

ESTIMATION OF WATER AREA INCREASE BY REMOTELY SENSED DATA IN THE NON-OPERATING OPEN PIT MINES MEDET AND KREMIKOVTSI

Denitsa Borisova¹, Hristo Nikolov¹, Banush Banushev², Doyno Petkov¹

¹Space Research and Technology Institute, Bulgarian Academy of Sciences, 1113 Sofia; dborisova@stil.bas.bg

²University of Mining and Geology "St. Ivan Rilski", 1700 Sofia; banushev@mgu.bg

ABSTRACT. Abandoned open pit mines create serious ecological risk for the region of their location. This is valid especially for the quality of the water since the rainfalls together with underground waters fill the open pit and form water body with different depth. The examples for such opencast, inactive mines are the copper mine Medet and the ferrous mine Kremikovtsi. There are many cases reported for water and soil pollution by heavy metals in the rivers running close to these open pit mines after autumn and spring rains. This justifies the need for long term and sustainable monitoring of the area of the water basins of these unused mines in order to estimate its acid drainage. The imaging spectroscopy combined with in-situ investigations is proved to provide reliable results about the area of the water table. In this study we have investigated multitemporal data gathered by remote sensing which allowed us to make conclusions about the year behavior of both areas. The team expects that the results of this research will help in the rehabilitation process of the inactive mines and will provide the local authorities engaged in water quality monitoring with a tool to estimate the possible damage caused to the local rivers and to the soils in the neighboring areas.

ОЦЕНКА НА ПРОМЯНАТА НА ВОДНИТЕ ПЛОЩИ ПО ДАННИ ОТ ДИСТАНЦИОННИ ИЗСЛЕДВАНИЯ ЗА НЕРАБОТЕЩИТЕ РУДНИЦИ МЕДЕТ И КРЕМИКОВЦИ

Деница Борисова¹, Христо Николов¹, Бануш Банушев², Дойно Петков¹

¹Институт за космически изследвания и технологии, Българска академия на науките, 1113 София; dborisova@stil.bas.bg

²Минно-геоложки университет "Св. Иван Рилски", 1700 София; banushev@mgu.bg

РЕЗЮМЕ. Изоставените открити рудници създават сериозен екологичен риск за региона, където са разположени. Това важи в голяма степен за качеството на водата, тъй като валежите заедно с подземните води запълват открития рудник и образуват водно тяло с различна площ, дълбочина и химичен състав. Примери за такива открити неработещи рудници са Медет (медна руда) и Кремиковци (желязна руда). Има много случаи, в които водата и почвата са замърсени с тежки метали от протичащите в близост реки до тези открити рудници, особено след обилни есенни и пролетни дъждове. Това обосновава необходимостта от дългосрочно и устойчиво наблюдение на района на формираните водоеми в тези неексплоатирани рудници, за да се оцени промяната на рН на водата. В настоящото изследване са използвани многоканални изображения, комбинирани с in-situ измервания, за които е доказано, че предоставят надеждни резултати за площта на водното тяло. В това проучване сме използвали времева поредица данни, събрани чрез дистанционни изследвания, което ни позволи да направим изводи за целогодишното поведение в двата рудника. Екипът се надява, че резултатите от това изследване ще подпомогнат процеса на рехабилитация на рудници извън експлоатация и ще предостави на местните власти, ангажирани в мониторинга на качеството на водите, инструмент за оценка на възможни щети, причинени на местните реки и почви.

Introduction

All human developed technological processes make sensible impact to the environment. This holds true especially for the mining sites irrespective of the method of their exploitation – open or underground. In both cases huge amount of supernumerary product is generated – top soil, waste rock, and lean ore. According to the EU legislation the "management of mining waste disposal facilities must take into consideration long term environmental issues, because these structures will more than likely survive both the mine and the mining company" (BRGM, 2001). In this study we focus our research on the long term impact of the water basins formed into two of abandoned mines in Bulgaria – a copper one and a ferrous one. The mentioned water started to accumulate into the pit of copper non-operating mine Medet since 1996 and into the pit

of ferrous inoperative mine Kremikovtsi since 2000. The above mentioned observation was ascertained first by multispectral data from remote sensing and after that by in-situ inspection too. In the past decade based on the same data and auxiliary ones we observed a steady increase of the area occupied by water table at both sites. The conclusions we make as results of this study are solely based on the satellite and aerial data since the region where the abandoned mines are located is considered to be of restricted access because it is inside of the mining complexes. In the framework of this research our main task was to estimate the approximate areas inside the pits filled by the water. We believe that this information would help in making future assessments on the possible effect on aquifer/s in the area and on the hydrographic network in the region. Because of lack of data collected from the water basins

we could not assess the proportion water/sludge inside the pit neither the concentration of the dissolved minerals.

Materials and methods

First site of interest is part of the Srednogorie metallogenic zone (Fig. 1). This zone is located in the central part of Bulgaria and belongs to Apuseni-Banat-Timok-Srednogorie belt, into which one of the Europe's' richest porphyry Cu and Cu-Au epithermal deposits are located (Strashimirov et al., 2002; Попов и др., 2012). In the Srednogorie zone and more specifically in the Panagyurishte ore district, situated 60-90 km east of Sofia, the ore deposits exploited contain mainly Cu and Cu-Au-Mo. In this region 150 ore deposits, ore occurrences and mineral indications are found and documented.



