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Monitoring the mining effect at drainage basin level using geoinformation technologies

Research Article

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Abstract: One of the priority lines of modern regional policy with regard to mining is a territory's sustainable use. One of the key issues is the development of local level monitoring systems to assess and control territories that are subject to intensive anthropogenic activity. The current work proposes a developed geodatabase model for remote sensing and ground-based monitoring of the effects of coal mining at drainage level using geoinformation technologies. Based on this model, the *Kutina* geographic information system for the drainage basin of the Kutina River has been constructed. The geodatabase is open and may be updated and supplemented with other types of information. This is the first monitoring of coal mining's anthropogenic impact on the land cover and the Kutina Pyramids natural landmark carried out on the territory of the Kutina River drainage basin, Bulgaria. It may assist local level managerial decision-making, among others. Generation of landslide processes and self-ignition of coal layers has been identified as well. The recorded change in the hydrographic network resulting from the performed open coal extraction affects directly the change of the erosion basis. Its increase enhances lateral erosion at the expense of vertical, which is one of the major causes for the Kutina Pyramids natural landmark's degradation.

Keywords: geodatabase model • land use • remote sensing • geographic information systems

1. Introduction

The intensive development of urbanization and industrialization during recent decades has been often accompanied by the unbalanced use of natural resources. The maximal utilization of natural resources and the available land use models, which operate without accounting for the natural and ecological characteristics of a given territory, are in contrast with the principles of sustainable development and concern all environmental components. Sustainable development complying with the territory's ecological characteristics is among the leading directions of any regional policy. For the purposes of sustainable development, the National Programme for Sustainable Development has been developed, based on the EU Strategy for Sustainable Development and the updated Lisbon Strategy.

The importance of this topic is emphasized by the all-European approach for preservation and sustainable use of natural resources, which underlies the *All-European Strategy for Biological and Landscape Diversity*. It attaches priority to the introduction of biological and landscape diversity problems in all social and economical branches, requiring their integration in agriculture, forest economy, hunting, fishing, water management, tourism,

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regional policy and planning.

Resolving the problems of anthropogenic impacts on the environment and the optimal use of natural resources underlie a number of international agreements and EU Directives, making them a priority for international and national organizations, which target their efforts at resolving the problems of environment preservation at global and national level. The current work aims to investigate territories which have been seriously affected by anthropogenic activities at local level, and specifically, at drainage level, with the prevailing use of modern technologies – geographic information systems (GIS) and remote sensing data processing systems. Remote sensing and GIS technologies are provided to perform unbiased monitoring of anthropogenic impact on the environment, and specifically, on land use and relief, using different aerospace data for different time periods.

The use of GIS and remote sensing data during recent years appears to be a key element to monitoring systems development. In this study, a *monitoring system* means observation, assessment, and forecast of the environment with integrated use of remote sensing and ground-based data, taking also into account the monitoring classification proposed by Dixon and Chiswell [1]. Depending on the objectives of the constructed monitoring systems, they classify them as:

1. Status monitoring – performed to describe and monitor the status of a given object over time. This type of monitoring is performed in cases where management, application of rules, or scientific research is required.

2. Trend monitoring or effect monitoring – performed to understand the possible effects (consequences) of some natural phenomenon or human activity on the studied or monitored object, such as the effect of agricultural policy change on land use in a given region, or the effect of mining activity on land use. The purpose of monitoring the effect is not only to identify whether there has been any change, but also to establish whether this change has been caused by a specific activity. The reason for performing such type of monitoring, according to Dixon and Chiswell [1] are the same as the reasons for status monitoring.

3. Regulatory or compliance monitoring – this type of monitoring aims to establish whether the object complies with certain regulatory standards or requirements, for instance, whether the concentration of fine powder particles is below the permissible exposure limits.

Accounting for the classification proposed by Dixon and Chiswell [1], the geographic information system for anthropogenic impact monitoring refers to the second type of monitoring, namely trend monitoring or effect monitoring.

The impact of mining activity on the environment has been the subject of consideration by Sengupta [2]. He established several impact classes: air (air quality, noise levels, and atmospheric pressure), surface waters (physical and chemical quality), underground waters (amount and chemical quality) and land use potential (topography, hydrographic network, vegetation). The quarry method of coal mining affects not only air and water, but land use potential, too. Upon operation activities and the subsequent reclamation procedures, land use potential depends on topography, configuration of hydrographic network, vegetation, texture and the type of topographic surface. In this sense, it is assumed that anthropogenic impact on the land use potential of a given territory involves several ecological features: topography, hydrographic network, and vegetation. Many harmful effects on the environment may result from open mining of lignite coal, if no reclamation practices for their elimination are applied [2].

