data

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Abstract. Archaeological monuments are an essential part of the cultural landscape. Modern condition of archaeological monuments of the Republic of Tatarstan is discussed in this article. Fortified settlements, with the system of defensive fortifications were selected as the objects of study, as they are easily identified by remote sensing data. Due to the fact, that most of monuments are 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 as their size and location in the landscape. The results of research will help to identify trends in monuments state and to quantify the risks of their destruction.

1. Introduction

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 [1]. 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 [2]. Here, various methods of aerial photographs and satellite image processing are widely used: comparative analysis of changes in the state of the monument [3], planning of targeted archaeological protection and rescue works [4], reconstruction of ancient landscapes and initial appearance of archaeological objects of different historical epochs [5]. Thus, remote sensing data solves the following tasks in archaeology [6]: 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) recognition and contextualization of the interplay between environment and human agency in 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 minimization of destruction caused by archaeological excavations.

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 [7]. 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 [8, 9], as well as the monitoring of their current state [10]. The use of UAVs also allows data combining for documentation and 3D visualization [11, 12].

The use of high-precision geodetic equipment is now becoming common and essential for archaeological works. Earlier 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 [13]. Also GNSS technologies are effective for determining and studying the dynamics of dangerous exogenous processes that threaten the monument [14]. Thus, the use of GNSS technologies provides accurate data collection, helps to build complex multi-layer maps and to form geodatabases on the object under study.

This work is continuation of the research [15, 16] aimed at developing a system for analyzing of disturbance of cultural heritage site (archeological monument) territory using both archaeological research methods and geomorphological and geoecological 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).

2. Methods

Remote sensing data of maximum possible time spectrum over the past 60 years were selected. Search for fortified settlements on aerial photographs was carried out with the help of descriptions based on the results of field survey of past years. The next step was to estimate the fortified settlements condition.

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 to determine the degree of their susceptibility to different types of impact and to justify the need for rescue activities.

Field surveys included:

- specification of location and visual features of settlement;
- photofixation of current monument state;
- GNSS survey of reference points;
- aerial survey of archaeological object under study.

Aerial photography was performed using a multi-rotor UAV DJI Phantom 4 (figure 1 a). The survey was performed with a 12-megapixel camera mounted on a quadrocopter; the gimbal provides a stable camera position during shooting. The UAV was controlled from a smartphone using Pix4D Capture software (figure 2) which allows to create a flight task and to configure the shooting parameters.

Aerial photography was performed with the following parameters:

- height – 50-100 m;
- pictures overlapping – 60-80%;
- camera position – 90°;
- coverage – area survey;
- meteorological conditions – no precipitation, wind no more than 15 m/s.

(a) (b)

Figure 1. Quadrocopter DJI Phantom 4 (a), special mark georeferencing by GNSS receiver (b).

