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Remote sensing of the Earth as a part of research of assessing the volume of technogenic raw and the environmental situation during the exploitation of placers

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Abstract. It is known that one of the main nowadays problems of subsoil use is the depletion of reserves. Every year many researchers pay attention on mining waste as a source of replenishment of the resource base. Disputes on the prospects of processing technogenic raw materials are relevant. The object of research is the technogenic neoplasms, which were the result of dredging and hydraulic processing of placer gold. The paper presents the results of assessing the prospects and places of application of information technologies, in particular, the analysis of Earth remote sensing data in the design and organization of work to involve technogenic placers in operation. It is shown that these technologies are able to increase the efficiency of work and reduce labor costs at the stage of preliminary study of potential development targets.

Possibilities of detailing the infrastructure facilities of the mining and processing complex are considered. It is proposed to use the vegetation index at a non-traditional time for vegetation research in order to isolate coniferous trees on the formed secondary phytocenoses. An area assessment of the technogenic raw materials of the Kerba gold-placer cluster has been carried out. The analysis of the methodological approach based on remote sensing data is carried out. Aspects of natural vegetation restoration in the post-exploitation period are covered. Optimal combinations of raster data channel combinations for the study of the territory within the boundaries of the object under study are proposed.

Keywords: technogenic raw materials, assessment of reserves, technogenic neoplasms, remote sensing, natural recovery

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Introduction

The mining industry makes a significant contribution to the global economy while also having a negative impact on the environment. Currently, mining leads to strong hydrobiogeochemical changes in the ecosystem (Evans et al., 2015; Feng et al., 2019) and is considered one of the most destructive economic activities that cause the deterioration of the functioning of the natural ecosystem. An increase in surface runoff contributes to the occurrence of flooding zones (Singh et al., 2013, 2015; Nemčić-Jurec et al., 2017; Kumar et al., 2017, 2018), climate change, and loss of habitat (Singh et al., 2017) and changes in landscape demography (Skole et al., 1994; Johnson et al., 1997; Pandey et al., 2012).

One of the main areas of subsoil use in the Far Eastern Federal District (FEFD) is the development of alluvial gold deposits. In the Khabarovsk Territory, in the last century, 90 % of gold and all platinum were mined from alluvial deposits. Now this share has significantly decreased, however, placer metal makes a significant contribution to the total volume of production. Gold mining in the Khabarovsk Territory has been going on for over 130 years; the largest alluvial gold deposits are located here. Due to this intensity of development, metal reserves have significantly decreased, and their significant increase is not expected. To increase the resource base and the extraction of precious metals, technogenic formations (gale-efel dumps of gold mining) should be brought into operation with the introduction of new technologies and equipment. According to expert assessments of specialists, in the technogenic placers of the region there are reserves of fine and fine gold that can extend the activities of enterprises for more than 10 years[1]. Prospects for technogenic alluvial gold deposits only in the south of the Russian Far East can be assessed in a volume comparable to those already withdrawn (Kuznetsova et al., 2019).

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A common characteristic feature of the technogenic formations of gold-bearing placers in the Far East is the accumulation of precious metal of such size classes and morphological forms that are not taken into account by subsoil users during geological exploration (Alekseev et al., 2018; Litvintsev et al., 2005). In the Far East region, rich geogenic and accessible placers have already been worked out, and at present, placer gold reserves are concentrated in deep-lying and technogenic deposits. The first of them are characterized by a complex structure, an increased clay content in formations and in dump complexes, and a high overburden ratio. The second is the predominance of fine and very fine fractions of the useful component and a significant averaging of the metal content over the dump volume. Therefore, a scientific search is needed in the creation of new, promising technologies for the development of deposits and equipment for the enrichment of minerals, as well as the identification of priority technogenic objects of placer gold mining.

Although the greatest negative impact on the ecosystems of economically underdeveloped territories is exerted by tree felling, the impact of alluvial mining is significant. During the development of alluvial gold deposits in general, the gold mining enterprises of the Far Eastern region retains the tendency of accumulation of lands disturbed by mining operations, but the rate of reclamation is low (0.01 %), and in recent years it has practically not been carried out. There is a constant accumulation of land on the balance sheet of the mining enterprise. Thus, the relevance of studies aimed at assessing the volume of technogenic raw materials and the prospects for their development, as well as determining the possibility of natural restoration of vegetation to reduce the area of land involved in processing, is obvious.

