Information and computational GIS for monitoring the natural and technical systems of placer gold deposits

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Abstract. It is known that nowadays one of the main problems of mining is the depletion of reserves. The researchers consider mining waste as a source of replenishment of the resource base. Disputes on the prospects for technogenic raw material processing are becoming especially relevant. The object of research chosen by the authors in this article is the technogenic neoplasms resulting from dredging and hydraulic processing of placer gold. The paper presents the results of assessing the prospects and application of the information technologies, in particular, the analysis of data from remote sensing of the Earth 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. Technogenic complexes of depleted fields are a significant reserve of the mineral resource base of gold and other precious metals. This paper presents the results of the creation of a method for expert assessment of spatial and volumetric indicators of technogenic complexes of alluvial fields and other landscape objects using remote sensing of the territory and analysis of geological information. The Kerbinsky gold-bearing region of the Khabarovsk Region was chosen as the object of research.

1. Introduction

Years of research have established [1], that the extraction of placer gold influences the landscape and river valleys, and leads to the destruction of indigenous vegetation and disturbance of the soil structure. It leads to the loss of habitat of species [2-6]. Natural wetlands are being destroyed, which play an important role in providing habitat for wildlife, protecting during storms and improving water quality [7].

The researchers [8] concluded that global mining has peaked in several species, namely, antimony, gold, arsenic, bismuth, indium, lithium, manganese, molybdenum, nickel, silver, tantalum, tellurium, and zinc. Production will begin to decline over the next 50 years. Wellmer and Scholz [9] note that since 1900 the global gold production has peaked five times: in 1912, 1940, 1970, 2001, and 2014. In four of these cases, high prices and demand have led to a recovery in the production after the recession. Thus, there is a high probability of stable demand for the precious metal, and, therefore, a decrease in production volumes should not be expected.

In Russia, placer deposits began to be developed about 200 years ago, while in Eastern Siberia that occurred 100–150 years ago. Today, almost all placer gold deposits, which are developed in Russia, are related to technogenic. For these reasons, over the past 30–40 years, there have been discussions
Concerning complete depletion of this type of resource and the need to switch to gold mining (indigenous) deposits. It should be noted that with a high degree of probability, it will not be possible to completely exhaust the mineral raw materials. There will always be hard-to-reach, complex and other under-access resources. Of course, the development of technology sooner or later will allow to master such resources. The depletion of stocks of raw materials may lead to a lack of its availability in the long run, resulting in an even greater increase in production costs and prices, which will reduce and ultimately eliminate the demand. At this stage, the Earth will still contain useful minerals, but their operation will be too expensive [10].

The disputes between scientists and mine workers about the rationality and investment feasibility of processing of recycled materials of placer gold do not subside. An important reason for the need to recycle man-made deposits was the restoration of disturbed areas, including disturbed stream flows, relief features, and landscape, as a whole. Accounting for the territorial features of the Far Eastern fields, their remoteness from large settlements, transport accessibility, the Earth remote sensing (ERS) data are of vital importance in assessing the potential of man-made deposits and the quality of environmental components of disturbed areas.

To sum up, the purpose of the work was to justify the possibility of estimating the reserves of man-made raw materials of placer gold relying on the information and computational GIS and remote sensing data.

Based on the goal, the algorithm of action is defined:
- analysis of the state of the problem and world trends in its solution;
- remote sensing data collection for the site studied and decrypting man-made deposits.

2. Materials and methods

Taking into account the remoteness of natural and technical systems in the south of the Russian Far East, the observations using Earth remote sensing contribute greatly to the issue of systemic monitoring of environmental quality, and the identification and evaluation of areas affected by the development of deposits. Multispectral data were analyzed using different approaches. The Landsat 7–8 images were used to detect changes in the landscape and soil cover. The images of the study area obtained at different periods were compared. The Landsat images were also used to detect changes in man-made dumps by deciphering terrestrial vegetation using different channel combinations. Analysis using satellite images allowed the detection of mining areas and revealing specific effects of these activities, the method of extraction, and the area of disturbed lands and vegetation state.

Mapping is aimed at deciphering spatial and temporal variations of the gold placer tailings in the study area. The work is a pilot project that also includes the transfer of data to the FE-MI GIS Mapping Database, designed to use it in various computer applications implementing GIS technologies [11].

