VEGETATION INDICES AS A MEANS OF MONITORING OF OBJECTS IN THE REGION OF OPEN PIT MINES

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ABSTRACT. The article discusses the essence, characteristics and applications of vegetation indices in analysing and assessing the state of vegetation. Photographs of forest and agricultural areas were taken by an unmanned aerial system equipped with an optical and multi-spectral camera. The advantages and disadvantages of the methods under consideration have been structured and the main applications related to the monitoring of such areas have been listed. The proposed method will help establish the reason/s of for the occurrence of environmental disturbances. They will also help solve various cases associated with ecological problems in mining.

Keywords: vegetation indexes, open pit mine, monitoring

ВЕГЕТАЦИОННИТЕ ИНДЕКСИ КАТО СРЕДСТВО ЗА МОНИТОРИНГ НА ОБЕКТИ В БЛИЗОСТ ДО ОТКРИТИ РУДНИЦИ

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РЕЗЮМЕ. Статията представя същността, особеностите и приложението на вегетационните индекси за извършване на анализ и оценка на състоянието на растителността. Извършени са заснемания с безпилотна летателна система с оптична и мултиспектрална камера на горски и селскостопански площи. Структурирани са предимствата и недостатъците на изследваната методика и са изброени основни приложения, свързани с наблюдението на такива площи. Предложената методика ще помогне за откриване на причината/ите за възникване на нарушения в околната среда и за решаване на различни казуси обвързани с екологични проблеми в минния добив.

Ключови думи: вегетационни индекси, открит рудник, мониторинг

Introduction

The mineral resources of a country are closely connected to its sustainable development and are the subject of research of various specialists. With the increasing needs of the population, the need for supplying more raw materials increases. This determines the search for new natural sources and their exploitation, which is directly related to the provision of a favorable living environment for all living organisms. Very often, the discussion or the mere mentioning of the mining industry is associated with pollution and/or environmental disruption. Other human and natural factors also affect the natural balance. In order to find out the exact cause of these violations, it is necessary to monitor forestry objects and agricultural sites which usually fall in the vicinity of open pit mines and quarries. The persistent monitoring, exploration and analysis of these territories is a responsible task for both environmentalists and mining professionals.

Various ways exist to perform periodic monitoring of areas occupied by forest and agricultural vegetation. Some are related to field measurements, others to remote analysis. Traditionally, satellite images are used to monitor and analyse vegetation for large areas (on a global and/or regional level). They usually provide low spatial resolution data.

The alternative to the previously mentioned methods for monitoring of objects near open-pit mines for a shorter period and with high spatial resolution are unmanned aerial systems. Equipped with miniature compact cameras not only in the visible but also in the invisible area of the electromagnetic spectrum, they are used for the vegetation analysis (Mahajan et al., 2016). Their appearance broadens the monitoring capabilities and allows to solve tasks of a different nature, like the implementation of precision farming and the monitoring of forest areas. Such equipment can also be used for the analyses of environmental problems and solving cases near mining sites. These uses are predetermined by the advantages and disadvantages of the methods.

Advantages and disadvantages of the methods

Advantages:

- *Flexible*

Remote sensing as a whole can be used to distinguish between different crops and to assess areas.Territories with complex farming systemsare more difficult to be traced when viewed through satellite images with low spatial resolution and temporal resolution and the occasional presence of clouds in images. This imposes the need of systems for data registering which are faster and cheaper when capturing smaller areas (Greenwood, 2016).

- *Providing high spatial resolution data*

The unmanned aerial systems (UAS) provide a high spatial resolution that allows differentiation of various cultures using optical and multi-spectral cameras. The high resolution allows for detailed monitoring and analysis of forest and agricultural areas. By means of UASaccurate numerical surface models can be generated that can be used to track soil erosion, obtain information related to surface water removal, etc. This information will help identify the causes of stress in plants.

- *Time saving*

Usually, the periodic monitoring of agricultural and/or forest areas is performed by field measurements or by walking across the field itself. Sometimes this is difficult due to the nature of the relief, the total area of the site, or to other factors. In other cases, this is even impossible. The use of UAS allows to capture such territories and to significantly reduce observation time.

- *Continuity of information*

For the purposes of the analysis, it is very important to obtain data not only on the individual parts of a certain territory, but also to maintain the continuity of the information. UAS easily solve this task by providing overall territorial observation (Puri et al., 2017).