Fig. 1. Metallogenic zones in Bulgaria (after Bogdanov, 1982; Bird et al., 2010)

In the said district three companies are engaged in copper mining, ore dressing and concentrate production exploiting the Elatsite, Assarel and Chelopech deposits. Since the start of active mining activities in the 50-ties of the last century from the Panagyurishte district over 460 Mt of Cu-Au ore was mined out. This amount is about 95% of the total Cu and Au production of Bulgaria (OMENTIN, 2001). The basic geological features that controlled the spatiotemporal development of metallogenic processes in the Panagyurishte ore region are determined by the features and evolution of the Upper Cretaceous magmatic complexes (Popov et al., 2003; Попов и др., 2012).

The focus of our research is set on the recent developments inside of the open pit mine of Medet deposit. It was surveyed in the early 60-ties and started its production in 1964 being the biggest copper producing mine in Europe and third largest in the world at that time. For first time in this open pit mine extraction and processing of copper ores with cut-off grade lower than 0,4% was organized. This practice for processing such ores was later widely adopted. The experience for exploration and mining complexes construction gained on this site was implemented on other mine plants across Bulgaria during 60 and 70-ies of same century. The Medet Mining and Processing Complex worked with its full capacity from 1972 to

1983. After 1984 it started to decrease production and in 1994 the open pit mine Medet was closed.

Taking into account the geological information it was found that the main enclosing rocks in the Medet deposit are South Bulgarian granites (Попов и др., 2012). The studied granite samples exhibit pinkish color, are medium-grained and their average composition, confirmed by laboratory analyses, is 50% orthoclase, 35% quartz, 15% plagioclase, 1% biotite and 1% magnetite. The main soil type in the area of Medet is brown sandy loam. The parental material of the soil sample studied is granite. This soil sample had moderate to coarse prismatic structure, very hard and friable with neutral pH (6.5) having the following composition – 1% organic carbon, 12% clay, 25% silt and 62% sand.

The second site targeted in this study is the abandoned open pit mine situated near the capital of Bulgaria, Sofia namely the Kremikovtsi ferrous mine. Kremikovtsi is a complexly barite-iron deposit. Ascertained are the following ores – hematite, siderite (manganese-siderite), ankerite, limonite, barite, oxidized lead and partially oxidized sulfide copper-lead (Панайотов, 1969; Канурков, 1988). The hematite ore forms compact bodies with dimensions 400 x 200 x 40 m located in the northwest part of the deposit. The ore itself is composed mainly of hematite and lesser of components like barite, siderite (manganese-siderite), goethite, calcite, quartz, and pyrite. The smaller quantities are those of galena and chalcopryrite (Канурков, 1988). The siderite (manganese-siderite) ore forms irregular bodies located in the low southern levels of the deposit. It is characterized by a heterogeneous composition manganese-siderite being the predominant mineral. Secondary minerals are barite, quartz, dolomite, calcite, siderite, hematite, pyrite, galena, chalcopryrite (Канурков, 1988). The ankerite ore is the poorest iron ore. It is composed by ankerite and ferro-dolomite having impurities of quartz, barite, calcite and dolomite (Канурков, 1988). On Figure 2 is shown the spatial distribution of different ore types in the Kremikovtsi deposit.

The data used in framework of this research came from various sources most of them being with free access or created by the authors based on such ones. Initially multispectral, multitemporal data from TM (Thematic Mapper) and OLI (Operational Land Imager) instruments onboard Landsat series satellites were used. They were obtained from websites hosted by USGS in geotiff format processed up to

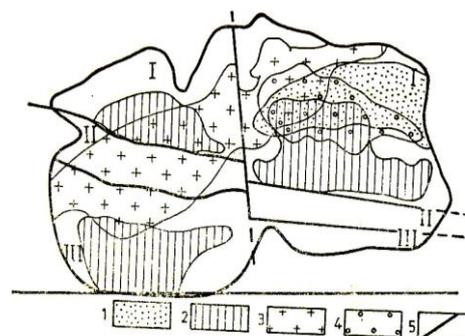


Fig. 2. Spatial distribution of different ore types in Kremikovtsi deposit (Панайотов, 1969): 1 – lead; 2 – siderite; 3 – hematite; 4 – barite; 5 – fault

level L1T. These data provided the principal information on formation, development and multitemporal behavior of the water body inside the non-operating Medet and Kremikovtsi open pits. Although the spatial resolution of the data, being 30 m, of the TM/OLI data did not allowed us to make precise delineation of the said water basins it provided grounds to convince us that process their of formation had started not long after the exploitation had stopped and is currently ongoing. Other source of raster data is the orthophoto made in year 2006 on which the size of the water area was measured with precision less than 1 m. For verification purposes images from Google Earth were also used in determination of the size of the water table during the years.