The construction of geospatial systems for assessment and analysis of anthropogenic impact on environment status and its preservation are a priority for many international and national organizations, but their major objective is to resolve the problems at the global, regional or national level. The geographic information systems for such type of large-scale studies and monitoring the anthropogenic impact on land cover/land use including the resulting relief changes, using integrated ground-based and remote sensing data, have not been sufficiently studied. Such a study of regions affected by mining activity has been conducted on the territory of the Czech Republic. This study accentuated the use of satellite data for monitoring ecological risk in mining regions [3]. There are several studies related to the assessment of the impact of coal mining on land cover and its dynamics. Several have used remote sensing data as an input to investigate land cover of two mining areas in China affected by coal fires. They use the maximum likelihood classification method in combination with vegetation index thresholding to distinguish the main land cover classes [4]. Another study focused on the conductance of environmental monitoring of coal mining, recording current land use at large scales and identifying the changes caused by mining activities. The main objective was to create an environmental monitoring system using remote sensing information as an important constituent [5]. Similar research has been carried out in India, where the emphasis is placed on the analysis of coal mining impact on land cover/land use using remote sensing and GIS. They have used the method of visual interpretation to map 6 land cover types and assess forest fragmentation [6]. The GIS construction methods described in this work use a combination of methods developed for the study of land use dynamics, the assessment of anthropogenic fragmentation and the assessment of the effects of mining activities, expressed as changes in the configuration of the hydrographic network and the development of landslide activity. These have been develped by the integrated use of ground-based and remote sensing data for various years using the GIS functionality. The integration of all these methods is used as a basis in the creation of a geodatabase model, providing the opportunity for various types of analysis. The development and application of such GIS may be targeted at resolving scientific-research and practical-applied tasks of different types.

The main sections outlined in the presented paper are the characteristics of the study area and the identifcation of the main problems associated with the area.

An essential part is allocated to the description of the study methodology and revealing the requirements towards the geodatabase model. Based on the created geodatabase model, a geodatabase for the Kutina GIS has been constructed. The last section of the paper presents the results from the conducted monitoring of the Kutina drainage basin. Emphasis is placed on assessment of anthropogenic fragmentation and mapping of the main effects from mining activity in the study area.

As far as the middle of the last century, remote sensing data processing technologies, geographic information systems, and cartography were developed independently of each other. Despite the differences between them, in recent decades there has been an increased integration rationalized by the closeness of the used methods, scientific-research means, and concepts. In this work, we have adopted a model integrating remote sensing data processing technologies, geographic information systems, and the cartography of Fischer and Lindenberg [7], where none of the considered research lines is dominating. Each of these research lines has its specifics, but all of them have contact points in the field of knowledge acquisition as well as in the methods and their application. The integration of the three technologies results in improvement of the cartographic image, improvement of the interpretation of remote sensing data, and the application of problem-oriented synthesis in GIS environment [8].

The monitoring of the effect of coal-mining requires framing a general system concept at the time of development of the geodatabase model, i.e. framing methods and approaches for using cartography, GIS, and remote sensing methods to study natural geosystems.

The objective of this work is to create a geodatabase to monitor the impacts of coal-mining on the land cover and relief of the drainage basin of the Kutina River, Bulgaria. Based on this objective and the formulated problems, the project was broken down into the following tasks:

1. To develop a methodology and micro-level geodatabase model;
2. To construct a geodatabase for the drainage basin of the Kutina River, Bulgaria, for the Geographic Information System *Kutina.*
3. To monitor the anthropogenic impact on the land cover and relief of the drainage basin of the Kutina River.

2. Studied territory

The subject of this study is the drainage basin of the Kutina River, Metropolitan Municipality, Bulgaria (Figure 1).
In choosing the study subject, the following criteria have been used:

1. The territory is strongly affected by anthropogenic activity that has been carried out for nearly 70 years.
2. Accessible and various-type basic information is available for the territory.
3. The region is poorly studied and at present there is no GIS for the purposes of large-scale studies have been constructed.

In physico-geographical aspect, the drainage basin of the Kutina River is located at the southern foot of the Sofia Mountain, a segment of the West Stara Planina Mountain. Administratively, the territory lies within the boundaries of the Metropolitan Municipality, 21km north of the City of Sofia (Figure 1). The boundary of the studied territory is natural, marked by the drainage of the Kutina drainage basin. Most of the watersheds are created naturally, except for part of the eastern boundary in the lower riverside of the basin, which has been formed artificially as a result of the coal mining. This area was chosen because during the last 68 years the territory has experienced extensive change as a result of anthropogenic activities. The Kutina River is a tributary of the Iskur River. In the northern part of the drainage basin the relief is strongly segmented and mountainous, featuring marked ridges and steep, eroded slopes. The water flows are intermittent. The southern part is less segmented, comprising the bottom of the Sofia Valley located in the lower boundary of the foot. The altitude varies between 504 and 1,116 m.