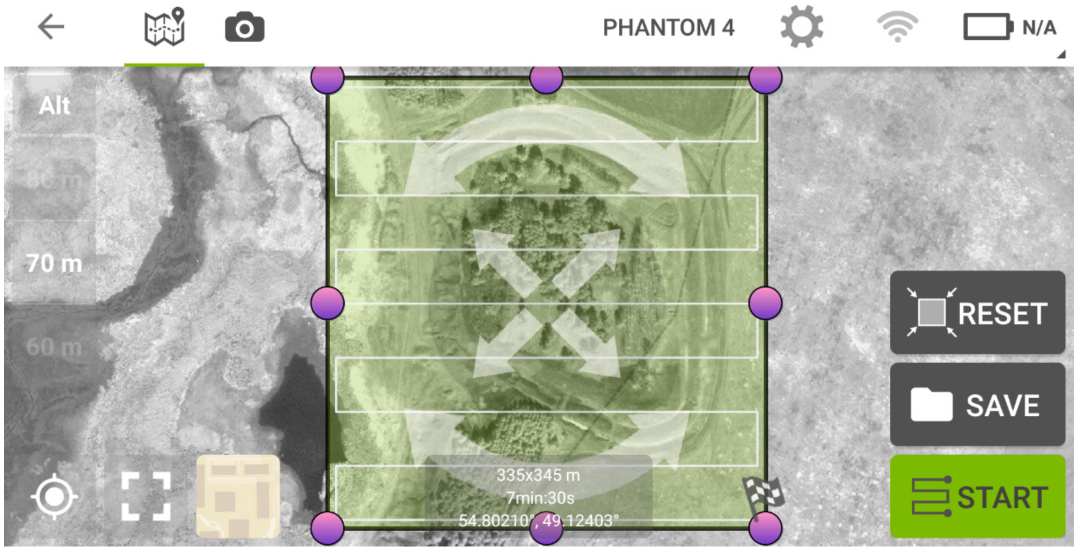

Figure 2. Flight task for Tankeevsky hillfort survey.

Coordinates in plan and height during aerial survey are determined by the GPS built in the UAV. This accuracy (4-5 m) is not sufficient for the construction of a topographic plan, digital terrain model (DTM) and digital elevation model (DEM) of an archaeological heritage object. To increase the accuracy of the survey before the flight a network of control points was formed on the territory.

For this purpose, the special marks were printed on the banner fabric with holes in the corners for fixing on the ground, and in the center – for a geodetic pole with antenna (figure 1 b). For high precise coordinates and height detection, GCPs centers were measured with a double frequency GNSS receiver with external antenna. Survey was performed in RTK regime in WGS84 with real-time corrections by satellite reference stations.

Coordinates of the GCPs centers were used to improve UAV data processing accuracy. Photogrammetric works were performed in Agisoft Photoscan in the following sequence:

- images inspection;
- pictures alignment;
- cloud of points construction;
- digital elevation model and orthophoto construction.

DEM analysis, mapping and calculations were conducted in Golden Software Surfer 13 software. A digital terrain model (DTM) with a step of 0.5 m showing the altitude characteristics of the settlement territory was generated by the point cloud. Profiles, inclination and aspect maps were built to describe the morphometric characteristics of settlement relief.

Ultra-high resolution orthophotos with a pixel size of 5 cm were also created. They were used to create electronic layers for topographic plans construction in MapInfo Professional 12.0 software.

3. Results

The mail goal of our investigation is a study of negative impact on cultural heritage objects with the help of modern technologies. In this context, to our opinion, 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.) where the threat of destruction is maximal. As 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 are usually located on the banks and terraces of small rivers where influence of fluvial and exogenous processes is possible. Therefore, important task is geomorphological description of ancient settlements placement in order to assess the risk of their destruction by natural processes. Another factor that increases the danger for historical objects is widespread process of plowing, irrigation, active construction, etc. that started in the middle of the XX century. Intensive territory development led to a significant change in exterior of monuments and often – to their complete disappearance. Therefore, another objective is to evaluate the role of the human factor in archaeological sites destruction.

As a result of analysis of multi-temporal archival aerial and actual satellite imagery 12 hillforts of RT were selected for subsequent detail field survey aimed to describe their current state. This article presents the first results of UAV and GNSS survey on an example of Tankeevskoe fortified settlement I.

Tankeevskoe fortified settlement I is known since the XVII century. It is located in the Republic of Tatarstan in Spassky district 1.7 km south from the southern outskirts of the Polyanka village and 0.35 km west from the Bolgar-Ulyanovsk highway. An ancient settlement is surrounded from the north, east and south by a system of ramparts and ditches. From the west it is bounded by terrace cusp 6-7 m high, beyond which there is a narrow (25-35 m) floodplain of the Yasachka river (currently the bay of the Kuibyshev reservoir). The settlement area is flat and softly decreases to the western border by 2-2.5 m. Pine and birch plantations are located on the site of the settlement territory at the time of the field survey.

