USING EARTH REMOTE SENSING DATA TO CONTROL
CHANGES IN WATER STORAGE BASIN COAST LINE

Alexeyi V. Dubrovskiy¹, Olesya I. Małygina², Viktor N. Moskvin³,
Tamara V. Vereshchaka⁴, Valery I. Tatarenko⁵

¹,²,³,⁴,⁵Siberian State University of Geosystems and Technologies, Novosibirsk,
Russia

¹avd5@ssga.ru, ²131379@mail.ru, ³mosk46@mail.ru,
⁴cartography@miigaik.ru, ⁵v.i.tatarenko@ssga.ru

Corresponding Author: Alexeyi V. Dubrovskiy
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Abstract

The modern organisation of infrastructural facilities and industrial complexes shall be environmentally safe and economically effective. The article poses the problem of creation of a system for the efficient use of and control over the state of water storage basins using geotechnology and Earth remote sensing systems. The Novosibirsk Water Storage Basing, Novosibirsk, Russia is taken as an example. Over the explored area of the water basing, the environmental situation is worsening as a result of the progressing wind and wave erosion of the coast line and intensive washout of soil, plants, trees, chemical fertilisers etc. The article reasonably introduces the concept of technogenic natural territorial complexes (TNTC). By Earth remote sensing, the speed of soil erosion along the whole coast line of the basin is determined. Soil exploration and typing provided materials for a forecast model of wearing away of the coast line.

The plots for geodynamic monitoring and data acquisition periods are defined. The need for bank-protection works and a wider recreational use of the basing water is stated.

Keywords: Satellite monitoring, technogenic natural territorial complexes, land resources, unmanned aerial vehicles, digital economy, water bodies.

I. Introduction

Presently, humanity faces a number of global problems of which the following five are most pressing to include social, environmental, food, energy and water supply issues. The first four of them cannot be solved without the fourth one having been solved first. Since the state of the water bodies is deteriorating year after year raising fears about the future of mankind, the water supply problem is believed to be the principal one by scientists of many countries. [VII, VIII, XXIX]
The critics of water management that unfolded recently in mass media has touched its modern basis – the water storage reservoirs. They are often referred to as causing material, environmental and moral damage their main disadvantages being substantial ecological deterioration, water pollution and sharp reduction of land resources. To overcome the problems, water surface elevation decrease or complete drainage are suggested. [XVIII, XIX]

According to general calculations, artificial water reservoirs have changed natural conditions over 700 thousand square kilometres not to mention the infrastructural changes and relocation of people over 1.5 million square kilometres.

In Russia, water basins have always been created in habitable areas with developed infrastructure or nearby, because such basins are intended, first of all, to satisfy various needs of the population for fresh water and electric power, to create transportation ways etc. However, the changing of relief and landscape of relevant natural territorial complexes disturbs their natural water flow wearing away the coast line, especially, of the lowland basins (see Figure 1). [XIII, IV]

![Fig. 1: Parts of the coast of the Novosibirsk Water Storage Basin worn away by wind and wave erosion: a) near Zavyalovo village, b) near Sosnovka village.](image)

A modern land use strategy must be not only efficient but expedient economically which implies the comprehensive exploration of land resources and development of a comprehensive land use model. Especially important is to develop and carry out an environmentally oriented land use policy in respect of lands used by the large industrial or so called technogenic natural territorial complexes (TNTCs).

Water storage reservoirs are complex structures capable (save for their direct functions) of solving some tasks related to provision of recreational resources to population. National parks and recreational areas are becoming more and more popular all over the world. [VIII] Creation of a recreational zone management system takes an economic development model where precise monitoring of the territory condition by geotechnologies shall combine with economic modelling and forecasting. Like any TNTC, water basins recreational zones shall generate profit.
Subject to the correct land use, sustainable income is available to private entities and local authorities alike. [XXVII, XXVI, XI]

II. Materials and Methods

According to the roadmap of development of geodesy and cartography until 2020 [XVI], to improve cartographic production and supply in the Russian Federation, the problem of the modern methods of space geodesic fund update and relevant infrastructure is urgent. One of the ways to solve it is to improve cartographic document update technologies using space mapping. The state cartographic monitoring carried out in RF consists of related informational and technological segments to include the cosmic, cartographic, satellite navigation and geoinformational ones. [XXX]

The lack of topical and reliable information on land resources makes efficient management, control, supervision and inter-departmental coordination impossible. Orbital photographs enable to create general plans of settlements, project documentation, to position investment sites, reveal illegal construction, create territorial plans etc. Moreover, the modern satellite remote sensing systems can photograph Earth with spatial resolution up to 0.23m while aerophotographic complexes ensure even greater quality of 0.1 m and larger. Such precision is satisfactory for virtually all works to be carried on by a land management professional. Delineation of territories and municipal borders, natural monuments and proprietary objects are only some of the works that can be carried out using the Earth remote sensing data (ERSD).