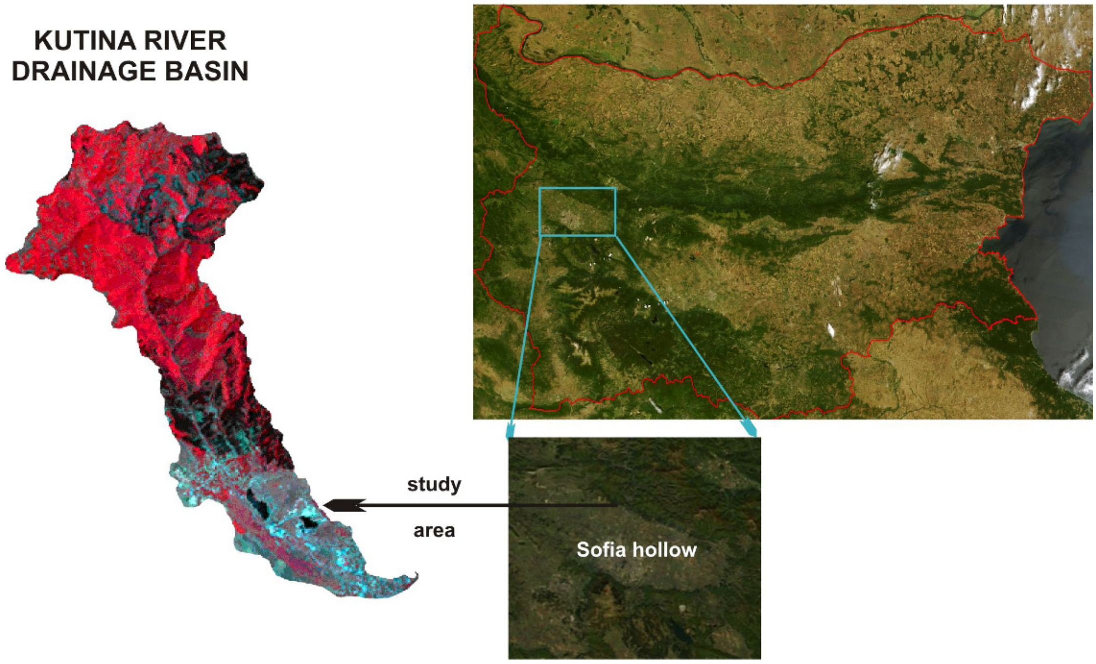

Figure 1. Location of the study area.

Until 1949, a Lignite mine was operated in the lower part of the drainage basin, here, coal was extracted through open mining. The low quality of the coal led to the mine's closure. Coal was mined by hand, using no mechanical equipment whatsoever. Between 1949-1953, the coal reserves were explored, which resulted in opening a new mine for open extraction in the north-west part of the territory. This open mine operated until 1973 [9]. The uncovering of the coal layers and the fuel's mining caused significant relief changes to the mine's territory. This called for technical reclamation on completion of mining activity. The performed reclamation was of very poor quality – with no congestion or selection of the filling materials and it comprised only the northwest territories of the west mining section. The destabilized slopes of the eastern section around the East Lake were not reclaimed.

Limited data on the geomorphological processes and phenomena taking place in the studied territory is available. The majority of the available data refers to the landslide processes, which are assumed to be technogenic and formed as a result of the mining activity, but they have not been subject to detailed study. The landslide processes on the territory were discussed for the first time in the works of [9, 10] and [11] after the start of lignite coal's mining. Nowadays, the landslide processes occupy significant parts of the drainage basins of the West and East Lakes formed on completion of the lignite coal-mining activities.

The area of the technogenic East Lake is also strongly affected by pyrogenic processes related to the self-ignition of coal layers, which further complicates the relief.

In the immediate vicinity of the Kutina coal area, a natural landmark known as the Kutina Pyramids is located. This is located in the Golemiya Dol locality on the land of the Village of Kutina, which is found in the southern part of the drainage basin of the West Lake. The Kutina Pyramids are a natural phenomenon formed as a result of a complex interaction of conditions and factors. Thus, groups of land pyramids of queer form were created, resembling medieval castles and towers, statues of people and animals etc. The pyramids in the Golemiya Dol locality were particularly impressive during the 1940s; in places where the depth of the diluvial depositions was greatest they reached maximum relative height of up to 30 m [12]. Some ten years later the natural formations fell within the scope of industrial mining of ores and minerals. In 1962, by a Resolution of the Chief Forest Administration, the pyramids in the Golemiya Dol locality were declared a natural landmark, comprising of a total area of 12.5 ha. After 1980 a steady tendency for faster and more intensive destruction of the natural landmark can be visually observed. The erosion process of the Kutina pyramids formation was described for the first time in 1992 [13]. This paper discussed their state, qualifying them as being in the stage of perishing, and clarified the reasons for this. Their current state may be described as a process of accelerated degradation as a result of the anthropogenic activity during the recent decades (Figure 2).