- *Health status tracking, vegetation vigour monitoring and yield increase*

The maps of vegetation indices provide quality tracking of the health status and vitality of forest and agricultural vegetation. The 3D models and orthophotomaps produced are also an important tool for establishing the water flow and the irrigation, for visual distinguishing of crops, and so on. Combining these data (optical and multi-spectral) from different capture periods will allow for an in-depth analysis of the state of vegetation near mining plants.

- *Assessment of the damage to agricultural and forest areas as a result of various disasters*

UAS data can be used to evaluate area damage due to various factors and, based on historical data, to compile statistical models related to risk management.

- *Effective and cheaper method*

The capture method is effective and less expensive in comparison to the traditional method that uses high resolution multi-spectral space images. It ensures an increase in data for different periods of time and reduces the cost of periodic monitoring of agricultural and forest areas. This also accounts for the tendency for an increase in the number of consumers who apply these methods.

Disadvantages:

- *Capture conditions*

Capturing can not be performed under the same environmental conditions (flights take place in different seasons, under varied climatic and weather conditions, and at different times of the day) and at standard settings during each flight.

- *Availability of an operator*

For performing the capture process, an operator is required to guide the capture itself.

- Illiteracy and disinterest

There are specialists in various fields of industry, agriculture, forestry and the environment, and other spheres of life in Bulgaria who are not yet aware or unable to apply these new methods.

This technology is a good tool suitable for application in the mining industry which is invariably related to sustainable development. This concept is subject to various interpretations. Initially, it was regarded as a way of using natural resources that would help meet the demands of today's and future human generations while preserving the natural balance in the environment. Gradually, its content began to expand. Objectively and more readily, this concept has begun to be seen as the focal point for the fundamental issues on which the present and future of mankind depends. Today we can say that, in its essence, it represents a new outlook paradigm for the further development of human society. A series of UN and EU solutions for sustainable development are a good basis for establishing national action programmes in the separate countries. Still, real and targeted actions on a national scale are too few, although a number of associations, scientific and educational structures and other organisations have been involved in fruitful action in this area (Josifov, 2016). Therefore, any new idea that has a positive effect on sustainable development is valuable to the society.

Monitoring of the state of vegetation is significant not only from an ecological point of view, but is also important for the sustainable development. The combination of unmanned aerial systems and multi-spectral cameras is an appropriate tool for the monitoring of vegetation near open pit mines by creating maps of the vegetation indices that determine the status, condition and variation of vegetation.

Capturing and processing of dataNDVI Vegetation Index Applications

The plants absorb light in the visible area and reflect it most strongly in the near infrared range of the electromagnetic spectrum. Dehydration or the influences of other external factors lead to a disruption of their natural state, and they cease to reflect light so strongly. Depending on the channels of the electromagnetic spectrum, a number of vegetation indices exist (NDVI, ENVVI, GRRVI, LAI, SAVI, GNDVI, NDRE, EVI, REDDVI) that have different applications. They primarily serve to determine the vitality and health of vegetation. The most common is the NDVI vegetation index. It provides information about the presence of stress caused by various factors. This method converts the reflective characteristics of each pixel in the image that are associated with the particular type of vegetation. The resulting NDVI images provide primary information which is analogous to field observations aimed at determining plant status. These images contain useful information to distinguish areas occupied by different types of vegetation - forest, agricultural, pastures, meadows, etc., i.e.

as a means of visualising spatial variability. They are employed in identifying critical areas affected by pests, diseases, fires, over-saturation, drought, or other factors disturbing their natural balance.

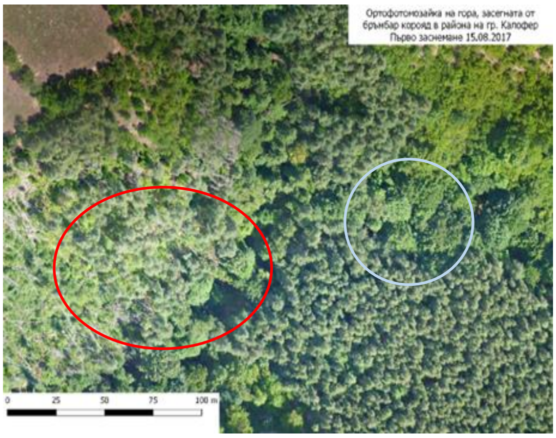
These data serve to carry out in-depth analyses related to the state of vegetation and can be a valuable tool for vegetation monitoring in the vicinity of opencast mines and quarries. The creation of a database over a long period of time will help solve ecological cases that are directly related to the impact which opencast mining does or does not exert on the plant and animal world and on the human living environment. This will be a good basis for the establishment of a national action strategy aimed at preserving the natural balance of the environment as a key objective of sustainable development.