The modern land monitoring and emergency early warning systems as well as meteorology services use ERSD actively. Moreover, there are examples of a satellite surveying system developed for particular purposes of emergency monitoring and support to relevant authorities with relevant data. One of them is the Russian space system Canopus-M. [XVII, XII]

Water storage basins are one of the most interesting and important from the point of view of geomonitoring which is due, first of all, to the strategic task of supplying fresh water to the people. Also, the state of a TNTC and its behavior as a technogenic entity are of interest. One of the mandatory parameters of a water storage basin design is its useful life being 450 years for the Novosibirsk one. However, preliminary calculations took only minimal coast line wearing speed into account while the actual one exceeds it by 10 times. As a result, the sludge setting rate is also above the design figures and the useful life of the basin may be as short as 250 years.

To analyze the situation with the coast line of the basin, a geoinformational project was developed to explore the geodynamic properties of the land as well as the wind and wave erosion, gullying and deterioration of the Novosibirsk Water Storage Basing coast lands. The work used orbital photographs taken in 1979, 1989, 1999, 2009 and 2016 as well as the field exploration materials. The work was supported by the Engineering and Technical Centre SKANEKS under the science and technology cooperation agreement (see Figure 2). [XIV, X, XV]

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For the automated vectoring of multi-temporal shapes of the basin after the space photographs, the bit-map image was broken into classes by unordered classification Iso data. This algorithm is used via Iso data classification within Image Procesion software. [XV]

The state of the coast line of the basin is monitored with unmanned aerial vehicles giving high-resolution photographs to solve the following tasks:

- current monitoring of the land
- determining the speed of the coast line wear-away
- making and updating maps and plans
- solving environmental management tasks (including recreational land use)
- inventory taking
- cadastre keeping

Digital photo cameras with full-scale or ASP-C matrices shall be to receive better prints. A geodesy class GNSS is also desirable onboard. Geoscan 101 and 201 [XIX] are used as examples of an unmanned aerial vehicle. Failing the geodesy class
equipment, it has to be replaced with geodesic methods. Aerial photographs are processed using digital photogrammetric stations PHOTOMOD or similar software such as Agisoft Photo Scan or Trimble Inpho UAS Master.

Most of the modern TNTCs change with time. The technogenic nature implies compliance with the design values of the TNTC. In some instances, such values are set by legal and other norms and rules etc. The state of the TNTC is monitored at many levels. In the modern sense, it is not limited to the definition of changes taking place. Diachronic databases are created containing heterogenous data. The ERSD and vector geoinformation is the basis for the monitoring geoinformational parameters. Figure 3 presents an algorithm of this. [XI, X, XXIV]

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**Phase 1. Analysing management**

**Phase 2. Building geoinformation basis of the territory**

**Phase 3. Building geoinformation resource**

**Phase 4. Comprehensive appraisal of territorial**

**Phase 5. Finding alternative solutions**

**Phase 6. Expertise**

**Phase 7. Taking management decision**

**Phase 8. Controlling geoinformation monitoring system**

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**Fig. 3: TNTC geoinformation monitoring process chart**

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**III. Findings**

The Novosibirsk water storage basing is the largest TNTC in the Novosibirsk Region. With its area being 1,082 square kilometres – two times as large as that of Novosibirsk - it is rightly called the Ob Sea. The water resources of the basin is supplied to Novosibirsk and Berdsk and used for power production, shipping traffic, agriculture, fish farming and recreation.

The TNTC of a basin is regarded as the aggregate of interacting natural and artificial objects resulting from construction and operation of engineering and other structures and facilities in their interaction with the environment. TNTCs are complex self-organising systems with natural components containing elements of various hierarchic levels. TNTCs typically have open and merely conventional limits because various technogenic factors influencing the environment to include its geological and physical aspects are synergetic in causing the general environmental distress not only within their limits but to the neighboring natural territorial complexes as well. Within developed industrial and agricultural areas, it is reasonable to define border areas of influence of TNTCs rather than their mere outlines.