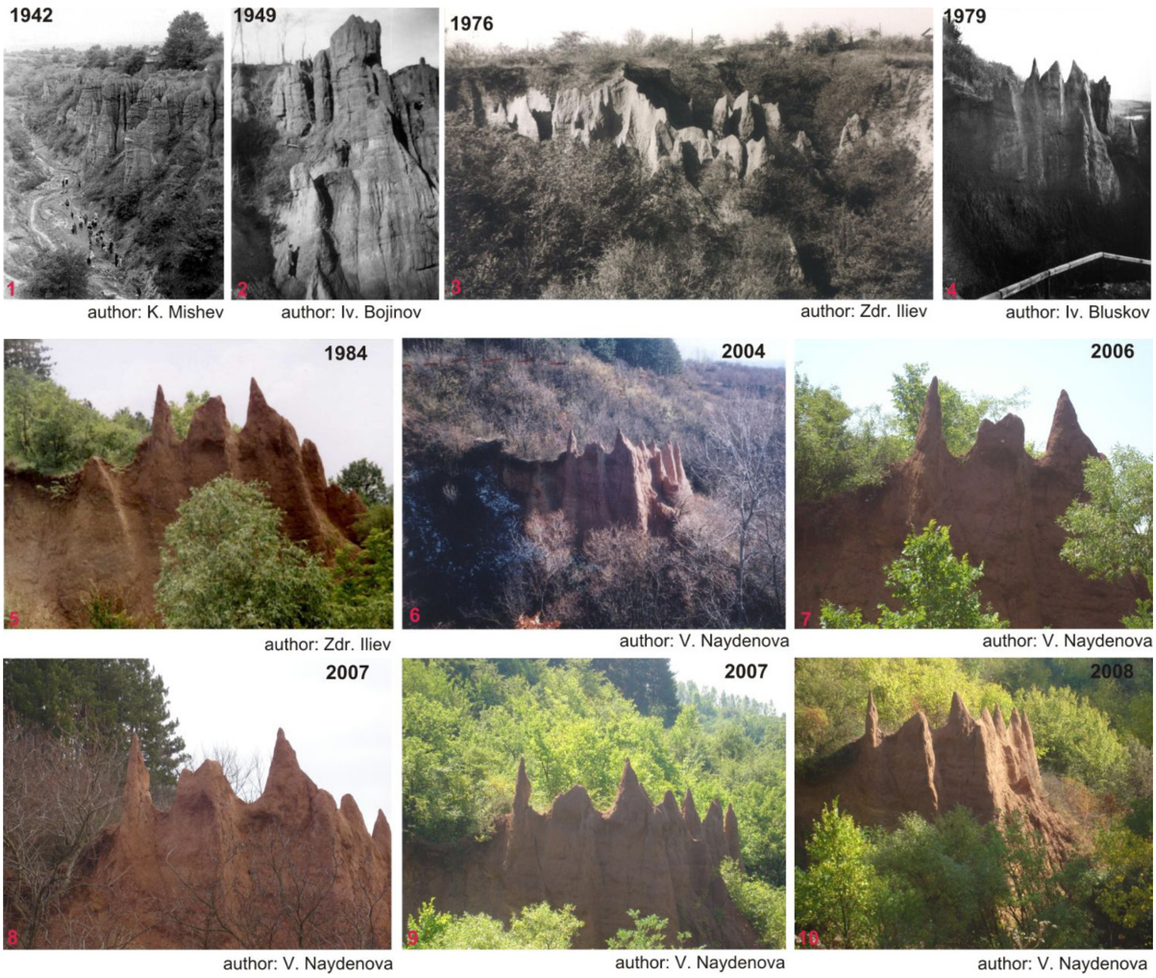

Figure 2. The *Kutina Pyramids* natural landmark.

With regards to the hydro-climatic aspect, no special investigations of the study territory have been made. It pertains to the South-Bulgaria subarea of the moderate-continental climatic area. The average thickness of snow cover in January is 10-12 cm and the average number of days with snow cover varies from 50 to 80. The average annual air temperature is 8-10°C. The average annual precipitation is between 570 and 670 mm/m^2. West and north-west winds prevail. The analysis has been made based on data from the meteorological annuals for the period 1949-1980 and data of the NIHM-BAS for the period 1980-2005 of the Kourilo Rain-Gauge Station (Town of Novi Iskur). Based on this data, a set of graphs has been drawn showing the maximum of precipitation (Figure 3 and 4), as well as the number of maximums and minimums by months which have an impact on the activation of landslide processes on the studied territory. Based on the analysis of the climatic information for precipitation, a spring-summer precipitation maximum has been identified with its highest values in June, and a winter precipitation minimum is marked by its lowest values in February (Figure 5).

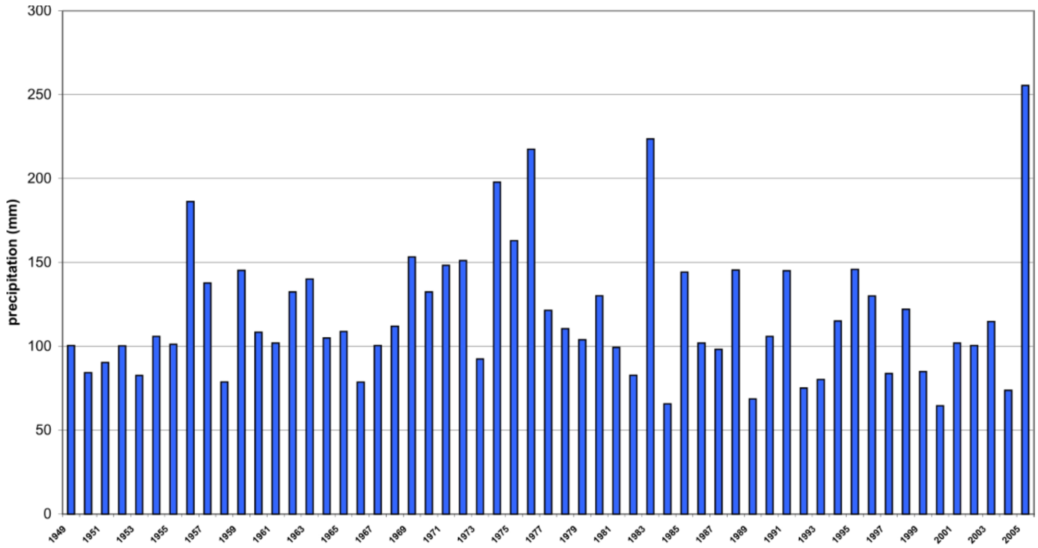

Figure 3. Maximum of precipitation for 1949-2005, Kourilo Rain-Gauge Station (Novi Iskur).

