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Coal Basins and the Environment

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Abstract

One of the most serious ecological problems caused by coal mining is acidic mine water (AMW). Authors studied environmental condition on the territory of the Kizel coal basin (the Western Urals, Russia) using GIS-based environmental assessment, including catchment-based approach and methods of mathematical and cartographic modeling. Investigation revealed that the polluted territory in the basin was more large than previously reported. Applied GIS technologies will be used at engineering of remediation measures to determine optimal dimensions and location in situ of artificial geochemical barriers and develop environment monitoring system based on both remote sensing images and field observations.

Keywords: acid mine water, GIS-based technologies, land deforestation, river pollution, remediation strategy

Introduction

Mining is one of the most important sectors of the world economy. Coal-bearing formations occupy 15% in the earth's crust over all the continents. Total coal resources are estimated as 16–20 trln. tons, prospecting resources — 3,366 bln. tons; coal mining reaches 2,025 mln. tons annually. Coal industry has a significant and regionally negative impact on the environment. One of the most serious ecological problems caused by mining industry is the occurrence of acidic metal laden (e.g. Fe, Al, Mn, As, Cd, Zn, Cu, and Pb) mine water (AMW) from metal or coal mines. Coal mining also generate large amounts of wastes, which are deposited as waste piles or tailings. Conventional disposal methods that expose sulfidic mine wastes to atmosphere promote sulfide oxidation and the release of acidity, sulfate, and metals. Acidic effluents can migrate from storage areas to adjacent aquifers, surface water, and surrounding land, affecting the quality of water resources and soil and can inhibiting the growth of living organisms (Alekseenko et al. 2017; Blowes et al. 2014).

Abandoned, closed, or orphaned mine sites cover approximately 240,000 km^2 of the Earth's surface (Wolkersdorfer 2008). Closure and abandonment of mine sites usually results in a legacy of pollution of local environments that may persist for decades and even centuries after mining activity ceased (Younger 1997). Environmental pollution is a result of various sources and the costs for remediation, including environmental monitoring, can be substantial (Soni, Wolkersdorfer 2016). Over the past several decades, a number of researchers and reclamation practitioners have contributed to the development of AMW passive treatment designs and science. Robust, reliable and economically feasible technological solutions for treatment of AMW are available (Khayrulina et al. 2016; Skousen et al. 2017; Soni, Wolkersdorfer 2016; Tyulenev et al. 2015). Effective remediation of polluted sites requires extensive site characterization, including detailed spatial information about AMW sources, because AMW characteristics are site-specific and no single treatment would be effective and financially feasible for all AMW discharges (Pinto et al. 2016). It was found that the spatial distribution of the point and diffuse AMW sources was critical for spatially targeted, cost-effective remediation measures (Baresel et al. 2006). A critical activity in passive treatment is the selection of the proper system type for a given situation. Factors to be considered in selection include the quality and quantity of waters to be treated, water treatment goals, access, and the land resources available for use in system construction. Generally, larger land areas (relative to anticipated acid loads) enable more effective treatment, and essential design features for all systems include surface area and/or volume (Skousen et al. 2017).

GIS technology is considered as a powerful tool that supports environmental impact assessment and environmental management decision-making in coal mining districts as it allows to manipulate heterogeneous spatial data using a mathematical simulation and map-based modeling approach (Pyankov, Kalinin 2009). Synthetic geo-images integrating land survey and remote sensing data can be used to detect zones threatened by environmental crisis and disaster at regional and local scales, evaluate the result of reclamation strategies, and plan new in-situ and on-site treatment options in future.

The main objective of this study was to characterize AMW-impacted territory of The Kizel coal basin with GIS technology to better understand the current extent of the problem and develop remediation strategy.