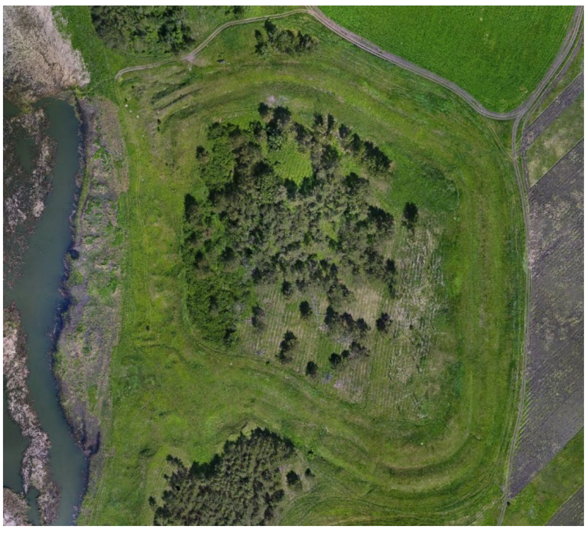

Figure 3. Orthophoto on the territory of Tankevskoe fortified settlement I.

Defensive structures are a triple system of ramparts in varying disturbance degrees. The extant outer (third) rampart (1-1.5 m) is found in the northeastern, eastern and southern parts of the settlement. The depth of ditches ranges from 2 to 4 m. In the northern part the outer rampart is not preserved practically due to the plowing of the adjacent territory. In the southwestern part defensive structures smoothly descend into a shallow ravine the mouth part of which is on the floodplain.

Based on the UAV survey, a dense cloud of points and a 3D model of the Tankeevskoe fortified settlement I were constructed required for DEM and orthophoto creation. The orthophoto resolution is 0.05 m (figure 3). With the use of an orthophoto, roads, vegetation, water objects, defensive structures were drawn for a topographical plan of the settlement.

Based on the digital model, hypsometric curves were constructed and preliminary morphometric analysis was performed (figure 4). Maps of territory inclination and aspects (figure 5) were also rendered to obtain characteristics for assessing the danger of modern exogenous processes development.

