Environmental assessment of closeded coal mine territory using GIS analysis

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Abstract Coal mining usually causes complex environmental problems. Reclamation projects for mined land require deep analysis of the spatial distribution of environmental risks. GIS-based assessment was performed to create effective reclamation plans for the area of the abandoned Kizel coal basin (Russia). The GIS-based environmental assessment utilizes a catchment-based approach and methods of mathematical and cartographic modeling using remote sensing data. GIS analysis was used to detect all possible sources of acid waters, visualize the spatial and temporal distribution of pollutants, the areas most threatened by soil degradation, and map the analytical and synthetic criteria characterizing the environmental situation.

Key words abandoned coal mine, GIS analysis, acid mine water, deforestation, flooding

Introduction

GIS technology is viewed as a powerful tool that supports environmental impact assessment and environmental management decision-making in coal mining areas with high anthropogenic pressure in China, USA, and Central Europe (Bian, Lu 2013, Gorokhovich et al. 2003, Naydenova, Roumenina 2009, Yu et al. 2014). GIS technology offers many tools for manipulating spatial data, including environmental monitoring, evaluation and prediction of negative technological environmental impacts, and provides an opportunity for shaping new approaches to the objective analysis of environmental damage, spatial analysis and assessment of environmental pollution, decisions for science-based planning and quantifying efficiency of reclamation activities, etc.

One of the most effective tools for the integrated environment assessment is the development of problem-oriented catchment-scale GIS applications and methods for handling a large amount of heterogeneous spatial data using a mathematical simulation and map-based modeling approach (Pyankov, Kalinin 2013). One of the major advantages of a comprehensive catchment-scale GIS modeling system is the possibility of combining multi-source heterogeneous spatial data for the implementation of the integrated geo-environmental assessment and improvement of environmental monitoring and planning.

The experience of development and implementation of such catchment-scale GIS technologies for environmental assessment and monitoring in areas with high anthropogenic risks is still virtually lacking in Russia. This causes the need for the development of new methods of integrated environmental assessment using a mathematical simulation and map-based modeling approach. The synthetic geo-images produced by modeling can be used to detect zones threatened by environmental crisis and disaster at regional and local scales (Pyankov, Kalinin 2009). Using such an approach allows us to analyze the wide variety of phenomena and relationships within the geosystem as a whole.

The Kizel coal basin (the Western Urals, Russia) was used as an example to tackle the issues related to the integrated assessment of environmental conditions in areas with high anthropogenic loads (fig. 1).

Mining in the Kizel coal basin had been carried out for more than 200 years. Over 35 million m^3 of waste rocks had been accumulated in more than 70 tailingspiles. Mines were closed down in the 1990s, but their closure did not resolve the environmental problems. The cessation of mining led to a gradual restoration of the water table, which in turn posed a serious environmental issue. Twelve disused mine adits started to discharge water to the surface as the water was allowed to rise to its natural position. As a result of discharge, the hydrochemical facies of river water are characterized to be SO_4–Fe–Al, with TDS between 640 and 6,000 mg/L, sulfate concentration between 1,000 and 3,700, iron between 70 and 900, aluminum between 11 and 160 mg/L, and pH of 2.5–2.9 (Maksimovich, Khayulina 2014). Now, the zone of environmental impact exceeds 10 000 km^2. Rivers play an important role in the long-range transport of pollutants from different sources of surface water pollution.