Forest and agricultural areas are often to be found near the opencast mines. This requires the tracing of their life status in order to identify possible disturbances in their condition caused by various factors such as pollution, pests, deforestation, and others. Experimental results are presented, which have been obtained through capturing with the DJI Matrice600 Pro hexacopter-type of unmanned aerial systemequipped with optical and multi-spectral camera. The terrain is captured with an optical 16-megapixel camera and a 5-channel multi-spectral camera.

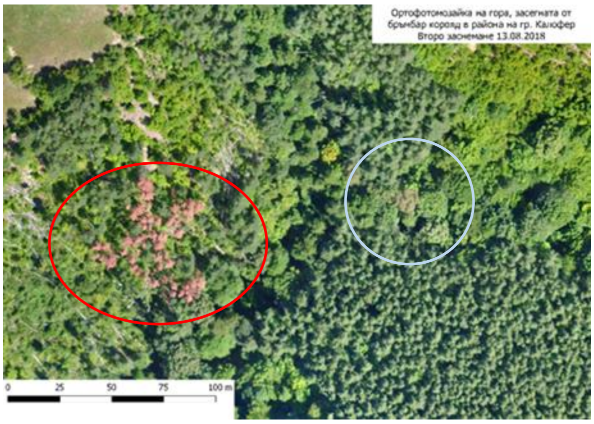
Applications of the vegetation indexes in the study of forest vegetation

The red and the adjacent infrared channels are two of the most informative channels for detecting the presence of tree stress caused by bark beetle infestation. The NDVI vegetation index has experimentally been shown to be one of the indices that shows the clearest distinction of the main categories of healthy, contaminated and dead forest (Minařík et al., 2016).

The study involves capturing of mixed coniferous and deciduous forests located north-west of the town of Kalofer in two consecutive years.The purpose is to identify and monitor areas with coniferous trees infested and destroyed by bark beetle. Within the period between the two surveys, a new region infested by bark beetle has been observed in the central part (Figure 1). The probable cause of the infestation of the new site is the removal of felled contaminated wood in this area (bottom left), as well as the pest favourable nutrient medium in this area.



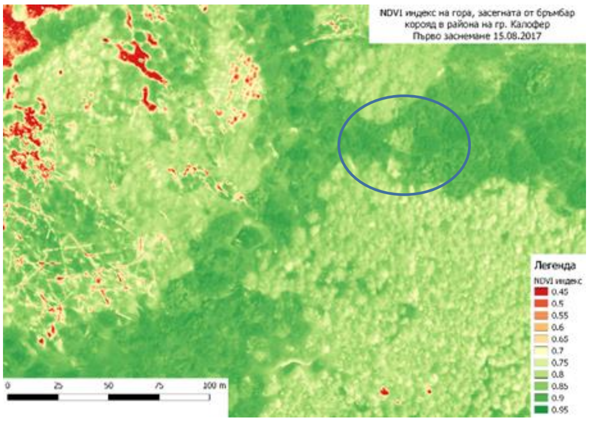
a)



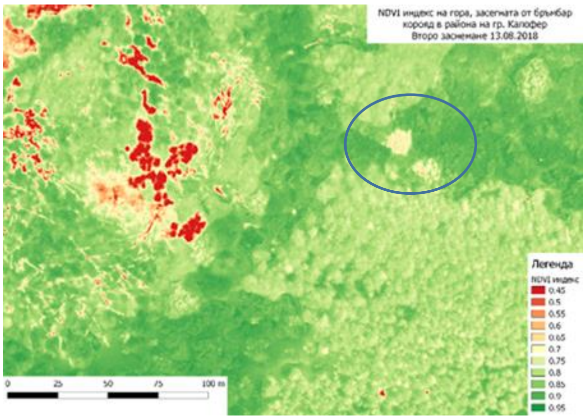
b)

Fig. 1. Orthophoto mosaic of a region affected by bark beetle in the central part of the surveyed territory in mid-August: in 2017 (a) and in 2018 (b), respectively

The area outlined in red on the two pictures shows the appearance of a new area affected by bark beetle in the central part of the surveyed area, which is not visible in the original shot in 2017 – Figure 1(a). The area outlined in blue shows trees that were healthy in 2017 and were infested in 2018 and can not be easily identified on the optical images but they are clearly visible on the NDVI map in Figure 2.



a)



b)

Fig. 2. Maps of the NDVI index in the central part of the surveyed territory in 2017 (a) and in 2018 (b), respectively

The NDVI index mapin Figure 2a is derived from the 2017data, and the one in Figure2b is from 2018. The NDVI map from 2018 shows infected trees outlined in blue that can not be easily identified as such from the optical images in Figure 1.