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Many studies led from 1957 to 2002 by various groups of scientists note negative changes underwent by land resources of water basins due to an inefficient use of lands, their deterioration, and progressing marginal erosion. [IV]

As to the Novosibirsk Region, the basin has a favorable influence due to the following [III, XXXVI]:
- less flooding, water shortages and mudflows;
- artificial seasonal, annual, daily and hourly distribution of flow to the benefit of power production, irrigation, water supply to Novosibirsk and Berdsk, recreation, water transport etc.;
- better natural conditions of surrounding territories such as milder climate, water amelioration etc.
- Improved drainage network.

The most tangible negative effects of the Novosibirsk Basin existence and operation are [XXXV, VI]:
- flooding of lands;
- Marginal erosion, progressing gullying;
- Higher level of groundwater causing bogging and water logging;
- changing living conditions of water and terrestrial fauna in the river gap;
- Fundamental transformation of water flow ecosystems;
- changing quality of water due to a slower drainage; slower water exchange and concentration of polluting substances in bed deposits;
- Weaker self-purification capacity of water bodies;
- Overdevelopment of blue-green algae (green scum), malignant microbes etc. making water of the basin unsuitable for bathing;
- flooding of productive bottomland; sometimes, grass invasion on the downstream side;
- Marginal, river bed and downstream bay erosion; greater geodynamics;
- Higher groundwater level; bogging and water logging;
- changing of the soil and vegetation cover under flooding;
- changing of the microclimate: stronger winds, higher humidity, different thermal regime;
- changing of the water body fauna; changing loving and reproduction environment of water animals including, especially, fishes.

The shore susceptible to strong marginal erosion had begged for technical protective measures.
The lack of financing for more than 20 years stopped all shore protection and repair works resulting in the loss of a large volume of construction materials at non-finished sites. Presently, shore protection works are becoming “obsolete” because of the fast marginal erosion changing the coast line shape and retreat (see Figure 4).

Fig. 4: Marginal erosion at Novosibirsk Water Storage Basin.

In 2014 – 2016, shore protection works were carried out over 10 km of the shore (see Figure 5).

Fig. 5: Shore protection at Novosibirsk Water Storage Basin.
By vectoring and comparison of multi-temporal space images, the speed of marginal erosion was determined (see Figure 6). In some places the erosion was as fast as 5 metres a year.

![Image of Novosibirsk Water Storage Basing remote sensing](image)

**Fig. 6:** Novosibirsk Water Storage Basing remote sensing: a) an example of shore retreat due to a progressing marginal erosion near Zavyalovo village; b) an example of destruction of the coast line by marginal erosion.

Using the shape of the basing determined by analysis, the degree of erosion over 40 years was determined as well as the places of the most severe erosion. Also, a shore protection plan was developed using the obtained data. [IX, XXXI] The following classification by the types of marginal erosion is suggested:

- The length of the shores susceptible to moderately dangerous, dangerous and rather dangerous marginal erosion (as classified by V.T. Trofimov) is 190 kilometres or 30% of the coast line;
- The length of the shores susceptible to catastrophic retreat of the coast line at a speed of more than 5 metres a year is 120 kilometres or 19% of the coast line.

The area of land destroyed over 40 years with the shore having retreated by 70 metres makes 10.5 square kilometres, and 18.5 square kilometres – with the shore having retreated by 70 to 140 metres. Thus, 29 square kilometres of land were destroyed over the period of 40 years.

The territories most affected by the process are shown on the gradient model of marginal erosion over 1979 to 2016 (see Figure 7).
Fig. 7: Novosibirsk Water Storage Basin marginal erosion gradient model. Parts of the shore requiring protection and geodesic monitoring are marked with figures. To create a predictive model of marginal erosion of the basin, soil exploration was carried out having revealed the sections most susceptible to washout. Figure 8 shows a part of the soil map.

Fig. 8: Fragment of Novosibirsk Region soil map (edited by K.S. Baykov) with greatest Novosibirsk Basin marginal erosion sections determined by geoinformational analysis.