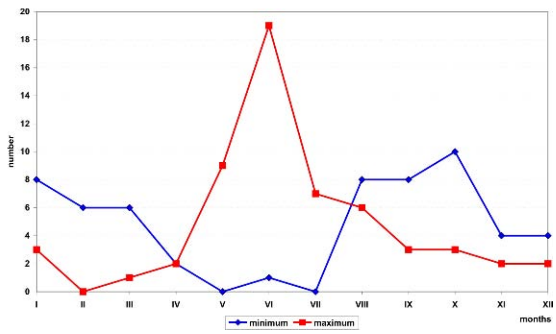

Figure 4. Number of maximums and minimums by months for 1949-2005, Kourilo Rain-Gauge Station.

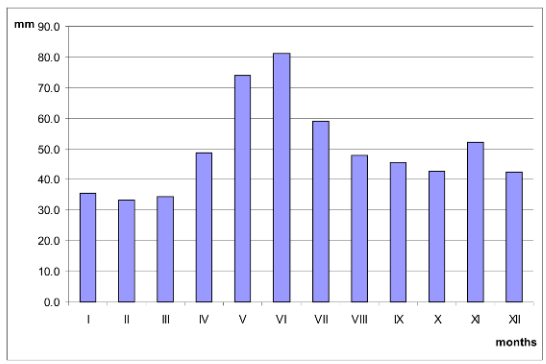

Figure 5. Average monthly amounts of precipitation for 1949-2005, Kourilo Rain-Gauge Station.

Regarding biodiversity, several investigations of the studied territory have been made. They aimed to study the floristic diversity of the Kutina Pyramids protected territory [14] and perform a biological survey and ecological assessment of the drainage basin of the East Lake, as one of the potential landfill areas of the Metropolitan Municipality [15]. The floristic study of the Kutina Pyramids natural landmark performed by Dimitrov, D. and V. Vutov [14] identified 199 species from 152 genera, pertaining to 53 families of higher plants. In the studied territory, two Balkan endemites are also encountered, *Scabiosa triniaefolia* and *Chamaecytisus jankae*, as well as the orchid *Himanthoglossum caprinum*, which is a protected species under the Convention on International Trade in Endangered Species (CITES). The study of biological diversity on the territory of the drainage basin of the East Lake has been performed in relation to an assessment study of several potential landfill areas within the Metropolitan Municipality [15].

The data for the anthropogenic changes and the ecological status in the surroundings of the Village of Kutina concern the extraction of ores and minerals. Large-scale studies of the ecological problems of the examined territory were described for the first time by Roumenina L. and V. Naydenova [16]. The publication considers the problems caused by open coal mining, coal layer self-ignition and the related landslide processes. Particular attention has been paid to the destruction of the Kutina Pyramids. The examined territory has not been subject to detailed study and monitoring of the anthropogenic impact of the mining industry on land cover and relief. Its large-scale and detailed study started in 2005 under a scientific-research project under the Bulgarian Ministry of Education and Science [17–20] and [21].

As a result of the physico-geographic assessment of the territory, the following major problems were identified, resulting from the intensive anthropogenic activity carried out during the recent years:

1. Technogenic relief change and landscape disturbance as a result of the lignite open coal mining in the Kutina Mine;
2. Spontaneous self-ignition of the surface coal horizon as a result of the mining activity;
3. Generation of landslide processes on the territory affected by the coal-mining;
4. Degradation of the Kutina Pyramids natural landmark.

In order to make a more detailed assessment of the anthropogenic changes and their effect on the territory's development, two test areas have been outlined. The first test area is the drainage basin of the West Lake, on the territory of which the Kutina Pyramids natural landmark is located. The second test area is the drainage basin of the East Lake. These two drainage basins have been chosen as test areas, since lignite coal was extracted on their territory. The boundaries of the drainage basins are determined in a natural way by the watershed lines. In their greater part, the boundaries of the drainage basins follow the natural course of the watershed lines, with the exception of the south-west boundary, which is artificially drawn by the man made road connecting the inhabited places of Kutina and Kourilo. The establishment of an artificial anthropogenic watershed is an anthropogenic impact itself. The main characteristics of the Kutina drainage basin and the two test areas, such as the area, the average altitude and the maximal and minimal are presented on Table 1.

Table 1. Main characteristics of the studied territory and the test areas.

Characteristic	Kutina drainage basin	Test areas	
		West Lake drainage basin	East Lake drainage basin
Area (km^2)	23.9 km^2	1.969 km^2 (196.9 ha)	1.706 km^2 (170.6 ha)
Average altitude (m)	801	657	589
Minimal altitude (m)	504.8	564	559
Maximal altitude (m)	1116	869	647

3. Methodology of the study

The methodology of the study describes the main objectives, tasks, methods for assessment of the anthropogenic impact, the choice of the years to monitor and the procedure used to create a geodatabase model.

The first main step is formulating the objectives and tasks to be resolved by the geographic information system to be built, based on the *a priori* information about it and choosing appropriate methods to assess the anthropogenic impact.