Geological and Environmental Settings

The Kizel coal basin (the Western Urals, Russia) occupies area of 200 km^2 and is located within West Urals folding zone adjacent to the pre-Ural boundary deflection. Rocks of the basin are represented by sandstones, mudstones, siltstones, shales, limestones, dolomites, marls, coals, and others. Carbonate rocks are intensely karsted, especially in the upper part of geologic cross-section. Coal of the basin exhibits elevated content of sulfur (mainly as a pyrite) – 5.8%. Mines were closured in the 1990s, and 12 adits of abandoned mines have started to discharge acid mine water into 19 rivers. Several tones of sediments which consisted of amorphous iron and aluminum hydroxides and have a high content of Mn, Cu, Ni, Zn, Pb, and other metals have been accumulated in rivers' bottom. These sediments were washed downstream to the Kama river, where they become a secondary source of water pollution. Over 35 million cubic meters of waste rocks had been accumulated in more than 100 waste piles. Spontaneous combustion of waste piles, roasting and melting of their rocks, and fumarole processes within piles were detected. Rainfalls drained waste piles are enriched in soluble compounds and have a high salinity (up to 50 g L^{-1}). Infiltration of these waters into underlying grounds changes their physical-mechanical and filtration properties and pollutes groundwater (Khayrulina et al. 2016).

Methods

An integrated environmental assessment of each particular site in the Kizel coal basin was carried out using a set of spatial criteria, which include pH, total salinity of water or water extract, sulfate content, metal content, species composition of the surface-water bacterial community, and the area of degraded land. Seasonal sampling of AMW at about 200 sampling sites during more than 35 years of survey permitted collection of a large, multi-seasomal database of geochemical and hydrological values. SPOT-6 satellite images in the visible spectrum bands, as well as high resolution satellite images obtained from open source mapping services were used to determine the area of intensive soil pollution and land deforestation. LANDSAT-8 satellite images obtained during the summer low water level period were used to detect polluted and unpolluted river waters as they were differed in color — yellowboy coated plants and sediments in the polluted stream beds, so long stretches of 'dead' streams were easily visualized in images.

Results and Discussion

Integrating land survey database and remote sensing data allows to develope a cartographic and attribute GIS database of the Kizel coal basin consisted of the digital elevation models (DEMs) and catchment boundaries delineated from SRTM-90, and SRTM-X band's DEMs. Detailed DEMs were generated for waste rock piles and adjacent areas and used to determine waste piles' drainage water flow direction and delineate polluted land areas in the scale of 1:10,000. To compile the inventory of acid mine and drainage water flows over the entire coal basin area both the land survey database and satellite images were used. As a result, the determination of hydrographic characteristics on 1:100,000-scale digital topographic maps revealed more substantial rivers contamination with AMW than it was established earlier. One of the most polluted was the Poludennyi Kizel river, the tributary of the Yaiva river: the excess in metal Maximum Permissible Content (MPC) was 9,450 times for Fe, 1,188 times for Mn, 639 times for Al, and 56 times for Be (Fig. 1, sampling site no. 6).

As seen, surface water is contaminated along the rivers pathway: the Poludennyi Kizel, the Bol'shoi Kizel, the Severnaya Vil'va, the Yaiva rivers right up to the Kama reservoir. Investigation revealed that special attention should be paid to the Bol'shoi Kizel river basin as most polluters were located there. This river starts from the confluence of two rivers: the Poludennyi Kizel and Vostochnyi Kizel. Seven small rivers flow into the Bol'shoi Kizel and only one of them (the Severnyi Kizel) is not polluted by coal mining. This tributaries bring a lot of pollutants into the Bol'shoi Kizel: about 15,300 tons of sulfates, 6,000 tons of iron, 400 tons of aluminium and 57 tons of manganese come into the Bol'shoi Kizel annually. Moreover, the Bol'shoi Kizel is impacted by acid piles' drainage water and mine water discharge. Piles' drainage water has a high concentration of pollutants and is acid (pH<3). High concentration of iron, aluminium, beryllium and manganese comes into water as a result of rain water infiltration and leaching of pile's rocks — the concentration of these elements 100-1,000 times exceeds MPC. Such metals as cadmium, cobalt, nickel were detected everywhere but in low quantity, lead and zinc were detected periodically and their quantity 2-70 times exceeds MPC. When the Bol'shoi Kizel flows into the Severnaya Vil'va river, the water of the latter changes the colour that is observed at the satellite image. Thus, the Yaiva river is greatly polluted by the sources located on its catchment area although they are tens of kilometers away from the river body and are restricted with watersheds.