Materials and methods

The complex of works for the preparation and involvement in the development of legacy placers includes geological, mining, technological, geographical, ecological, economic types of research. Without taking into account the legal side of the issue, the organization of production requires the choice of a gold-bearing region, the identification of technogenic objects, the development and implementation of technology, a preliminary assessment of resources and an assessment of the economic feasibility of their development and environmental risks, as well as a forecast of the development of the situation. For large-volume placers, it may be necessary to take into account the potential value of accompanying mineralization: many placers in the region contain minerals of tin, tungsten, titanium, which are concentrated in black concentrate. In the Kerbinsky region, they can contain corundum, beryl, amethyst. At the stage of preparation, information technologies (IT) in the form of geographic information systems (GIS) logically fit into this series. This primarily concerns the use of earth remote sensing (ERS) data. In this case, these are satellite images and SRTM (Shuttle radar topographic mission) terrain matrices (http://srtm.csi.cgiar.org). Their strengths are wide visibility, high visibility and efficiency of data acquisition. In addition, thanks to the extensive archive, it becomes possible to assess the chronology of the field development process and post-production recovery.

When assessing the state of the natural environment, we used multi-temporal multispectral satellite images of the Landsat series (https://earthexplorer.usgs.gov). Single-band and multi-band raster layers were extracted from them, on the basis of which virtual rasters were built. To identify an effective and reliable method for detecting disturbed by mining lands and calculating their areas, first of all, the most informative combinations of spectral channels for the synthesis of quasi-color images were selected, which would make it possible to identify technogenic areas as accurately as possible, evaluate their structure and characteristic features of their location.

For the implementation of GIS data processing technology in previous years in order to study the dynamics of the development of the ecological situation, a geographic database "Cartographic database FE-MI GIS" was designed and created (Usikov et al., 2019).

Within the framework of the research using the remote sensing method, a forecast of natural restoration of vegetation in the territory after the termination of technogenic impact was carried out. The work was carried out using the VEGA-Science satellite monitoring service (Lupyan et al., 2011) to substantiate models of landscape-geochemical stability and ecological capacity of the natural environment.

Description of the research object

The object of research is the Kerbinsky gold-placer cluster. The node is characterized by a high density of alluvial gold content; areal density is 5.1 kg/km^2, linear density in terms of reserves – 95 kg.lin km, according to predicted resources – 186 kg.lin km. The area of the district is 6075 km^2. The most productive are the placers of the river Sem, Gongrena, Kerbi and others. In the central part of the region, the placers have been practically worked out, and some of them have been transferred to the category of technogenic. Mainly, placers with low gold grades or buried ones remained. In total, 52252 kg of gold were mined in the Kerbinsky region, there are 2591 kg of explored reserves, and 35.1 tons of predicted reserves. The gold content in placers ranges from 86 to 962 mg/m^3. The area is characterized by an exceptional density of alluvial gold content:

area – 5.8 kg /km^2, linear in reserves – 65.7 kg/lin km, according to predicted resources – 455.3 kg/lin km (Sorokin et al., 2000).

The total area of the worked-out territories is at least 3600 hectares. According to available data, it is possible to find deep-lying placers along the tributaries of the Sem river, however, they are characterized by high water cut, low hypsometric position and considerable depth (up to 30 m), which complicates development. Technogenic placers along the rivers Sem, Sulakitkan, and Botoon are of practical interest, where about 30 tons of gold were mined in total. The predicted resources for these man-made placers (taking into account the technological losses of 15 % during the development of the corresponding natural placers) are more than 5 tons, but the probable content is low (at the level of 80 mg/m^3). Many geogenic placers of the cluster are characterized by high clay content and fine gold. In the process of their primary mining, a significant part of the clay is washed out and stored in sludge ponds. This facilitates the gravitational enrichment of the material of technogenic objects formed at the site of these geogenic deposits. Valley of the Kerbi river, on a section from the Kut river to Maklan river, is characterized by industrial gold content, but gold is distributed extremely unevenly: there are nests with a very high content and very low. The average gold content by weight is about 50 mg/m^3. Dredge mining gives an alluvium coefficient of 0.43. Terrace placers along the Kerbi river are also characterized by very difficult mining conditions and scarce resources. The imperfection of the gold mining technology at the beginning of the 20th century and, as a result, the high metal content in the mining waste made it possible to involve in the processing of technogenic material from dumps located in river valleys, including the Kerbi river. Back in the early 2000s, researchers argued that with the improvement of equipment, technologies for the development and enrichment of sands, the role of technogenic objects will increase.

The reprocessing of gale-efel dumps contributes to a significant transformation of the landscape-geochemical conditions formed in the process of primary processing, due to the withdrawal and repeated movement of large masses of rocks and natural waters within the mining allotment. Technogenic pollution of the territory of mining and industrial development is determined by the composition of rocks and the technology of mining and processing of minerals. The rivers Sem, Sulaktikan, Kerbi, Nilan (Kerbinsky ore-placer cluster) are located in anthropogenically created valleys, represented by a complex of open and vegetated dumps up to 5 m high, artificial reservoirs, a channel. The shape and length of technogenic placers depends on the power of the source – the geogenic placer. The high-resolution images clearly decipher the main objects of the industrial infrastructure of the enterprise. Of particular interest are the mined and under development alluvial gold deposits, access roads to the sites.