The results of the study show that, compared to satellite data, the multi-spectral images obtained from capturing with an unmanned aerial system make a good alternative for remote observation. They can be used for early detection and mapping of small diameter infected areas. This will make it possible to take timely preventive measures to limit and eliminate pest attacks or other external factors (Gospodinova et al., 2018).

Other studies exist that are related to the monitoring and determining of the status of forest vegetation by using various vegetation indices and classification methods (Gospodinova et al., 2018; Dash et al., 2017; Rudolf et al., 2015; Brovkina et al., 2018; Xiao et al., 2005; Minařík et al., 2016). The combination of optical and multi-spectral data broadens the scope for analysis, such as distinguishing coniferous from deciduous tree species in mixed forest surveillance. Performing field measurements, combined with optical data (orthophoto mosaics), along with theclassification methods, allow the creation of maps that contain the individual species of forest vegetation and reflect their current state (Brovkina et al., 2018).

The relatively easy, fast and cost-effective generation of NDVI images, their analysis and reliable classification are a promising pest detection tool that will facilitate forest management in the future and save time and finances by more than 50% (the percentage will be significantly higher in the case of almost inaccessible forestated areas, even if investment in equipment is taken into account) (Rudolf et al., 2015).

A methodology was presented, which used color compositions, including NIR and SWIR spectral bands to identify areas affected by pests (bark beetle) for two forest sub-regions in Western Bulgaria. A computer-assisted interpretation of the multitemporal satellite and aerial digital images was performed using the methodology, software and images of the CORINE Land Cover 2018 Project. All coniferous forests in the study area (larger than 5 ha), which were damaged in the period 2012-2018, were detected and mapped. The obtained results were compared to ground data. They demonstrated the suitability of the approach in comparison to traditional ground observations, in terms of accuracy, time and money (Tonchev et al., 2018).

To support local GIS users in forestry, the indexed NDVI images can be distributed through an image mapping web service according to the standards of an open geospatial consortium (OGC). Raster data obtained from unmanned aerial systems can be exported in such a format that would ensure the compatibility between the ArcGIS server (ESRI 2014) and the GEO server (OGC 2014). In this way, potential users can easily combine these maps with theirs in order to provide a perspective of the studied areas over a long period of time (Rudolf et al., 2015).

All these studies demonstrate the potential of the vegetation index maps for forest surveying and monitoring. The multispectral data from unmanned aerial systems, especially in the presence of symptoms such as defoliation and altered reflectivity of the foliage, will be increasingly used in the development of forest monitoring strategies. This approach also offers an inexpensive alternative to private owners of forests who aspire to a sustainable management strategy.

Future developments are related to the creation of a three-dimensional NDVI model of forest areas which will further enhance the monitoring and analysis capabilities up to the level of monitoring each individual species of vegetation (https://www.suasnews.com/2016/12/pix4d-parrot-explore-vegetation-research-3d-ndvi/).

Applications of vegetation indices in agricultural crop surveys

NDVI images are widely used in tracking the living status of various crop types – flat-sown, trench, vegetable, orchard, etc. (Kavvadiasa et al., 2017; Nasir et al., 2017; Duchsherer, 2018; Agüera et al., 2011; Vega et al., 2015; Primicerio et al., 2012; Allah et al., 2015). They demonstrate the applicability of the observation methods for a particular crop during the growing season, as well as their application to precision farming.

Other vegetation indices and algorithms exist that serve to determine the viability of plants and to solve specific tasks in agriculture (Mookherjee, 2016; Papadopoulos et al., 2014; Lelong et al., 2008; Rogers III, 2013; Greenwood, 2016; Wahab et al., 2018; O'Halloran, 2016; Candiago et al., 2015; Shafian et al., 2018).

One of the most important tasks in agriculture is the use of herbicides that can have a negative impact / have side effects on the biotic and abiotic environment and can be hazardous or harmful to human health. Therefore, reducing their quantities in modern agriculture is an important step towards its sustainable development (Lottes et al., 2017).

