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REMOTE SENSING OF CHEMICAL ANOMALIES IN THE ATMOSPHERE IN INFLUENCE ZONE OF KORKINO OPEN PIT COAL MINE

Mining practices feature the most significant environmental impact. The impact of mining activities on the air quality is among the highest in the industry. In terms of pollutant emissions, the mining industry is second only to heat power facilities. In this respect, this work estimates the emissions of pollutants from Korkino lignite mine in the Southern Urals. The mine is distinguished for its gigantic dimensions and is called "the deepest man-made hole in Eurasia" therefore.

The fundamental factor of the economic and environmental imbalance in the regions of coal mining hazardous to life and health of the local population is burning of carbonaceous rocks under endogenous and exogenous effects.

Ill-timed detection of fires leads to uncontrolled burning of renewable energy resources, which hinders extraction of minerals and causes serious pollution due to huge emissions of toxic oxidation and combustion products into the atmosphere. In mined-out coal fields, coal residues can burn for years, which may lead to emergency evacuation of residents of adjacent settlements.

The chemical anomalies induced in the atmosphere by coal fires is a serious problem worldwide. Considering high level of anthropogenic disturbance in the territory of the test open pit mine operated for more than 80 years, as well as the complex geomorphology of the area, this study proposes a new approach to the atmochemical research and analysis using a modern unmanned aircraft system of environmental monitoring.

Keywords: *remote chemical monitoring of the atmosphere, unmanned aircrafts, open pit lignite mine, air pollution, endogenous fires, accumulated environmental damage.*
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Introduction

The coal industry's environmental problems feature full-scale attack on all components of the environment, especially in extraction of coal using the open pit method.

Open pit mining operations result in the geomechanical damage of vast surface and underground areas, which largely worsens anthropogenic load and, as a consequence, induces erosion of soil, dusting, noise, ground and underground water contamination, and also affects bio-diversity in local ecosystems [1].

The coal industry, as the other branches of mineral mining, has a singularity which directly influences ecological security. Particularly, fire development potential both in operating and closed mines. The scale of impact of exogenous and endogenous fires in open pit coal mines is governed by the mine capacity, equipment condition, technological advance and process discipline, by the size of the coal lease and land allotment, geography, climate and by many other factors. All these end in financial expenses, deterioration of health conditions of miners and in huge emissions of toxic pollutants. Each coal mine must design and introduce an ecological monitoring system meant to evaluate air pollution level in the influence zone of open pit mining, including fire-induced contamination.

As of today, chemical monitoring of the atmosphere is drastically needed at hazardous and highly technical objects within the mineral sector, including the coal industry.

Theory

The location features of Korkino Open Pit Coal Mine (OPCM) are typical of the majority of lignite deposits in Russia. The mine is situated inside the Korkino district 30 km southward of the city of Chelyabinsk in the Chelyabinsk Region. The coal mining infrastructure is arranged along the northern skirts of Korkino town (**Fig. 1**).

The nearby residential areas, aside from Korkino town, are Roza urban-type community in the east, Timofeevka rural settlement 3 km westward, Bektysh community 5 km southeastward and Kalachevo community 7 km northeastward of Korkino mine.

Korkino OPCM had been operating from 1932 to 2018.

By 2017 Korkino OPCM was the largest mining project in the Chelyabinsk Region. The area of the pit was 700 hectares (3000 km wide and 2500 m long on ground surface). The pit depth was 493 m [2].

Korkino OPCM is considered an object of hazard category I, which means the potential cause of the nation-wide emergency.

The major ecologically inherited issue of this open pit is endogenous firing which induces pollution of the atmosphere in Korkino town and in the nearby residential communities [3].

The sources of endogenous fires seat mostly on the spoil banks of the open coal pit and at points of outlets of underground excavation in the mined-out void of the pit. By 2019 in Korkino OPCM 3 sources of endogenous fires were identified with the overall area of 410 m^2.