The objective is to construct a geodatabase for monitoring the effects of coal mining and their impact on land cover and relief at drainage basin level. The designed and constructed geodatabase should be able to resolve the following tasks:

1. Assessment of the anthropogenic fragmentation for the drainage basin.
2. Registration of land cover/land use dynamics and creation of an interactive matrix between land cover/land use change and earth moving activities as a result of the running in and operation of a coal segment over a time period covering the years before starting lignite coal extraction until 2008, reflecting the current status;
3. Assessment of the landslides generated as a result of the mining activity;
4. Assessment of the anthropogenic impact on the relief and the change in the hydrographic network.
5. Assessment of the anthropogenic impact on the natural landmark.

Table 2. Characteristic of the required input information in accordance with the set tasks and the methods envisaged for use.

Nr	Task	Author of the methods	Description of the methods	Required input information
1	Assessment of the anthropogenic fragmentation for the entire drainage basin of the Kutina River	Chris Steenmans Ulla Pinborg (2000) [22]	Determination of the anthropogenic fragmentation of potential semi-natural and natural areas, resulting from various human activities, accounting for the impact of urbanization, industry, agriculture, and transport infrastructure thereon	Land use Transport Infrastructure Satellite images
2	Assessment of the landslides generated as a result of the mining activity	Mantovani, F., R. Soeters and van Westen (1996) [23]	The paper describe the remote sensing methods for study and analysis of landslide processes on the territory of Europe and presents a review of all required input data for landslide risk analysis, the required information acquisition methods and their usefulness for 3 scales of study – regional, average and large-scale	- aerial photos for different time periods - satellite images - terrain studies - geomorphological units - landslides – test site and line - digital elevation model (DEM) - slopes - curvatures - lithology - structural-geological map and seismic map - land use - infrastructure – modern and for a past period - hydrographic network - drainage basin - precipitation and temperature
		Saha et al. (2002) [24]	In the methods, the required input information to determine landslide risk areas is specified. Methods for preparation of the thematic layers are presented, and a system for weighed risk analysis and a procedure for performing GIS analysis and landslide risk zoning are proposed.	- satellite images - aerial photos - digital elevation model (DEM) - landslides - configuration of the river network - slopes and exposure - contour lines - map of the relative relief - lithology - faults - land cover/land use
3	Land use dynamics	Bossard, M., J. Feranec, J. Otahel (2000) [25]	Land use dynamics and construction of a matrix of change – Technical Guidelines of Corine Land Cover	Land use – for different time periods
4	Construction of a matrix of the interaction between land use change and earth mass shift	Dedzoe, C.D., B.A. Raji, M. Staljanssens (2001) [26]	Monitoring of land use change for the purpose of assessing the impact on the environment of the activities related with earth mass shift. For the assessment, a matrix of the interaction between land use change and the territories affected by earth mass shift and a network of the impact on the environment are used.	- aerial photos - satellite images - topographic maps - geological map - soil map - GPS measurements - modern infrastructure - thematic layer with the territories affected by earth moving activities - land use

To resolve the tasks listed above, a combination of methods has been used. The constructed geodatabase should comply with the requirements for the input of information and the options for performing analyses and assessments in compliance with the chosen methods. The basic characteristics of all used methods, their authors, and the required input information are presented on Table 2.

The geodatabase is intended to resolve a wider problem scope. Its construction is consistent with the chosen methods underlying Table 2, part of which will be the subject of further developments. In the current study the results from the assessment of anthropogenic fragmentation, land use dynamics and the effects of mining activity are discussed.

3.1. Selection of land cover/land use classification diagram

To assess anthropogenic impact, appropriate land cover/land use classification should be selected. Its selection is a major point of the study.
In selecting land cover/land use classification, the following criteria have been taken into account, suggested by [27]:

1. The interpretation and classification accuracy of the land cover/land use types using remote sensing data should be no less than 85%;
2. The classification should be appropriate for using remote sensing data and applicable for various seasons of the year;
3. The classification should provide for unification of the land-use categories and formation of the major classes;
4. The classification should provide to compare land cover and land use over the different time periods.

Of the international land cover/land use classifications, the classifications suggested by the US Geological Survey (USGS) at the Ministry of Interior [28], the University of Minnesota [29], and the classification of the European project CORINE Land Cover [25] are considered. For the purposes of the current monitoring, a combined land cover/land use classification diagram has been used, based on the two international classifications – USGS and CORINE Land Cover. The proposed classification diagram is harmonized with the chosen methods for studying the anthropogenic impact and the examined territory. It is organized in 2 levels. The first level includes 6 land cover/land use classes, and the second level includes 20 classes (Table 3).

Table 3. Land cover/land use classification in combination with the requirements of the methods for assessment of anthropogenic fragmentation.