The methodological basis of the study was a classic systemic approach formulated as follows: all objects of the study are interconnected systems, including human, which is an open system, the functioning and development of which depends on the state and dynamics of the parameters of the external environment [12].

The complex of methods which is used in the research includes the following techniques: the content analysis of the literature data; downloading the medium- and high-resolution satellite images from open sources and their interpreting and analyzing. Special software was used as a software framework, in particular, open geo-information systems of QGIS, GRASS, SAGA, Microdem, etc.

The calculation and analysis of the vegetation index (Normalized Difference Vegetation Index, NDVI) was carried out using the QGIS and science research tool for analysis of satellite observation “Vega-Science”.

This indicator is calculated by the formula:

$$NDVI=\frac{(NIR-RED)}{(NIR+RED)},$$

where NIR is the reflection in the near-infrared part of the spectrum, RED is the reflection in the red part of the spectrum.
The information base of the study consisted of different and multi-seasonal space images of different spatial resolution, digital elevation models, topographic maps of the scale of 1:100 000 – 1:1 000 000, and cartoschemes. All results are reduced to the FE-MI_GIS database FE-MI_GIS.

The share of the most earth-intensive method of the open-pit mining is constantly increasing, in the Far East, 80% of placers are developed. Annually, more than 15000 hectares of areas are disturbed here and 2/3 of them is covered by placer deposits. Generally, there is a tendency towards the accumulation of disturbed land among the Far Eastern gold-mining enterprises. The study area was the Kerbinsky gold-bearing deposit classified as highly productive (with the predominant extraction of placer gold), which is characterized by abnormally high outbreaks within the province of gold mineralization. It is known from archival data that more than 45 tons of gold were mined here exclusively from scatterings, and now this node belongs to the man-made territories, the most promising for development [13]. The visual analysis of the territorial image allows a clear determination of technogenic areas, exploratory lines, river network, and gale-epheval dumps, concentrated in the northern part of the Kerbinsky gold-bearing region in the Kerby River middle reaches. The area covers 6075 km². In the central part of the district, the deposits are practically fully developed and some of them have been transferred to the category of man-made. According to our data, a total of 52252 kg of gold was mined in the Kerbinsky gold-bearing region, the proven reserves are 2591 kg, and the projected reserves are 35.1 tons. The area is characterized exclusively by the density of : 5.8 kg/km², linear – on reserves of 65.7 kg/pog, 455.3 kg/pog. km. The gold contents in the deposits range from 86 to 962 mg/m³. The area is characterized exclusively by the density of placer gold content: 5.8 kg/km², linear - by reserves 65.7 kg/linear km, according to predicted resources – 455.3 kg/linear km [14].

To assess the prospects for the development of technogenic deposits, the satellite images were decoded in order to identify the worked-out gold-placer areas of the Kerbinsky gold-bearing cluster based on the digital elevation model. The infrastructure map has been built. During the study, it was necessary to identify polygons of combined separate mining, hydraulic mining sites, dredging landfills, exploration areas; infrastructure facilities; power lines, roads marked on the topographic map, roads established on the basis of image interpretation and lacking on the topographic map (Figure 1).

![Figure 1. Map of the Kerbinsky gold-placer cluster](image-url)
3. Monitoring of technogenic raw materials

Analysis of the results obtained through the interpretation of remote sensing data and topographical maps has led to the conclusion that the area has been sufficiently developed. The presence of roads and power lines determines the investment attractiveness of the exploration area.

Using the software it was established that the total area of spent sites is amounted to 3600 ha. If we assume the average thickness of the tile blade to be 2 m, then the volume of technogenic raw materials can reach $72 \cdot 10^6$ m$^3$.

The development of man-made gold reserves is important for several reasons: preservation of untouched gold reserves, restoration of disturbed territories and channel flows, and availability of technogenic raw materials.

![Figure 2. Images of the section of the Kerba gold-bearing cluster in the area of the confluence of the Kerby and Briakan rivers in the Pseudomercator projection.](image)

a. Landsat 8 panchromatic image (spectral band 8) December 13, 2019
b. Synthetic colour satellite image of Landsat 8 in the same parts of the spectrum from July 7, 2018.

Waste recycling from placer gold mining can also have favourable environmental aspects. Rational planning of the technology for the extraction and processing of secondary raw materials will allow the restoration of the disturbed landscape and the ecological frame of the territory. The studies have established that in the post-technogenic period, the exploration river valleys have a great potential for natural restoration of vegetation. Therefore, there is a high probability of reproduction of the food base and attraction of wild animals to historical habitats.