Burning of coal is accompanied by emission of widely ranged pollutants in the atmosphere, including the most hazardous nitrogen oxide, sulfur dioxide, hydrogen sulphide and carbon monoxide (hazard categories 3–4). By early estimates, given endogenous fires are unsuppressed in Korkino pit, the annual emissions of toxic agents in the atmosphere will total 950.7 t.

Such areas feature extremely high level of anthropogenic damage, and, in view of the difficult natural geomorphology, the conventional contact methods of ecological monitoring are inapplicable in this event.

The review of literatures sources in open access exhibits the basic framework and procedures for evaluating the environmental components during remote sensing-based ecological monitoring [4–6].

The remote sensing techniques reduce by several times the amount of ground surveys [7]. On the other hand, the ground surveys are equipped with an exhaustive regulatory framework to ensure a unified approach to studying the quality of the environment components irrespective of the territory size under analysis. Thus, the current interest is mostly drawn to the technologies which couple the two methods towards complete and real-time information on the quality factors of the environment, including the atmospheric air.

The choice of the remote sensing methods is governed by the size of the test areas and by the scale of the problems to be solved. In this regard, the unmanned aircraft systems are the most effective facilities to be used in the environment quality evaluation in the areas of mining agglomerations as compared with the aerial and space surveys.

From the ranking data, the best carriers for metering devices of air quality evaluations in mining areas are the unmanned aircraft systems represented by helicopter-type drones.

The remote sensing-based ecological monitoring procedure for the atmospheric air quality was developed using an unmanned helicopter-type aircraft from the Ecological Situation Modeling Laboratory of the Saint-Petersburg Mining University; the unmanned aircraft was pre-programmed and navigator-controlled.

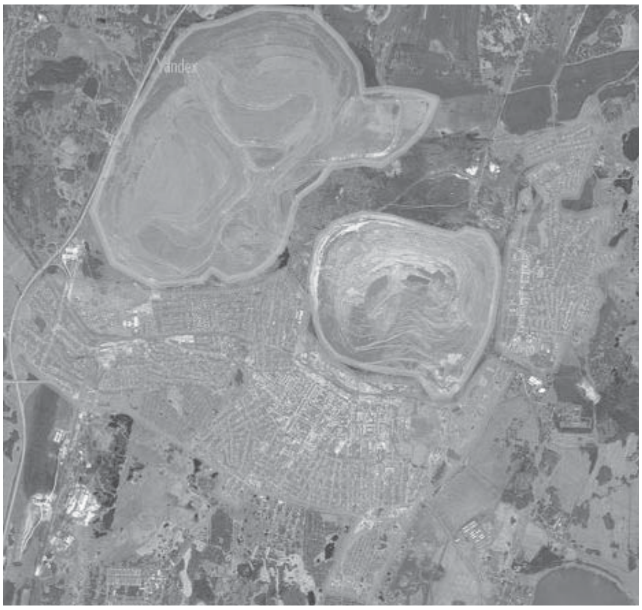

Fig. 1. Korkino OPCM area map

Procedure

Ecological monitoring of air quality in the area of mining agglomerations using unmanned aircrafts can improve accuracy of the results, enhance efficiency of determining dominant pollution bubbles at different elevations above a pollution source, and refine finding of real distances of transport of pollutants [8–11].

In the course of the monitoring procedure development, aiming to set universal flight tasks in air quality evaluation in coal mining areas, we undertook preliminary modeling of pollutant agent migration in the lowest atmospheric layer from some standard emission sources of pollutants.

The modeling used unified air pollutant emission program UPRZA Ekolog 4.6. The calculation algorithm implemented in this program complies with the standards of computation of toxic (hazardous) emission dispersion in atmospheric air [12].

The lowest atmospheric layer contamination modeling assumed some typical emission sources, namely: a point source (major characteristic is elevation of 50 m); a linear source (major characteristics are extension to 1000 m and elevation of 2 m) and an areal source (major characteristics are linear sizes of 200/2000 m and elevation of 2 m).

The modeling results also allowed evaluation of joint influence produced by various combinations of the standard emission sources.