Impact index	Aggregated land cover types used to assess anthropogenic fragmentation	Land cover/land use classes: Level 1	Land cover/land use classes: Level 2
P	Artificial territories	Built-up lands	Residential territories
			Summer houses' areas
			Industrial territories
			Transport, infrastructure and utilities
			Territories for relaxation and sports
P	Vegetated areas, strongly artificial	Agricultural lands	Croplands
			Perennial plants
N	Vegetated areas, less artificial		Pastures
S	Non-wooded semi-natural areas	Low-stemmed vegetated land	Herbaceous vegetated land
			Shrubs
			Mixed low-stemmed vegetated land
		Barren land	Bare soil and scarce vegetation
			Bare rocks and scarce vegetation
N	Anthropogenic territories without forests		Disturbed lands
S	Forests	Forest land	Deciduous forests
			Coniferous forests
			Mixed forests
N	Water surfaces	Water surfaces	Rivers
			Lakes
			Reservoirs

During the visual deciphering and interpretation of the land cover/land use classes by archive panchromatic and modern coloured aerial photos with high spatial resolution, the following requirements have been taken into account:

1) The minimal mappable unit is 0.1 ha;

2) The linear objects with width greater than 5 m are presented as plane objects;

3) The linear objects with lesser width are proportionally distributed between the two neighbouring classes, and the object itself is presented in a separate linear feature class;

4) As a basis for land cover/land use deciphering over the various time periods, the modern status is used.

The deciphering of the other time stages is made only through corrections and marking the changes with respect to the current stage.

3.2. Assessment of the anthropogenic fragmentation

The proposed classification has been used in performing the monitoring of the anthropogenic impact. For the drainage basin of the Kutina River it has been assessed after the methods for anthropogenic fragmentation of Steenmans, C. and Pinborg, U. [22].
The established land cover classes have been aggregated into higher types (Table 3), according to the methods of Steenmans, C. and Pinborg, U. [22]. During the analysis of anthropogenic fragmentation, each aggregated land cover type is assigned certain attributive characteristics, called impact index. It is determined depending on whether these land cover types affect the neighbouring territories or are themselves sensible to such effect (Table 3). In accordance with this, the classes are divided into:
P – is supposed to put pressure (P) to the adjacent area contributing to fragmentation;
S – is sensitive (S) to pressure; these are assumed to be potentially natural and semi-natural areas;
N – neutral areas; these types of land cover are assumed to be neutral areas which do not affect considerably the natural and semi-natural areas, compared to anthropogenic impact.

3.3. Land cover/land use dynamics

To determine the land cover/land use classes shown on Table 3, computer-aided visual decyphering has been applied to the aerial photos and panchromatic satellite images.

3.4. Assessment of the anthropogenic impact on the relief

The assessment of the anthropogenic impact of mining industry on relief has been performed based on mapping the territories with marjed technogenic relief, the manifestation of landslide and other processes. In assessing the landslides, the method of landslide distribution analysis has been used. This is one of the most suitable methods for large-scale study of landslide processes as regards the feasibility of obtaining remote sensing data and their usefulness [23]. The distribution analysis includes mapping of the landslides and other slope processes and provides information only for the landslides' location. The mapping of the territories affected by landslides was performed by visual decyphering of aerial photos and satellite images and conducting terrain studies and measurements. During the conducted terrain studies and measurements mapping and GPS measurement of the sections affected by self-ignition of coal layers was performed.

3.5. Selection of years to monitor

The second major step before creating the geodatabase model for the monitoring study is the choice of years to observe and monitor, using definite criteria. With respect to monitoring, two approaches to determine the baseline year may be used – the initial monitoring period or the current status. In performing the current study, the current status shall be used as a baseline.
The selection criteria for the years in which the chosen test areas are monitored are as follows:

- The years are selected in compliance with three time periods corresponding to the development of the major anthropogenic activity on the territory – the running and operation of a lignite coal mine. The three time periods comprise:
  – the period before lignite coal extraction started - until 1945;
  – the period during lignite coal extraction - from 1945 to 1973;
  – the period upon termination of lignite coal extraction - after 1973 upto present day

- The years for monitoring are determined in the following way: one monitoring year for the periods before and during the mine's operation and several monitoring years for the period upon the operation's termination. The greater number of years for the third stage is rationalized by the fact that the manifestation of the effects of anthropogenic impact on the environment such as land cover, land use, relief change etc. is strongest during this period. This decision is also favoured by the great amount of available data for this period – ground-based data, aerial photos and satellite images and the possibility for updating them with terrain data.

- Availability of the required economic and thematic maps, aerial photos and satellite images.

Accounting for the above-mentioned criteria, the following years for monitoring of the test areas have been selected – 1940, from the period before lignite coal mining started; 1966, during the period of lignite coal mining. For the period after the coal mining's termination, in accordance with the considered criteria, the years 1989, based on topographic maps, and 2004, 2006, 2007 and 2008 have been selected.

3.6. Development of a geodatabase model for remote sensing and ground-based monitoring of anthropogenic impact

- To resolve tasks related to inventory-making, the GIS should provide for effective use of various information sources and maintain a great number of data formats;
- To resolve assessment tasks of various nature, the GIS should feature great effectiveness;
- To study, track and map the change of a certain process or phenomenon in nature, land use or anthropogenic impact on the environment, it is essential for the GIS to comprise varied time information and to integrate it, i.e. to combine varied-scale and varied-age data. This places the requirement for providing options for transformation and maintenance of various dynamics analysis functions, such as overlay, reclassification, matrix of change etc;
- The forecasting of the trends and pace of the processes and phenomena's dynamics places requirements related with modelling options.

The geographic information system provides efficient options for organization, analysis, and transformation of spatial and non-spatial data in a uniform geodatabase, in view of obtaining the required information in a specific format – cartographic products and reports, providing for making queries to the database by the end user, for the purpose of retrieving some specific information. An essential and fundamental element of the construction of each information system is the design of its geodatabase [30]. The organization of the geodatabase model for monitoring the effects of coal mining at drainage basin level has been made in three stages – conceptual, logical, and physical.