Establishing the exact cause of a violation committed on agricultural vegetation in open-cast mining areas is of a particular importance for taking the necessary measures to restore it.

A study was carried out to analyse data from a multi-spectral camera, to track the growth of field crops, and to give recommendations for production enhancing. The subject of the survey is a field in the Pleven region of approximately 850 decares sown with rape seed.

From the data obtained, a map of the NDVI index was generated in a georeferenced TIFF format with a resolution of 17 cm per pixel (Fig. 3), and also a digital surface model (Fig. 4).

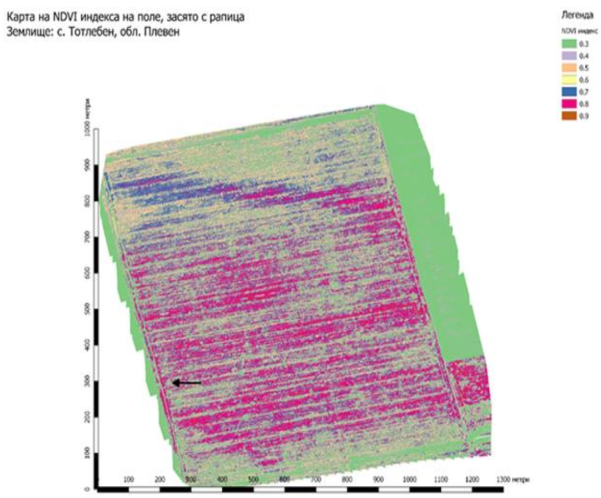


Fig. 3. Map of the NDVI index obtained with the data from the multi-spectral camera. The arrow shows the location of the flight site

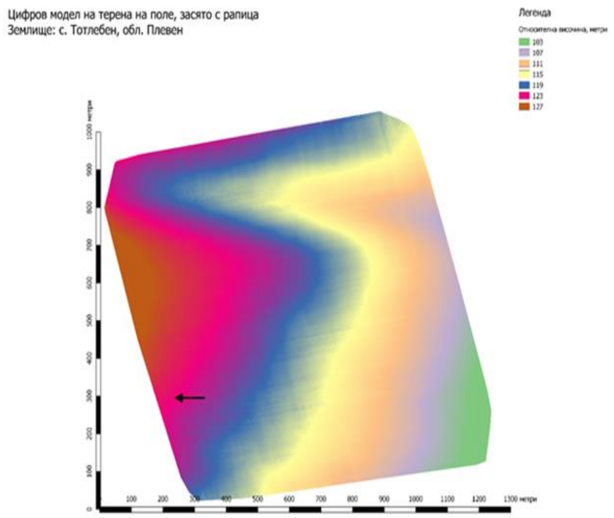


Fig. 4. Digital Surface Model (DSM). The lowest area of the surveyed region is in the southeast, and the highest is in the northwest

The site under investigation is arable land planted with clearly visible vegetation at the time of capture: rape which is uneven due to poor sowing and pre-sowing preparation. The NDVI culture index is 0.8. The phase is 6-7 sheets. Values with an index lower than 0.7 correspond to poorly developed rape due to retarded germination or to phosphorus deficiency (spots or belts). An NDVI index of 0.5-0.6 corresponds to dried vegetation. The old leaves have a bright pinkish-violet colouration, indicating that they have started to dry. The uneven phosphorus intake, or phosphorus malnutrition, is due to the erosion processes in this field and to the rising of lower soil horizons to the soil surface. Sowing is done on the slope, thus further enhancing terrain erosion and profile flushing.

The results of the laboratory analyses of soil samples show that the soil in the studied plot is a typical black earth. But according to the mapping material, this particular field is predominated by carbonate black earth. Black earth is an alkaline soil, so urea is not used. The analyses show phosphorus deficiency and low nitrogen amounts (therefore, it is good to compensate for the amount of nitrogen in the soil in spring). Ammonium sulphate should have been introduced with the basic fertilisation in autumn. Ammonium nitrate should better be employed in feeding. It is advisable to make a more detailed study of the soils. There are two main species of weeds whose density is 0.5 -1 per square meter and is thus below the harm threshold.

