Application of GIS technologies to monitor secondary radioactive contamination in the Delegen mountain massif

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Abstract. The territory of the Degelen mountain massif is located within territory of the former Semipalatinsk nuclear test site and it is an area of ecological disaster. Currently there is a process of secondary radioactive contamination that is caused by geodynamic processes activated at the Degelen array, violation of underground hydrological cycles and as a consequence, water seepage into the tunnels. One of the methods of monitoring of geodynamic processes is the modern technology of geographic information systems (GIS), methods of satellite radar interferometry and high accuracy satellite navigation system in conjunction with radioecological methods. This paper discusses on the creation of a GIS-project for the Degelen array, facilitated by quality geospatial analysis of the situation and simulation of the phenomena, in order to maximize an objective assessment of the radiation situation in this protected area.

1. Introduction

During over 40 years of confrontation of nuclear powers, 456 nuclear tests were conducted in the territory of the former Semipalatinsk nuclear test site (SNTS). In these tests, 616 nuclear and thermonuclear devices were detonated, including underground (131 in the wells and 209 in the tunnels). Although the tunnels were created with a stemming complex with hermetically sealed elements of high strength with damping devices and gas blocking, explosions of high enough power (up to 150 kilotons of TNT equivalent (TE) contributed to rock strata deformation, cracks, activation of geodynamic changes [1]. These processes are typical for the Degelen mountain massif (DMM). Given that the main aquifer located at a depth of 10 to 30 m from the surface, geodynamic changes as a result of explosions contributed to underground hydrological cycles disturbance.

According to the literature data [2, 3], there are about two dozen tunnels with the manifestation of radioactive water in the DMM SNTS. Water from some tunnels flow into local rivers, which in turn are in the basin collecting waters of Shagan river, falling into the Irtysh river. Water manifesting tunnels of SNTS are sources of the secondary pollution by long-lived radioactive isotopes, which is extremely dangerous for human and animal health. According to Polyakov et al. [4], the underground water of DMM is located in an open fracture (intensive weathering) of rocks and partly in unconsolidated sediments of the Quaternary age. This increased radioactivity is identified in the south, east, north and northwest massif underground water. In general, the condition of water resources of the Degelen massif appears unsatisfactory.
The effectiveness of monitoring the secondary pollution of the DMM due to modern geodynamic processes depends on the methods of control. Using modern technology of geographic information systems (GIS), satellite radar interferometry and high accuracy satellite navigation systems contribute to the overall analysis of the current situation and elaborate recommendations to overcome the effects of pollution of the environment. Integration of GIS, remote sensing and modeling of processes applied for the environmental protection fields is an important tool to the management and decision-making [5]. One of the research goals in SNTS is a creation of expanded geographic information platform of the DMM for environmental monitoring and control the secondary pollution of the environment based on GIS technologies and ERS data.

2. Methodology
For development of a geoinformation system of the DMM and the surrounding regions, digitization of individual thematic layers of the DMM SNTS was conducted using ArcGIS. The development of a geodatabase and spatial models were done using the ArcGIS' 3D Analyst and Spatial Analyst applications. In order to create a DMM spatial model, electro-optical space images from ALOS and Spot-5, as well as radar images from COSMOSkyMed were used.

Elaboration of a geoinformation system of any object requires inter-summand and mutual complements of each component. The structure of the geoinformation system for the DMM contains the following interrelated components: attribute database, which contains the narrative components and information about the DMM; mapping information database, which is a complex of electronic thematic maps for the study area; block data analysis and processing, which are formed by means of problem solving, statistical data processing, mathematical modeling tools.

The DMM is located in the south-western part of SNTS with lowlands of mountains, dissected by valleys and decays. The DMM represents spatial object with a complex structure, which is the basis of the developed system of low mountains. Therefore, the using of such a powerful and convenient means of integrating spatially-distributed data as GIS is justified and promising.

3. Results & discussion
Direct use of DMM geoinformation system provides information support for monitoring the effects of nuclear explosions on the mountain massif territory. To fulfill the main task of developing a geographic information system - monitoring of the ecological balance of the DMM territory - a graphical representation of information form of plans and schemes applied to data on topography, elevation, geology, human-induced changes, etc. The creation of digital maps on the basis of GIS technologies according to actual data of remote sensing reduces the complexity of creation of informative materials, and increases efficiency and effectiveness of measures for management of
ecological safety area. The GIS structure of the DMM and its subsystems, core modules and data relationships are shown in Figure 2.

Figure 2. Structure of GIS monitoring of the DMM.

As a rule, at the initial stage of creation of the GIS, the inventory of the district topographical data is produced through the creation of different classes of geodatabase or sets of classes. The geodatabase of the DMM as vector model of the district consists of six directories and 18 thematic layers with attributive information. Figure 3 presents all the thematic layers and directories of the DMM GIS.