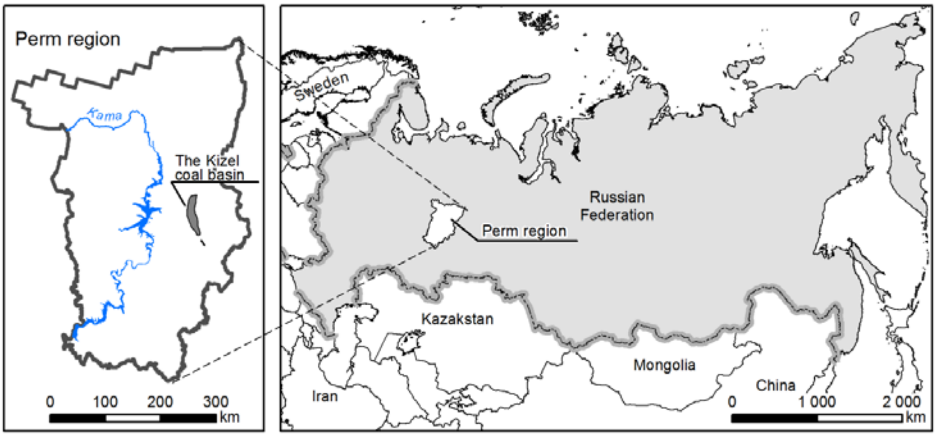

Figure 1 *Location of the Kizel coal basin (a, Russian Federation, b, Perm region)*

The national environmental monitoring program adopted for the area of the Kizel coal basin includes collection of water samples from acid mine drainage zones and polluted rivers. Data on land degradation and variations in pollution levels are not available. The results of the national monitoring program did not allow reliable determination of the extent of pollution and identification of secondary pollution sources in order to locate potential areas for land reclamation. The developed GIS is designed to solve the following tasks.

Methods

An integrated environmental assessment of each particular site is carried out using a set of spatial criteria, which can be used to monitor environmental changes and identify areas of environmental concern. These criteria may include pH, sulfate content, heavy metal content, species composition of the surface-water bacterial community, and the area of degraded land. The area of intensive soil pollution with degraded forest was detected from SPOT-6 satellite images in the visible spectrum bands, as well as from high resolution satellite images obtained from open source mapping services.

The visible part of the spectrum are also used to assess the degree of acidic mine water pollution. LANDSAT-8 satellite images are obtained during the summer low water level period, the polluted water is distinguished by brown or orange colours. The ratio of green and red could be used for the identification of contaminated sites of water bodies.

Integrating land survey and remote sensing data allows one to produce synthetic geo-images, which provide objective representation of the environmental conditions and can be used to evaluate the effectiveness of reclamation strategies.

A cartographic and attribute GIS database of the Kizel coal basin consists of the digital elevation models (DEMs) and catchment boundaries delineated from SRTM-90, SRTM-Xband's DEMs. Detailed DEMs were generated for waste rock piles and adjacent areas which will be used for the identification of the direction of drainage from piles and delineation of polluted areas (scale 1:10 000).

The documentation and mapping of data on potential sources of surface water and groundwater contamination (mine drainage, waste rock piles, polluted springs) will help identify variations in the pollutant levels at watersheds.

Results

Both historical data and satellite images are used to compile the inventory of flows and mine drainage from waste rock piles over the entire coal basin area. The determination of hydrographic characteristics on 1:100,000-scale digital topographic maps revealed the exceedance of the maximum contaminant levels streams (tab. 1).

River bottom sediments the chemical composition of which is impacted by the discharge of acid mine water and drainage water is recognized as a permanent secondary source of contamination to river systems. Field studies showed that mining-impacted bottom sediments of rivers contain large amounts of amorphous Fe and Al hydroxides (up to 77 %) and are bright orange in color. They accumulate in stream reaches and are present as rusty coatings on coarse-grained sediments on channel bars. Aqueous extracts have high contents of sulfates and iron oxides and pH of 2.5-4. Common accessory minerals are goethite (до 2 %), lepidocrocite (up to 3 %). Annual variations in river water level lead to the increase in the areal extent of contaminated bottom sediments and also cause harmful effects on coastal ecosystems.

Table 1 *Proportion of polluted rivers in the Kizel coal basin*

Basin	Length, km		Proportion, %	Total length of rivers in the basin, km		
	Main stream	Polluted portion		Total	Polluted	Polluted by mine drainage waters
Yaiva	303	138	45	4864	417	178
Kos'va	307	103	33	4404	170	40
Us'va (without Yuzh. Vil'va River)	272	93	34	2237	94	-
Yuzhnaya Vil'va	173	35	20	1851	48	10
Chusovaya (without Us'va River)	307	74	13	7823	88	28

LANDSAT images of rare flood events were used to detect and map areas of potential contamination in river floodplains during flooding (fig. 2).