Results and discussion

As a result of monitoring, areas were identified where the development of man-made placers is already underway. During periods of cessation of mining, natural restoration of vegetation is recorded in the worked-out areas.

To assess the prospects for the development of technogenic deposits, the interpretation of satellite images was carried out in order to identify the worked-out gold-placer areas of the Kerbinsky gold-placer cluster based on a digital relief model. On the basis of the SRTM03 DEM, an infrastructure map was built (Fig. 1).

The advantage of such a map is that official topographic maps lack many elements of technological infrastructure: internal roads of the junction, access roads to placers, temporary power lines for power supply of mechanisms, but they are confidently displayed on satellite images (Fig. 2). From the images, it's possible presumably assess the current state of the roads, for example, the dirt road on the Sivaki–Nilan watershed on the map is less pronounced than others and is interrupted in places, which suggests that it is at the stage of overgrowth.

Also, areas with transformed and displaced soils are recognized on the images, i.e., the actual technogenic placers are outlined. As a result of the methodological work, it was revealed that for such delineation, the most suitable are color images synthesized by groups of spectral bands (channels) 6–5–4 or 7–5–3, taken in a leafless period on the ground, and, as a rule, snowless, i.e., in spring or autumn. Sometimes a similar result is obtained at the very beginning of summer. NDVI maps of the normalized vegetation index are also suitable for this. The same images can be used to identify dredging polygons by the characteristic texture of the image (Fig. 3). In this combination of strips, the dumps are identified by the change in the texture of the image, open water is displayed in dark blue, almost black, extended curves correspond to dredging passages, which are especially clearly manifested in the polygons of the lower reaches of the Nilan and Sivak rivers. Also, areas of river valleys and springs are confidently identified, where mining operations have completely transformed the channels and turned into dump chains containing separate ponds with running water draining loose material, for example, the Branja, Yanka rivers and many others.

The reprocessing of gale-efel dumps contributes to a significant transformation of the landscape-geochemical

conditions formed in the process of primary processing, due to the withdrawal and repeated movement of large masses of rocks and natural waters within the mining allotment. Numerous studies have established that the spatial variability of the state of plants over time can be used as an additional indicator (Strilesky et al., 2017; Wood et al., 2015; Petrone et al., 2014). Earlier works by employees of the Institute of Mining of the KhBRC FEB RAS established that natural self-recovery of phytocenoses occurs on the dumps of gold mining (Ozaryan, 2018): in this area, complete self-overgrowing occurs in 7-16 years, therefore, special reclamation measures are probably not required for this, however, the real damage can be considered as the violation of river channel sections, affecting the aquatic fauna. On the basis thereof, restoration of normal watercourse in such areas should be a necessary requirement when planning recultivation.

Some waste landfills, highlighted in the images, are painted in pink and purple tones (Fig. 4), by analogy with the Komsomolsk ore district, where anthropogenic pollution of the territory with products of sulfide oxidation (primarily pyrite, arsenopyrite, chalcopyrite) is indicated. Attention should be paid to such areas in terms of assessing environmental risks. Many of them are rather large for alluvial objects, so it makes sense to assess the potential practical significance of the accompanying mineralization, as well as the possible environmental risks from chemical compounds extracted on the surface as pollutants.

Certain collisions with the nature protection zone may arise during the preparation of areas for the operation of man-made objects, in particular, clearing them from the forest. In order to minimally affect the more valuable, dark coniferous tree species, it is necessary to outline the areas of their distribution in advance. For this, it is necessary to use NDVI (Normalized difference vegetation index) maps and make a classification by highlighting different types of vegetation. However, a simpler, faster and less labor-intensive option for applying the NDVI is also possible – calculating the index based on an image taken in early spring, after the snow cover has melted, but before the grass and leaves appear. Figure 5 illustrates this technique. NDVI maps are also used to clarify the location and contours of man-made placers.