In order to identify environmental trends in the DMM, we need to know about the relationship of drainage tunnels and hydrological features of the study area. The directory has been created as "Hydrology", which contains thematic layers of "rivers_full", "river_dry", "dumb" and "spring". The mask "rivers_full" can be traced to some rivers, such as Karabulak, Uzynbulak, Baitlesov and Toktakushik waters fall from the radioactive tunnels. Visual representation of hydrological posts in the form of thematic layers contributes analysis of possible radioactive contamination areas. The formation of a vector layer "shtolny_water" in the directory "Shtolny" displays of all water-manifested tunnels of the Degelen massif. The attribute information shows the exposure dose of radiation, reflected by the intensity of the manifestations of water (Figure 4).
This vector layer represents only 12 tunnels with signs of water seepage. Attribute sampling was formed from the layer "schtolny", which indicates the location of the 180 tunnels. For a comprehensive assessment of the environmental situation in the DMM for the emergence of secondary contamination risk by radioactive substances, as well as to improve the accuracy of solving problems of long-term forecasting of multivariate object situations, this requires clustering of data in the DMM GIS. The main blocks of the DMM GIS (block of hydrometeorological data, geological unit performance, block of physical and geographical factors, block of the socio-economic indicators, and unit of the environmental performance) are composed a number of constituent components. Moreover, the indicators of each block (cluster) must be ranked by character and optional historical aspect.
Hence, the block of environmental performances is considered background contamination, maximum permissible concentrations of harmful substances, the potential contamination and others. The meteorological data block is formed by data-term and annual rainfall averages, temperature and wind data, which have an indirect impact on the ecosystem of the DMM. The hydrological data area of the DMM includes the length and mesh of the river system, presence and depth of groundwater, as well as indicators of pollution.

The geological data includes exogenously and endogenously-geological and geological changes, and also indicators of modern geodynamic changes of the DMM defined on the basis of radar pictures. The physiographic aspect is very important in the creation of the GIS for the mountain territory as the key characteristic of intensity of processes. The relief defines zones of accumulation and redistribution of polluting substances and soil characteristics causing buffer action and resistance of the territory pollution. The landscape characteristic is given on the basis of genetic types of landscapes and possible scenarios of development the denudation processes.

The socio-economic infrastructure block includes infrastructures of nearby settlements, population, transportation routes, the results of recent medical inspections, etc. The design of the DMM GIS does not apply for completeness of the accounting factors and communications. Nevertheless, it gives a reasonable picture of the ecological situation in DMM. In connection with specifics of the studied area, conditions of environment, and also degree of technogenic loading, the GIS can be supplemented also with other clusters.

The creation of the DMM GIS uses the most common software and hardware implementation for realization and establishing standard structure of the mountain areas GIS database, which ensures optimum control of the manifestations of radioactive contamination that includes sequences and content thematic layers, structure of thematic clusters. The results of the geospatial analysis of the situation of the DMM generates three-dimensional model of the DMM in order to maximize the objective assessment of the radiation situation in this protected area. On the basis of archival optical-electronic space images (stereo pair), a digital three-dimensional model of the DMM was created in different scale. The GIS system is necessary, especially for high-precision of forecasting development processes proceeding in the highlands (the analysis of geomechanical changes – subsidence of the soil, shift of rocks; the analysis of a geodynamic situation – change of crust, a motion, etc.), which gives the advance to prevent the occurrence of environmental problems. The integrated three-dimensional digital model of the investigated mountain massif at 1:50,000 scale is shown in Figure 5. Lighter areas is subjected to the destruction of rocks, where intensive geodynamic processes are possible.

![Figure 5. Three-dimensional digital model of the DMM at scale of 1:50,000.](image-url)
The developed GIS was used to study modern activity geodynamic processes of the DMM using radar interferometry methods and high-accuracy satellite navigation systems. In the north-eastern part of the DMM, during the observation period, displacement (shifts) of the earth's surface, size of 3.1 cm was detected, which indicates a relatively high activity of geodynamic processes in this area [6].

Based on GIS modeling and forecasting, the situations that led to increased environmental hazards in the DMM include increase of groundwater levels, violation of radioactivity balance, secondary pollution processes of the territory and changes in the nature of the biosphere.

4. Conclusion

The DMM GIS allows us to give environmental assessment of the territory. The spatial geodatabase actualized by the DMM GIS provides a more detailed spatial analysis of the migration and transformation of artificial radionuclides in the DMM. The prepared vector and attribute basis of the DMM GIS allows for subsequent creation of geoproducts with high added value as a set of indicators can reflect more realistically the anthropogenic influence, in order to develop recommendations for the reduction of social and ecological intensity of the territory.

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