Mathematical and map-based modeling of the river floodplains impacted by mine drainage from the Kizel coal basin combined with the results of field studies was used for the interpretation of remote sensing images and modeling of flood prone areas. The results of interpretation showed that the polluted area is much larger than previously reported.

The total area of the river floodplains where near-stream vegetation could be affected by abandoned mine drainage during a peak flood event was estimated (from a LANDSAT image of 23.05.1998) to be 9642 ha.

The evaluation of environmental damage and development of mitigation measures should be done on the basis of estimating the area of degraded land and forest as a result of soil acidification or increased trace element concentrations. High-resolution satellite imagery and field data are used to detect and map degradation in land areas (fig. 3).
These data will be used to control the progression of changes in environmental conditions as a result of acid mine drainage from waste rock piles, mine waters and contamination caused by polluted flood water.

Conclusions

The proposed method of GIS-based environmental assessment uses mathematical simulation, map-based modeling, and remote sensing data. GIS analysis was used to identify all sources of acid mine drainage, map spatial and temporal distribution of pollutants, analytical and synthetic criteria characteristic of the environmental situation, e.g., soil degradation and deforestation. The results of this project were used to update historical data from the national environmental monitoring program, and delineate areas of bottom sediment contamination which are considered as a secondary source of environmental contamination.

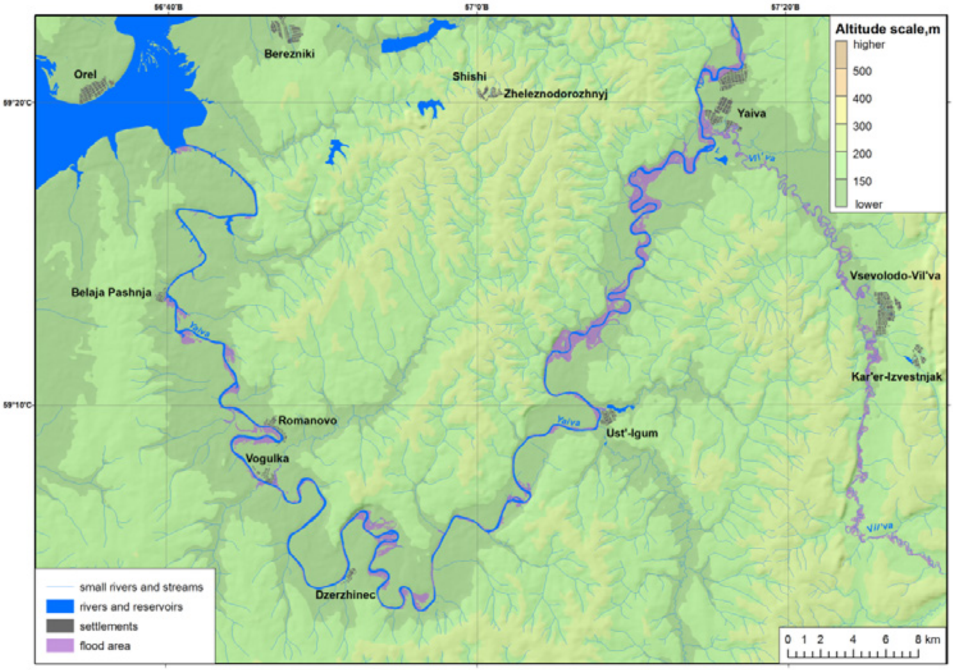

Figure 2 *Flood prone areas along the Yaiva and Severnaya Vil'va Rivers*

Figure 3 *Areas of forest degradation as a result of acid drainage seeping from mine shafts in the Sev. Vil'va River valley*

GIS analysis was used to map areas with the highest environmental risks and prioritize reclamation activity. The government can use these results for the implementation of a complex reclamation project within the Kizel coal basin.

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