The analysis revealed 61% of the washed out shores composed of pine forest sands, 26% - of dark grey wood sands, 7% - of pratal earths and 6% - of pratal dark earths. The information on earth types and speeds of their washout in the past enables to...
determine the speed of marginal erosion in dependence on its constituent soils. Forecasting the marginal erosion speed depending on soil types and defining land plots to be most affected by wind and wave erosion due to their soil composition is also of some practical interest. It may be supposed, that the parts mostly composed of pine forest sands would suffer most and the washout would substantially slow down over 20 years as pine forest sands were being replaced with dark earths. It should be kept in mind, that without preventing the degradation of lands around the Novosibirsk Water Storage Basin in the places of most intensive marginal erosion, valuable recreational lands are lost not to mention possible damage to infrastructure. The loss of agricultural lands and forests, silting up of the water body and negative environmental consequences of the marginal erosion have all made the monitoring and protection of adjacent territories extremely topical. [XXVIII, XXXIV]

For ground monitoring, 10 sections of the coast line most susceptible to erosion were chosen (see Figure 7). Three steady reference points were set in each of them to measure changes of the coast line. Measurements were taken over every 10 metres (see Figure 9).

Thus, monitoring of the Novosibirsk Water Storage Basin coast line is undoubtedly topical. Especially, intensive erosion areas close to the roads, buildings and structures shall be monitored. Remote sensing along with traditional geodesic means would cut the costs and time spent on the land resources monitoring system development and maintenance.

For remote sensing, optical range high resolution orbital survey or unmanned aerial vehicles are expedient to be used. Orbital surveying may be less efficient due to the complicated and prolate form of the plot of which the image providers may
disapprove. It is most expedient to set the monitoring system using unmanned aerial vehicles. For the sections of the coast most susceptible to intensive washout, not only topographic monitoring but aerial surveying with unmanned vehicles and specific software (allowing, in particular, creating a geoportal) is suggested. [XXII, XXI, I, II, XXXIII, V]

Aerial photographing shall be made along two routes: over the shore horizon and the adjacent coast area (to ensure horizontal and vertical survey). Resolution shall be 5 – 10 centimetres to identify connection and reference points. The whole length of the basin’s coast line is 600 kilometres making the survey lines 1,200 kilometres long. In this connection, airplane-like unmanned vehicles are best used due to their high productivity of up to 500 kilometres a day. To monitor the plots with catastrophic marginal erosion additionally (totaling 120 kilometres of the shore) and local object, quadcopters are more convenient. Aerial surveying is planned with the help of unmanned aerial vehicles control stations such as, for example, Mission Planner.

Fig. 9: Planning aerial photographing using Mission Planner: a) general routes outline, b) surveying parameters calculation.

The surveying gives an orthophotomap of the coastal area of the basin to determine the current water horizon with a precision up to 10 centimetres. [XXIV]

IV. Discussion

Water reservoir coastline monitoring is required, first of all, to prove a wind and water erosion predictive model. The study showed compliance of the marginal erosion forecast values with actual ones at the level of 87%. First of all, the difference was due to the incorrect definition of soil types and the speed of their destruction. Also, the model has to be specified considering water levels during the time period in question. In low water years, marginal erosion slows down by 25-40% at different sections of the coast line depending on the amount of snow, first of all, in Altay. Also, the speed of erosion changes seasonally with maximal damage caused in spring when water is at its highest marks decreasing then gradually to stop completely in winter when ice sets in.

To solve the task of efficient land use at the coast of the water storage basin, it is most expedient to develop recreational zones. For the territory under study, the
Government of the Novosibirsk Region used services of many territorial planning, cadaster, land use and healthcare professionals to plan the development of this line of natural resources management. In particular, along with the existing recreational infrastructure, two large recreational zones are planned for the inhabitants of Novosibirsk and nearby localities. The projects are expected to be completed in 2018-2025. A substantial commercial effect is also forecasted to increase the income from the coastal zone by 40%. Transition to the digital economy using geotechnologies is the main element of the new economically efficient land use. 

Construction or the touristic and recreation infrastructure includes shore protection works over more than 20 kilometres of the shore. That would substantially improve the quality of water and increase the water basin’s useful life.

V. Conclusion

Thus, the suggested geoinformation technology is time- and cost-effective providing for a permanent and immediate control of the state of the coast line and assessment of shore protection works.

The most critical marginal erosion sections of the shore are identified with monitoring technologies and surveying periodicity set for them. The programme of comprehensive environmentally friendly and sustainable use of water storages would solve the problem of fresh water supply to the population and enable the use of the coastal territories for recreational needs in most commercially effective ways.

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