Considering nearly uniform propagation of air pollutants from the point sources, as well as the localization of the atmospheric plume and the coal-and-dust cloud transport distance, it is proposed to set a flight task for the unmanned aircraft monitoring route along the Archimedean spiral such that the spiral axis is co-directional with the priority direction of the pollutant transport.

The main variable parameter in the flight task implementation is a helix pitch distance in a range from 200 to 500 m. This characteristic is gradually increased as the unmanned aircraft goes farther from the source, and the maximum radius of the spiral is found from the criterion of determinability of the pollutant concentrations in the whole atmospheric plume at a distance.

The step of climbing in the proposed flight task can be varied from 25 to 100 m subject to the monitoring research scale and required accuracy. The minimal flight height is determined as per the standard technical documentation in the area of safe operation of unmanned commercial aircrafts and makes 25 m above ground surface.

The analysis of the unmanned commercial aircraft operation connected with monitoring of linear objects has revealed that it is efficient to determine the linear emission source contribution to overall air pollution in monitoring flights along traverses across the extension of a linear source and along its axis as shown in **Fig. 2.**

The main adjustable characteristic in this flight task implementation is the traverse width governed by the transport distance of a pollutant along the normal to the source axis. The traverse width cannot be smaller than the size of the protection zone of an emission source. From practice of unmanned aircrafts, this zone ranges from 200 to 500 m for a standard linear emission source.

In case of air pollution from an areal source, toward complete estimation of the emitted pollution concentration, it is proposed to execute the monitoring flights along a spiral route, from the geometrical center of the source to its periphery.

In localization of different standard emission sources in the test area, it is most efficient to perform monitoring flights along traverses as in assessment of contribution of linear sources in air pollution. On the other hand, in this approach, the traverse

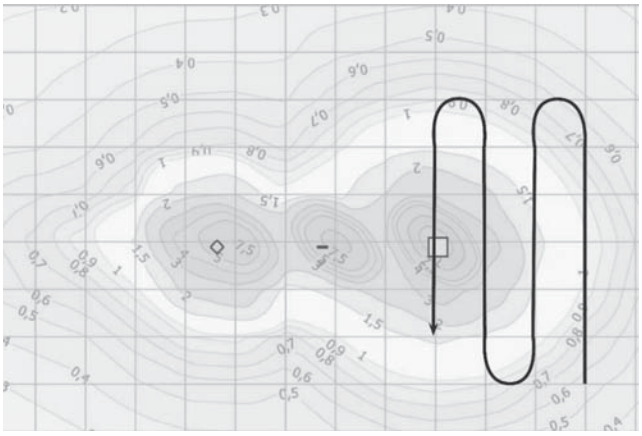

Fig. 2. Diagrammatic view of flight task in influence zone of linear source

Fig. 3. Chemical envelope of contamination in the lowest atmospheric air layer with sulfur dioxide from unmanned aircraft measurements

Fig. 4. Chemical envelope of contamination in the lowest atmospheric air with nitrogen dioxide from unmanned aircraft measurements

width should conform with the localization of the chemical envelope of contamination in the atmosphere (i.e. it should run up the contrast coefficient value of 1 in the charts of contour lines). In this case, it is required to assign the monitoring flight direction along the longest axis of the chemical anomaly in the atmosphere, subject it is acceptable by the criterion of safe operation of unmanned commercial aircraft.

The research system had a modular architecture, which allowed on-line redesign of the playload.

The concentrations of air pollutants were measured by a multi-component electrochemical gas analyzer capable to measure contents of up to 9 pollutants at the same time.

The equipment is also fitted with the dedicated droppable sampler to be used when it is necessary to eliminate influence of crews on the air flow uniformity in the sampling area [13].

This approach integrates the advantages of the contact ecological monitoring method, such as high measurement accuracy and measurement capability at any specific space point, and of the remote sensing method, such as high mobility, increased flexibility and air quality evaluation capability in hard-to-reach areas.

For instrumental measurements to be legitimate, it is required to provide metrological assurance of the measurement systems mounted on unmanned aircrafts. The related studies are described in [14].

Evaluation of air quality in the influence zone of Korkino OPCM was implemented in the summer seasons in 2017–2019.