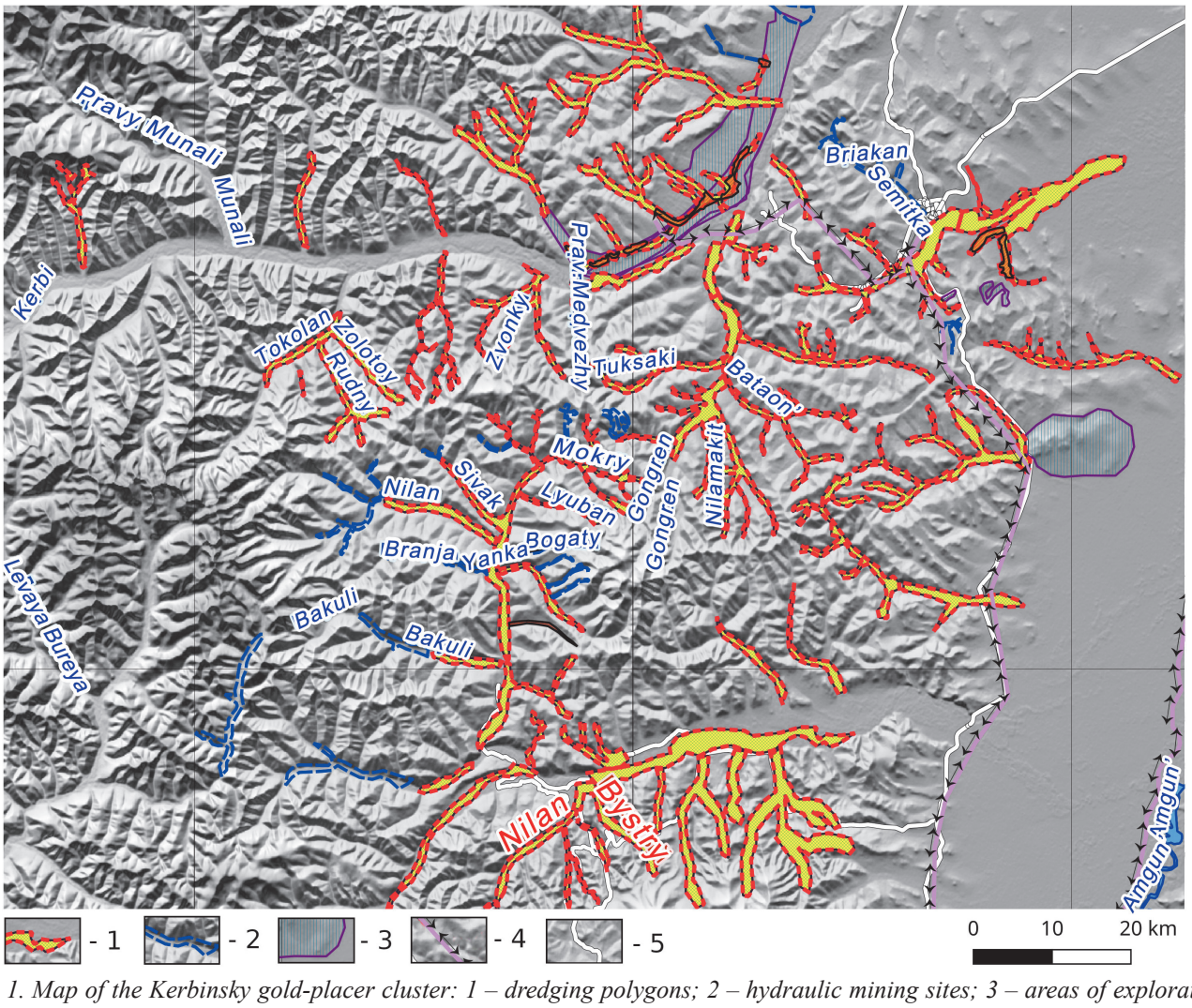

Fig. 1. Map of the Kerbinsky gold-placer cluster: 1 – dredging polygons; 2 – hydraulic mining sites; 3 – areas of exploration; 4 – power lines; 5 – roads