A survey has been carried out of a single array (approximately 500 decares) in the district of Veliko Tarnovo sown with wheat in the stage of intensive growth. The aim is to capture the whole terrain with a multi-spectral camera mounted on an unmanned aerial vehicle. On the basis of the obtained data, a NDVI index map has been drawn and analysed that characterises the agro-ecological state of the terrain, the strength and resistance of the crops. Also, a combined aerial photography has been taken for the purpose of visualisation. After data processing, the following have been obtained: a map of the NDVI index (Fig. 5) in a geo-referenced TIFF format with a resolution of 15 cm per pixel and an orthophoto mosaic (Fig. 6) with a resolution of 3 cm per pixel.

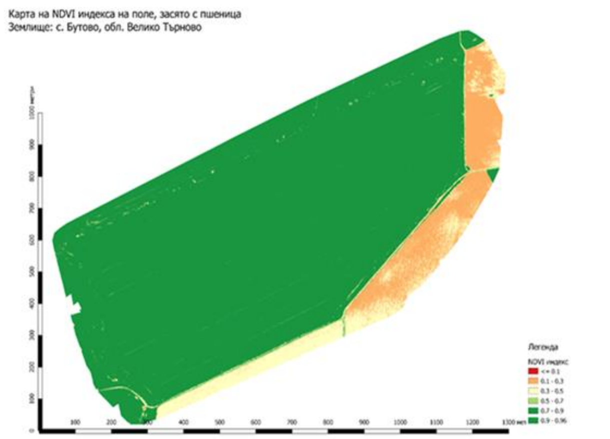


Fig. 5. Map of the NDVI index obtained with data from the multi-spectral camera

Fig. 6. Orthophoto mosaic of the terrain obtained with data from the optical camera

The analysis of the data has shown that the wheat crop is well developed. No morbidity has been observed. There has been no weed vegetation above the harm threshold.

All of these studies show that such technologies raise farm management to a higher, modern level, increasing their profitability and enhancing the healthy crop production.

The storage of information from different vegetation indices over a long period of time will help automate data interpretation and improve the status of vegetation, as well as identify the cause/s of various breaches.

Methods for the monitoring of territories in the vicinity of opencast mines and quarries through a combination of optical and multi-spectral data

Very often, the effect of mining on the environmental pollution is capitalised on; yet, there are cases where breaches are committed and violations do occur. For this reason, it is essential to carry out periodic monitoring of the areas where there is an opencast mining of minerals. The traditional method of observing the state of the land cover (namely, of the vegetation) is through remote sensing, in particular, through satellite imagery (Suh et al., 2017; Koruyan et al., 2012; WuB et al., 2009; Baodong et al., 2009; Whiteside et al., 2016; Yang et al., 2018). The disadvantage of this method is low spatial resolution that is inappropriate for certain tasks, the lack of flexibility in data acquisition and processing (e.g. the presence of shadows in some images that are an obstacle in subsequent analyses, etc.). However, with the dynamic development of unmanned aerial systems, these obstacles can be eliminated, especially when performing local capturing.

The modern open-cast mining technologies include mining operations that lead to changes in the land cover (forest biomass, soils, etc.) for a very short period of time, affecting neighboring habitats. A method is available for capturing open pit mines, quarries, and adjacent areas through UAVs using an optical and multi-spectral camera. The combination of images extends the scope for analysis as presented in the above-mentioned studies. Indexed vegetation images can serve not only to track rehabilitation processes (deforestation, afforestation decision making, and actual afforestation), but also to monitor these areas and solve various environmental cases during the expiration period. They will help identify the causes of vegetation disorder in the vicinity of open pit mines and quarries, as well as find such a solution to the problem that will appropriately ensure the yield continuance. Providing timely and valuable information on the impact of mining activities in a particular area will also be beneficial to ecologists and to the mining companies themselves, especially since the latter are often erroneously referred to as environmental pollutants.

The remote sensing systems and the geographic information systems play an increasingly important part in the management of mining. Their joint application provides information and statistical data to assess habitat diversity and land-cover change. This information can be used to formulate policies and guidelines on land management, monitoring, reclamation, and landscape preservation.

Conclusion

Mining is invariably related to sustainable development and ecology. These issues are discussed at almost every mining conference, whereby various results, analyses, and specific solutions and recommendations are given for expedient mining while maintaining the natural equilibrium.

The accessibility of data and the analyses obtained from the observation of sites in the vicinity of open pits through UAS will allow for better communication and cooperation between mining enterprises, environmental and governmental organisations, and society.

The availability of information in the form of maps with vegetation indexes, orthophoto maps and, if necessary, field measurements and lower resolution data (from satellites) is important for the management of natural resources not only on the regional and national levels, but also on the international one.

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