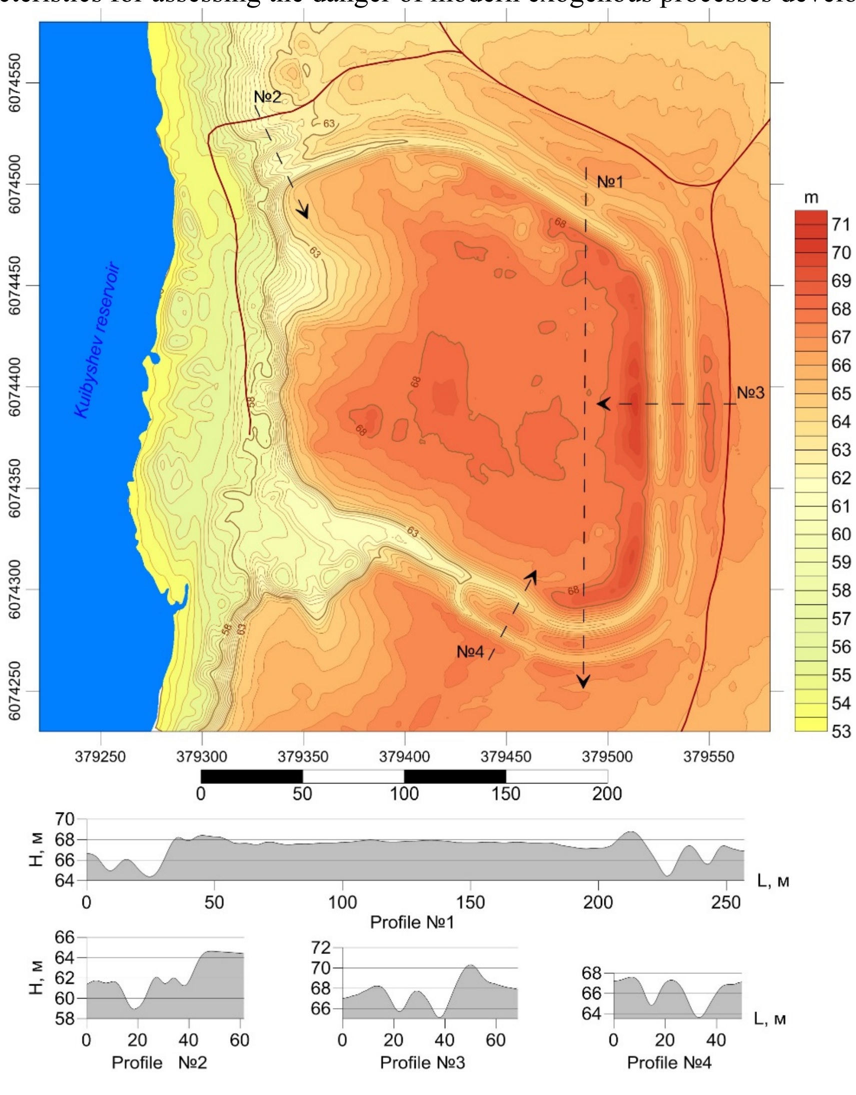

Figure 4. Digital elevation model of the Tankevskoe fortified settlement I.
Elevation profiles: through the settlement – 1; trough defensive structures – 2-4.

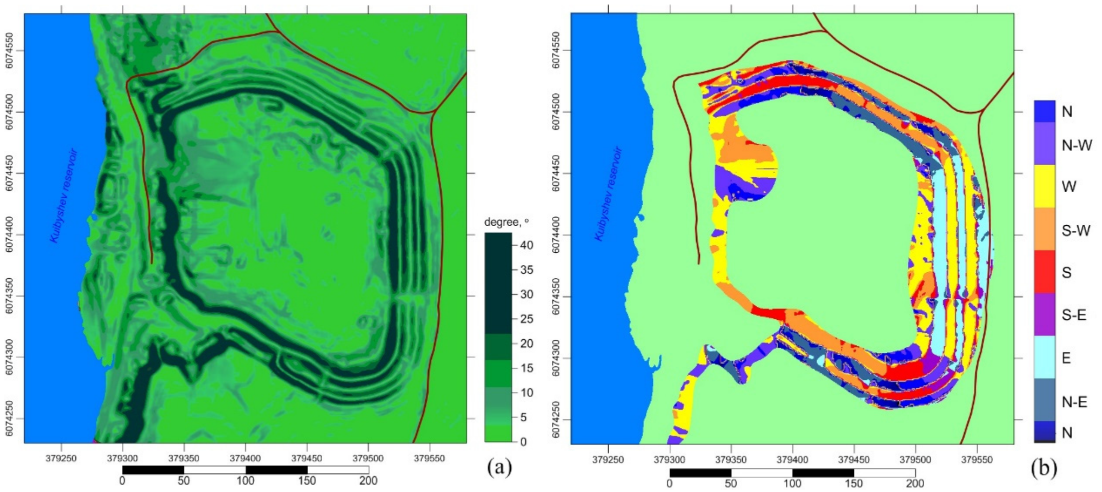

Figure 5. Inclination map (a) and aspects map (b) on the territory of the Tankevskoe fortified settlement I.

The results of UAV survey revealed that the Tankeevskoe settlement I is under significant exogenous and anthropogenic impact. There are furrowing traces from reforestation works on the settlement area. In the eastern part the ramparts are strongly deformed under the influence of slope processes. As a result the passes through defensive structures are practically not recognized. The plowing partially destroyed the third (external) system of fortifications. As a result of exogenous processes and anthropogenic impact, ramparts are destroyed in the northwestern part of the site. In the eastern and north-eastern parts, the remains of previously existing field roads are marked on the fortification. On the ridge of the north-western tip of the middle rampart a longitudinal excavation (possibly traces of archaeological research) with length of about 25 m and depth – 0.5-0.8 m, is noted.

It should be underlined that the negative impact on the territory of the Tankeevskoe settlement I was noted in the works of researchers of the past. According to SM. Shpilevsky in the XVII-XVIII centuries saltpeter was produced here. In the 1870s. the territory of ancient settlement "was plowed up under crops". At the time of the last survey of the ancient settlement in 1961, the fortified settlement area was also plowed up.

4. Conclusions

Thus, for the first time for the territory of Republic of Tatarstan, works were carried out to get actual data on fortified settlements transformation, dynamics of monuments destruction with the use of modern technologies and methods. The results of research will help to identify trends in the monuments state and to quantify the risks of their destruction. During the field works an original method for risk assessment of archaeological monuments destruction will be developed using unmanned aerial vehicles, photogrammetry, 3D-modeling, GNSS technologies.

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