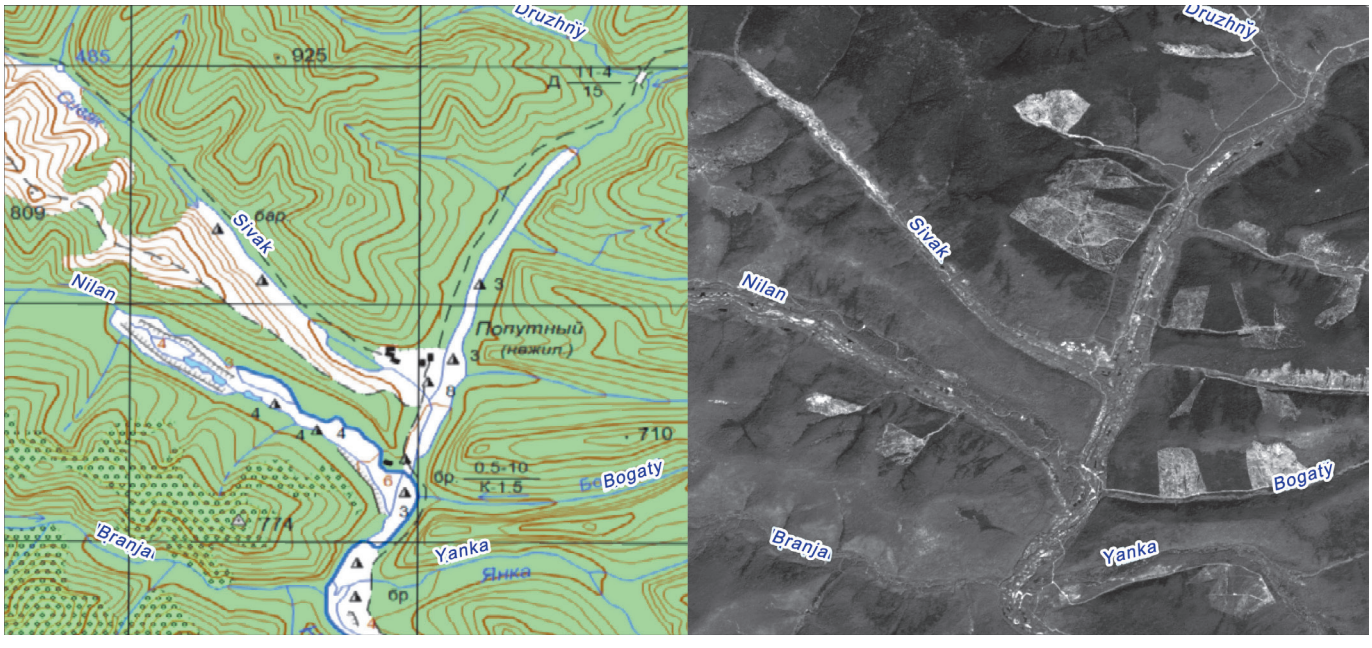

Fig. 2. Comparison of images of the study area on the topographic map and satellite image

NDVIs greater than 0.2 identify vegetated areas. Obviously, in early May, these are conifers. Negative values of the index indicate an exposed surface or surface water.

Conclusions

Gold mining in the Khabarovsk Territory has been going on for more than 130 years, so the reserves of the metal have significantly decreased, and their significant increase is not expected. To increase the resource base and the extraction of precious metals, technogenic formations (gale-efel dumps of gold mining) should be brought into operation with the introduction of new technologies and equipment. The predicted resources for these technogenic placers (taking into account the technological losses of 15 % during the development

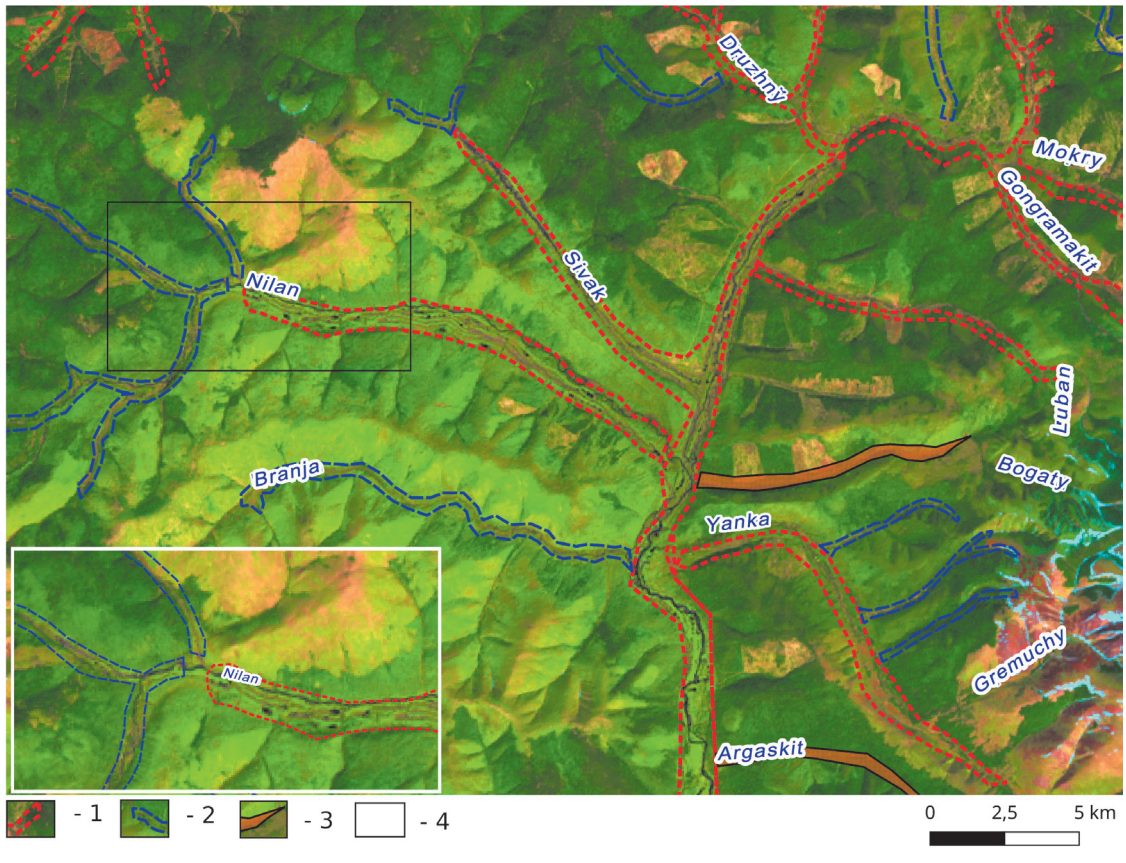

Fig. 3. Synthesized color image of a section of the Kerbinsky gold-bearing cluster. Landsat 8 image, spectral bands 6–5–4. 1 – dredging polygons; 2 – polygons for hydraulic mining of placers; 3 – polygons of combined mining; 4 – inset section