For a qualitative analysis of the exploration area and an increase in the man-made dump areas, the images were considered using various combinations of data channels (Figure 3).

Based on preliminary studies, a set of 6–5–4 stripes provides the most contrasting selection of displaced soil during mining and a clear image of open water (almost black). We could not find a high-quality image of the 2019 summer period, so a panchromatic image from December 13, 2019 was used.

Its diagram shown in Fig. 6 is optimized by choosing a lower threshold of 5800 and an upper threshold of 12177.

Based on these images, the monitoring of the increase in the areas of production polygons was carried out from 2013 to 2019. To do this, the image was re-projected into Pulkovo-42 and the work areas were vectorized manually, followed by the area calculation in QGIS. The result is shown in figure 4.

Thus, the man-made dump area was 626.825 ha in 2013–2014, 283.384 ha in 2018, and 160.613 ha in 2019. Thus, a decrease in the man-made dump area was 59 % in 2018, and was 43 % in 2019 relation to 2014. A decrease in the man-made dump area is associated with the natural restoration of vegetation in the territory under consideration. So, a decrease in the disturbed land area by 466, 212 ha can be
regarded as an increase in the naturally restored area covered with vegetation over 6 years. To confirm this version, we carried out an NDVI study in the territory of the Kerby gold-placer cluster (Figure 5).

Figure 3. Mining areas of the Kerby gold-placer cluster. Interpretation of Landsat 8 satellite images. Basis: Digital elevation model (DEM). Digital elevation map based on DEM SRTM03. 1–production sites in 2018; 2–production sites in 2019; 3–production sites in 2013–2014; 4–exploration areas 2013–2014; 5–names of large streams

Analyzing the data obtained, we may conclude that for the studied time interval of 2001–2020, there is a positive trend towards an increase in the vegetation index. In addition, the forecast for the change in the index until 2025 indicates the continued positive dynamics.

The aim of the work was to substantiate the possibility of assessing the reserves of technogenic raw materials of placer gold based on the information and computational logging, and remote sensing data.

Relying on the data obtained, it was possible to make a preliminary calculation of the reserves of technogenic raw materials in the exploration area. Using the software, the total area of the worked out areas was determined amounted to 3600 hectares. If to assume the average thickness of the tile blade to be 2 m, then the volume of technogenic raw materials can reach 72·10⁶ m³. According to the inferred data, the gold content in the deposits ranges from 86 to 962 mg/m³, the value close to the minimum 100 mg/m³. Accounting for the man-made dump volume, we assume the possibility of extracting at least 7 tons of gold from man-made raw materials. In this case, this ensures the environmental safety of the process of secondary processing of technogenic raw materials by restoring the original river channel when moving technogenic dumps.

4. Conclusion
An analysis of the dynamics of the indicators of the vegetation state on the dumps of the goldfish allowed the conclusion that the natural restoration processes occur here quite quickly, every five years a
significant update of the species composition of secondary phytocenoses is recorded. The positive dynamics of the NDVI has been recorded throughout the entire period of the study. Natural and climatic factors have a significant impact on the processes under study, the analysis of the average values of the index for the observation areas have provided forecasting an index increase in the short term. The graph (Figure 4) clearly shows the NDVI growth in predicted values until 2025. The authors assume that in the next five years the indicator will be stable with minor fluctuations within ±0.05.

![Figure 4](NDVI.png)

**Figure 4.** The graph showing the NDVI in the study area within the Kerby gold placer cluster

Under a combined condition that ensure active restoration of vegetation, the process of natural restoration is dynamic and has a positive outlook.

We consider reasonable to involve in the processing of technogenic placers in terms of economic and environmental parameters. The recycling of dumps poses a lower environmental hazard for the components of the natural-technical system than the involvement of new sites in the processing. To ensure the highest possible level of environmental safety of the technology, it is necessary to develop a rational set of preventive measures.

The performed studies based on the information and computational GIS have indicated a stable natural restoration of vegetation, which is due to some factors. The main factor is the location of the site in the taiga zone, which is characterized by dense diverse vegetation, exerting powerful pressure on bare areas for quick and high-quality restoration. The authors consider reasonable developing technogenic deposits, because it will allow the preservation of the existing reserves and intact natural complexes in the regions of such technogenic areas.

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