In view of the almost round shape of the coal pit in plan, it was assumed as the most efficient approach to fly round the test area along the spiral from the center of the pit to its periphery.

In accordance with the developed procedure, the monitoring flights were executed at different elevations from ground surface (from 25 to 100 m at a pitch of 25 m). The average time of the monitoring flights was 33–36 min.

The real-time observation data were transferred to a ground control panel housed in a commercial notebook for the further processing.

Results and discussion

Interpretation of the research findings on chemical contamination of the atmosphere was carried out as mapping of anthropogenic pollution envelopes using the GIS technologies. The mapping was implemented with Surfer software, and the interpolation method was the Inverse Distance Weighting. The topographic base was the satellite image of the test locality. Considering small building heights as against the coal pit depth, the elements of the residential area were assumed equal to the terrain roughness in the models of chemical contamination envelopes in the atmosphere.

In the assumed method of interpolation, the points of data were weighted so that the influence of a point versus another point grew with decreasing distance to an arbitrary mesh point. Weighting of data points was executed using the force (capacity) to control the increase in the weight coefficient with the decreasing distance to an arbitrary mesh point. As the capacity is higher, the influence of the farther data points lowers during interpolation. As the capacity is increased, the value of a mesh point approaches the value of the nearest data point.

As per the environmental legislation effective in Russia, using the data of monitoring flights and dedicated software, the concentrations of pollutants were determined in the lowest atmospheric layer (at an elevation of 2 m) [15].

The calculated parameters of total dissipation of pollutants in the atmospheric air are presented as the planimetric maps of Korkino OPCM, including contour lines plotted from the contrast coefficients which image locations of the chemical contamination envelops in the atmosphere. **Figure 3** and **4** demonstrate the chemical envelopes of sulfur dioxide and nitrogen dioxide in the lowest atmospheric air, respectively, obtained using an unmanned aircraft during the operational season in 2019.

The contrast coefficient relative to the maximal allowable daily concentration of sulfur dioxide in the territory of Korkino OPCM reaches a value of 9.5. The major sources of sulfur dioxide locate in the north and west of the pit wall. In the residential communities nearby the pit, slight overshoots of MAC_{daily} are recorded. The contrast coefficient relative to MAC_{daily} in Korkino town and in Rosa community ranges from 0.5 to 2. Contamination propagates mainly northwards.

The estimate of the lowest air layer pollution with nitrogen dioxide points at excess of the allowable values by 8.9 times in the test territory. The major nitrogen dioxide sources locate in the north and southeast of the pit wall. Slight overshoots of the maximal allowable concentrations are recorded in Korkino town and in Rosa community, too.

The zones of increased pollutant concentrations in the north of Korkino pit wall agree with the locations of the largest seats of endogenous fires.

Despite the positive trend in reduction in toxic emissions in the test territory, associated with Korkino OPCM reclamation for the first turn, endogenous fires yet are the key factor of anthropogenic chemical envelopes of pollution in the atmosphere. The analysis of the diagrammatic representations of the ecological monitoring data on air pollution in the lowest atmospheric layer shows that the chemical anomalies in the atmosphere have an area from 0.6 to 27.5 km^2. The distance of propagation of the induced chemical anomalies in the atmosphere reaches 18–23 km at wind velocity of 3–4 m/s.

Conclusions

In the course of the implemented research, the integrated procedure has been developed for the ecological monitoring of air using unmanned aircraft systems equipped with special measurement facilities.

Trial of the procedure in the summer operational seasons in 2017–2019 proved its efficiency. For instance, with the monitoring system mounted on a vehicle and with the increased range of the unmanned aircraft, the time of the atmospheric air quality evaluation in the test area has been reduced to 1–2 h. Furthermore, mobility of the drone and its ability to be hovered at a space point at a high precision of positioning allows ecological monitoring in mining territories with complex geomorphology due to extensive mining-induced damage of landscape.