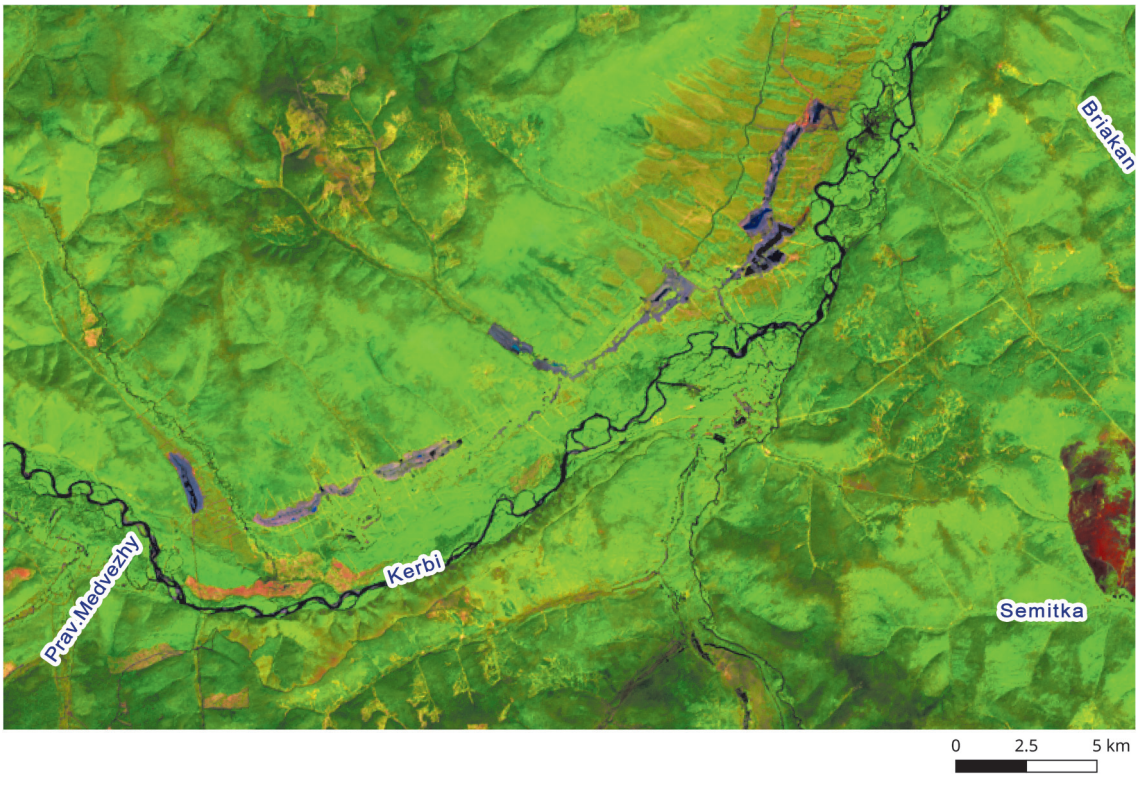

Fig. 4. Synthesized color image of a site in the northern part of the Kerbinsky gold-bearing cluster. Landsat 8 image, spectral bands 6–5–4

of the corresponding natural placers) amount to more than 5 tons.

When preparing man-made deposits for operation at the stage of preliminary study of objects and areas in the complex of works, it is advisable to use the analysis of remote sensing data. With the help of SRTM terrain matrices, it is possible to clarify the details of the structure of the earth's surface. Color and pseudo-color images are synthesized from satellite images using different spectral bands. On the basis of their analysis, the technogenic objects themselves (primary mining sites) are revealed, their contours and areas are determined. Also, technologies for the development of landfills, used in primary development, and sections of rivers with disturbed channels are determined. The same images are used to identify the technological infrastructure and the possibility of its reuse. In many cases, it is possible to isolate dumps (parts of dumps) containing accompanying minerals in high concentrations.

According to NDVI maps, tracts of more valuable dark coniferous forests are recorded in order to minimize damage to the natural environment during the performance of exploitation works.

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References

Alekseev V.S., Banshchikova T.S. (2018). Non-conventional technologies for gold extraction from commercial placers of Priamurye. *Gornyi Zhurnal = Mining journal*, 10, pp. 52–57. (In Russ.)

Evans D.M., Zipper C.E., Hester, E.T., Schoenholtz S.H. (2015). Hydrologic effects of surface coal mining in Appalachia (U.S.) J. Am. *Water Resour. Assoc.*, 51, pp. 1436–1452. https://doi.org/10.1111/1752-1688.12322

Feng, Y., Wang, J., Bai, Z, Reading, L. (2019). Effects of surface coal mining and land reclamation on soil properties: A review. *Earth-Science Rev.*, 191, pp. 12–25. http://dx.doi.org/10.1016/j.earscirev.2019.02.015

Johnson L.B., Richards C., Host G., Arthur J.W. (1997). Landscape influences on water chemistry in midwestern streams. *Freshw. Biol.*, 37, pp. 209–217.