LANDSAT images of rare flood events were used to detect and map potentially contaminated areas in river floodplains during flooding. Mathematical and map-based modeling of the river floodplains combined with the database on field survey was used to interpret remote sensing images. The results

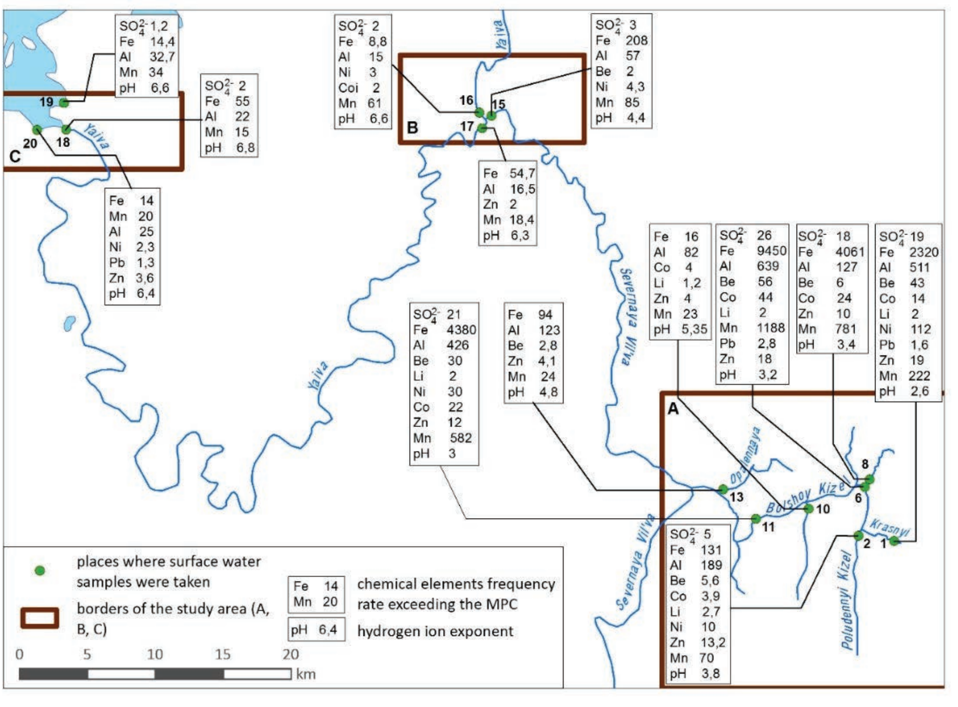

Figure 1 *Pollution of the Yaiva river basin with acid mine water.*

Figure 2 *Deforestation of the Poludennyi Kizel river floodplain (left) and land area near the Kospashskaya shaft waste piles (right) as the result of acid water influence.*

Figure 3 *Satellite images of the Poludennyi Kizel river floodplain (left) and land area near the Kospashskaya shaft waste piles (right).*

of the interpretation revealed that the polluted area in river floodplains was more large than previously reported. The total area of the river floodplains where near-stream vegetation could be affected by AMW during a peak flood event was estimated to be 9,642 ha.

High-resolution satellite images and field data were used to detect and map degradation in land areas affected AMW. Polluted land areas and river floodplains exhibited deforestation property (Fig. 2) and were easily observed in satellite images (Fig. 3).

Conclusions

GIS technologies applying to analyse environmental pollution at the territory of the Kizel coal basin had given more extensive its characterisation — more substantial pollution of lands and rivers with AMW than it was established earlier were revealed. Combination of field survey data and satellite images allowed to localize spotted sources of AMW, and delineate pollution boundaries and spatial distribution precisely.

AMW-impacted site remediation could be achieved either at the source of AMW or along the subsequent AMW pathway. Applied GIS technologies, combining data on the quality and quantity of waters to be treated, water treatment access, and the land resources available for use in passive treatment system construction, will be used at engineering of remediation measures in future.

The results of this investigation could be used to implement a complex remediation strategy in the Kizel coal basin, which will include both active and passive systems for AMW treatment. The construction of artificial geochemical barriers implies determination of their optimal dimensions and location in situ using GIS technologies. The development of an environment monitoring system based on both remote sensing images and field observations will be a constituent part of the strategy also.

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