In the influence zone of Korkino Open Pit Coal Mine, the use of the proposed approach has enabled determining chemical envelopes of contamination in the lowest atmospheric layer with various pollutants (the maximal allowable daily concentrations of sulfur dioxide and nitrogen dioxide are exceeded by 9.5 and 8.9 times, respectively). The maximal concentration zones of sulfur oxide and nitrogen oxide coincide with the locations of seats of endogenous fires. The area of the revealed chemical contamination envelopes reaches 30 km^2.

Aimed to ensure ecological security in the influence zone of Korkino OPCM assumed as the critically hazardous and technically high object, it is recommended to introduce the new-developed approach into the system of industrial environmental monitoring, which can enhance efficiency of monitoring at the sufficient reliability of the obtained results and at the improved accuracy of mapping of chemical anomalies in the atmosphere.

The developed and approved procedure complies with the standards of the best allowable technologies in the sphere of ecological safety. The introduction of the procedure in the mining and processing industry can reduce the risk of unfavorable situations and can raise the approval rating of performance of the industry among population.

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INTEGRATED MONITORING-BASED ASSESSMENT OF DEFORMATION AND RADIATION SITUATION OF TERRITORIAL DOMAINS

The article describes integrated monitoring (space, geodetic, radioecological) in the area of earlier underground explosion at Semipalatinsk Test Site (STS). The data of space monitoring of the territory and the experience of the data integration into the geographic information system (GIS) are analyzed.

The primary analysis of geodetic monitoring results is performed as a case-study of Balapan and Telkem sites where ground surface subsidence is up 5–6 mm. Based on the integrated monitoring, the dynamic maps of temperature and ecological characteristics of the test site territory are obtained. The results are used for additional assessment of pollution consequences at STS and to work out recommendation on the use of the lands in the context of radiation safety.

Keywords: *underground nuclear explosion, geographic information systems, space monitoring, geodetic monitoring, radioecological monitoring, analysis, temperature anomaly, ground surface deformation, radioactive contamination maps.*
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Introduction

Eco-systems in Kazakhstan feature weak resistance to anthropogenic impact. About 75% of the territory of Kazakhstan (Aral Sea, Semipalatinsk Test Site (STS), the coast of the Caspian Sea, desert and semi-desert land ranges in Central and Southern Kazakhstan, etc.) are subject to an increased risk of environmental disruption. STS had been used as the main site for nuclear tests for 40 years [1, 2].

By the decree of the President of the Republic of Kazakhstan N. A. Nazarbayev, the test site was closed on August 29, 1991, with internal and adjacent contaminated areas left behind. That circumstance caused intensive researches of the nature and pollution level of test site territory with the aim to determine the nuclear explosions after-effects and and for monitoring of radiation-hazardous objects.

For the timely indication of further changes, assessment of the rates and areas of the natural environment degradation, for the impact prevention and situation stabilization, the operational control of these regions is necessary. Considering the vast territory of Kazakhstan, hardness of many areas and limited funding in modern conditions, such control can be only effective based on the integrated research (satellite monitoring and ground investigations).

Description of Semipalatinsk Test Site

STS is located at the intersection of three regions of Kazakhstan: Pavlodar, Karaganda and East Kazakhstan, and covers 18 thousand km^2. During the operation of STS (1949–1989), 456 nuclear tests were conducted on its territory, including 86 air tests, 340 underground tests and 30 contact tests. Here, the first in the USSR nuclear (1949) and the world's first hydrogen (1953) bombs were tested.

As the result of nuclear explosion in 1965, more than 10 million tons of ground was thrown to a kilometer height and a funnel with a diameter of 430 m and depth of 100 m was formed. This funnel is called the Atomic Lake. As a result of the tests, radioactive decay residues – radionuclides covered STS territory [3].

Methods and results

Ample research had been devoted to the territory of the former STS [4-6]. However, the research had no common information basis, which would allow moving from theory to solving practical problems.

In this case, creation of GIS is the most effective way, which allows not only preserving the available and readily accessible data but also enables simulation, the results of which can be combined with the geographical and space images of the region under study [7, 8].The main tool that combines subsystems into integrated GIS is the ArcInfo