Kumar N., Singh S.K., Singh V.G., Dzwairo B. (2018). Investigation of impacts of land use/land cover change on water availability of Tons River Basin, Madhya Pradesh, India. *Model. Earth Syst. Environ.*, 4, pp. 295–310. http://dx.doi.org/10.1007/s40808-018-0425-1

Kumar N., Singh S.K., Srivastava P.K., Narsimlu B. (2017). SWAT Model calibration and uncertainty analysis for streamflow prediction of the Tons River Basin, India, using Sequential Uncertainty Fitting (SUFI-2) algorithm. *Model Earth Syst Environ.,* 3(30). http://dx.doi.org/10.1007/s40808-017-0306-z

Kuznetsova I.V., Safronov P.P., Moiseenko N.V. (2019). Matter-mineral characteristics of technogene placers – potential sources of precious metals (on the example of the Nizhneselemdzhinsky gold-bearing node of Priamurye, Russia), *Georesursy = Georesourses,* 21(1), pp. 2–14. https://doi.org/10.18599/grs.2019.1.2-14

Litvintsev V.S, Ponomarchuk G.P, Banshchikova T.S. (2005) Morphological characteristic of gold of legacy placers of the Dzhalinda River and Inagli River and problems of its extraction. *GIAB = Mining informational and analytical bulletin*, Special edition – Far East, pp. 319–327. (In Russ.)

Lupyan E.A., Savin I.Y., Bartalev S.A., Tolpin V.A., Plotnikov D.E. (2011). Satellite Service for Vegetation Monitoring VEGA. *Sovremennye Problemy Distantsionnogo Zondirovaniya Zemli iz Kosmosa = Current Problems in Remote Sensing of the Earth from Space,* 8(1), pp. 190–198. (In Russ.)