Several vector layers based on the above mentioned raster ones were created in order to be able to calculate the increase of the area of the water. We tried to obtain the height of the water body inside the pits for different years and for this reason some additional vector layers were created from topographic maps despite their poor accuracy. But the results obtained this way were considered not to be reliable and accurate and this why they were not included in the outputs reported.

Results

For Medet open pit year 1995 was selected as reference, because for first time in that year several pixels (corresponding roughly to 1 ha) with spectral reflectance typical for water were found. In 1999 by data processed by same method it was doubtlessly proved that at the bottom of the open pit a water table has formed. This positive trend in water table increase was determined by sampling the area of the mine for pixels corresponding to typical turbid water (*USGS spectral library, 2013*) in data from years 2006, 2011 and 2013. The results for 2006 were checked and affirmed by other raster data too – the orthophoto high spatial resolution of 0,6 m.

In Kremikovtsi open pit mine two separated water bodies having different size were detected using remotely sensed data since year 2006. As ascertained by data from 2013 they already joined and formed one water body. Here the same procedures applied in the investigation of the open pit Medet were used. The results we obtained for the water table areas in Kremikovtsi are presented as sum value of the two bodies.

The only thing that could be ascertained by the data we processed was that the water present into Medet open pit is expected to behave spectrally as turbid water (Fig. 3). This conclusion was confirmed by two facts – spectral reflectance of the water body as in autumn of 2011 and web site publication that states “the water level in the Medet mine in 2010 is about 160 m” we consider enough for deposition of the heavy particles.

In Figure 4 the reflectance spectra of water body in the open pit mine Kremikovtsi is compared with the spectral reflectance of the reference water body in the region of interest. The behavior of the reflectance signature of the reference water and of the water in the open pit is one and the same. We could conclude that the water present into the second open pit is more likely to behave spectrally as clear water (*USGS spectral library, 2013*).

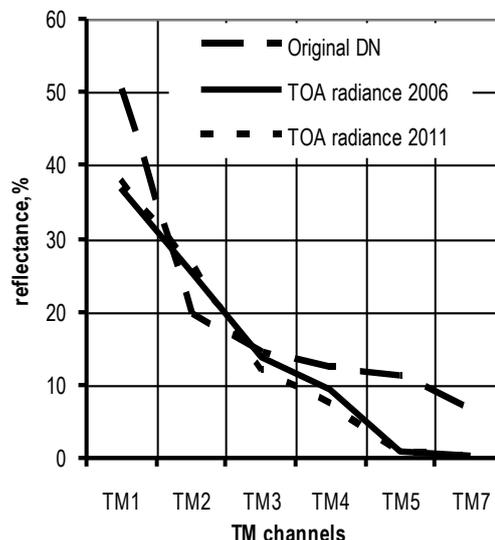


Fig. 3. Spectral reflectance of water body in the open mine Medet

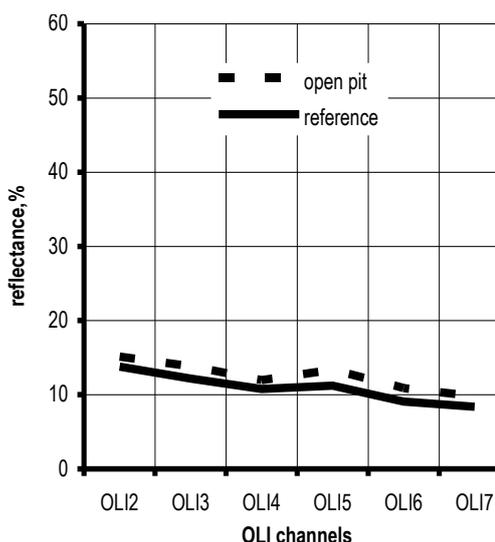


Fig. 4. Spectral reflectance of the reference water body and of the water body in the open mine Kremikovtsi

The results for the changes of the water table areas in the two inoperative open pit mines Medet and Kremikovtsi are summarized in Table 1.

Table 1. Observed increase in water table areas [ha] in inoperative open pit mines Medet and Kremikovtsi

Year	1995	1999	2006	2011	2013
Medet	1,1	13	26,3	36,3	36
Kremikovtsi	-	-	6,6	11,6	19,4

Conclusions

The water table areas in the monitored open pit mines Medet and Kremikovtsi show stable increase starting from their discontinuing. As seen on Figures 3 and 4 the water behaves differently which might be due to different way the rocks react with water. In the Medet case one may conclude that the embedding rocks dissolve more rapidly in water, but this must be proved by direct in-situ sampling.

This research should catch the attention of the public due to high risk posed by the increase of the volume of the water collected in the pit which can overflow in the next years. We plan to apply in our next studies passive microwave radiometry used for dykes monitoring as tool for assessment of the moisture content in the soils and rocks surrounding the open pit thus estimating the extent of the underground water spreading.

The present study points at the need to monitor the water in the closest rivers and springs at regular basis for contamination by metals. Inclusion of the water body in the open pit Medet as separate class 511 in the next phase of CORINE project is recommended.

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