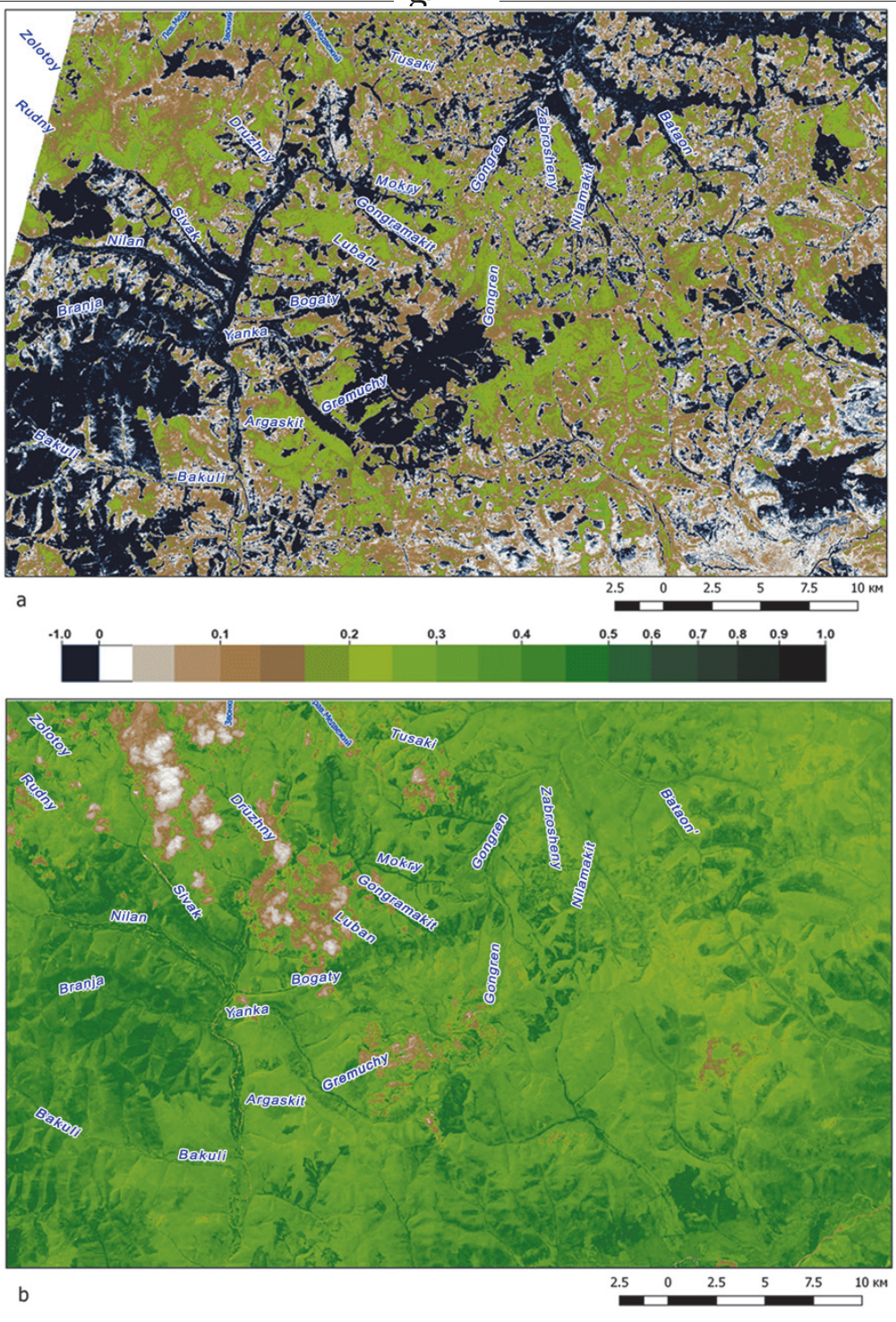

Fig. 5. NDVI map of the Kerbinsky gold placer cluster: a) May 6, 2013; b) July 16, 2013

Nemčić-Jurec J., Singh S.K., Jazbec A., Gautam S.K., Kovac I. (2019). Hydrochemical investigations of groundwater quality for drinking and irrigational purposes: two case studies of Koprivnica-Križevci County (Croatia) and district Allahabad (India). *Sustain. Water Resour. Manag., 5,* pp. 467–490. http://dx.doi.org/10.1007/s40899-017-0200-x

Ozaryan Yu.A. (2018). Assessment of natural biota rehabilitation in the influence zone of mining in the Khabarovsk Territory by satellite monitoring data. *Gornyi Zhurnal = Mining journal,* 10, pp. 84–88. (In Russ.)

Pandey P.C., Sharma L.K., Nathawat M.S. (2012). Geospatial strategy for sustainable management of municipal solid waste for growing urban environment. *Environ. Monit. Assess*., 184, pp. 2419–2431.

Petrone R., Chasmer L., Hopkinson C., Silins U., Landhausser S., Kljun N., Devito K.J., 2014. Effects of harvesting and drought on CO2 and H2O fluxes in an aspen- dominated western boreal plain forest: early chronosequence recovery. *Can. J. For. Res.*, 45(1), pp. 87–100.

Singh S.K., Srivastava P.K., Pandey A.C., Gautam S.K. (2013). Integrated assessment of groundwater influenced by a confluence river system: concurrence with Remote Sensing and Geochemical Modelling. *Water Resour. Manag.*, 27, pp. 4291–4313. http://dx.doi.org/10.1007/s11269-013-0408-y

Singh S.K., Srivastava P.K., Singh D., Han D., Gautam S.K., Pandey A.C. (2015). Modeling groundwater quality over a humid subtropical region using numerical indices, earth observation datasets, and X-ray diffraction technique: a case study of Allahabad district, India. *Environ. Geochem. Health,* 37, pp. 157–180. http://dx.doi.org/10.1007/s10653-014-9638

Singh S.K., Srivastava P.K., Szilard, S., Petropoulos, G.P., Gupta, M., Islam, M. (2017). Landscape transform and spatial metrics for mapping spatiotemporal land cover dynamics using Earth Observation data-sets. *Geocarto Int.,* 32(2), pp. 113–127. http://dx.doi.org/10.1080/10106049.2015.1130084

Skole D.L., Chomentowski W.H., Salas W.A., Nobre A.D. (1994). Physical and human dimensions of deforestation in Amazonia. *BioScience,* 44(5), pp. 314–322.

Sorokin A.P. et al. (2000). Atlas of Charts of the Southern Far East Gold Placers and Their Mining and Geological Models. Vladivostok-

Blagoveshchensk-Khabarovsk: FEB RAS, 334 p. (In Russ.)

Strilesky S.L., Humphreys E.R., Carey S.K. (2017). Forest water use in the initial stages of reclamation in the Athabasca Oil Sands region. *Hydrol. Process,* 31(15), pp. 2781–2792.

U.S. Geological Survey. https://earthexplorer.usgs.gov

Usikov V.I., Lipina L.N., Bubnova M.B., Ozaryan Yu.A. (2019). MIFE GIS Cartographic Database. Certificate of registration of the database 2019620201 RF. FSBSI IGD FEB RAS. (In Russ.)

Van-Van-E A. P. (2010). Resource base of natural-anthropogenic gold placer deposits. Moscow: Gornaya Kniga, 268 p. (In Russ)

Wood M.E., Macrae M.L., Strack M., Price J.S., Osko T., Petrone P., (2015). Spatial variation in nutrient dynamics among five different peatland types in Alberta oil sands region. *Ecohydrology,* 9(4). https://doi.org/10.1002/eco.1667

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