Conceptual stage

At this stage, according to the previously set objective, the level of detail of the geodatabase and the scale of the data contained in it are determined. The spatial scope of the study territory is outlined by the water drainage basin of the Kutina River, which determines the micro-detail level of the developed geodatabase. To resolve the tasks set forth for the geodatabase of the territory of the Kutina water drainage basin, the work scale of 1:10,000 has been chosen, and Ì 1:5,000 for the key sections.

In choosing input data, the requirements specified by the chosen study methods have been taken into account (Table 2). The required input information has been supplemented with data about the forests and information about forestation and the wood cuttings on the territory. This data will be used during the assessment of land use change. The available natural landmark requires supplying the geodatabase with one more feature class, namely – the boundary of the Kutina Pyramids natural landmark, through information from the forest maps issued by the Chief Forest Administration in 1999.

The geodatabase is time-coordinated, i.e. the data stored in it correspond to the time periods outlined for the study. Regarding aerial photos and satellite images, only those pertaining to the relevant time periods have been selected, i.e., before, during and after termination of lignite coal extraction on the territory, which feature appropriate spatial resolution for the chosen scale and detail level.

The approaches for presenting the spatial objects have been determined and the data model has been chosen. Since the developed geodatabase is intended for remote-sensing and ground-based monitoring, both data models are used – the raster and the vector one. The contents of the geodatabase with respect to spatial and non-spatial (attributive) data have been determined at the conceptual level [30].

Logical stage

The selection of the database model is a key element of the organization's logical stage [31]. The most widely distributed logical structures – database models and their database management systems (DBMSs), are the hierarchical, net, relational, and in recent years – the object-oriented one [32]. Of the 4 basic logical models listed above, the relational one has been chosen as the most appropriate for the geodatabase's objectives.

For the current purposes, UTM projection, zone 34 N with datum WGS 84, has been selected, which ensures compatibility of the current geodatabase with other data that may be added to it. This coordinate system is recognized internationally and allows information to be easily combined from various sources. In constructing the geodatabase, a unified coordination system shall be used to provide for high position accuracy of the input information. For the purpose, a reference image of the studied territory featuring high position accuracy has been constructed to which all input data have been orthorectified and georeferenced.

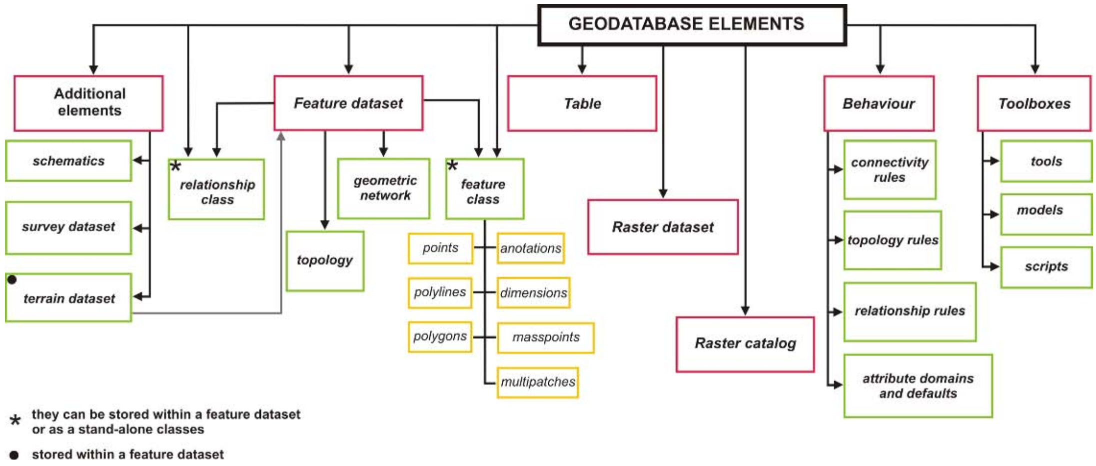

Figure 6. Geodatabase elements.

Appropriate elements of the geodatabase (Figure 6) have been chosen, depending on the characteristics and specifics of the input information and the optimal analysis options provided by each of them. The basic elements that shall be used are feature classes, stored individually or in a feature dataset, relational and topological classes, the raster catalog and raster dataset, and the tables containing the non-spatial information for the objects. In determining the spatial and non-spatial behaviour of the geodatabase, major emphasis has been placed on setting the relational classes between attributive data, determining subtypes and domains, and setting the objects' spatial relations through topology rules.

Physical stage

The physical organization of the database is related with the hardware provision and the possibilities of the GIS's hardware components [32]. It is based on the database design principles laid down in the software products of ESRI – ArcGIS 9.2, with ArcInfo license. For its purposes, the file one has been chosen on account of the advantages it has compared to the other types offered in the products of ESRI with respect to functionality, restrictions and data storage mechanisms, maintained platforms and operational systems and user number [33]. It is based on the relational database concept and satisfies the requirements of the logical model. The selection has been made accounting for the hardware and software requirements arising from the type and volume of the input information.

The chosen file geodatabase structure provides for the geodatabase's further updating to include new data in both vector and raster format. This is facilitated by the fact that this type of database has no restriction on the amount of the stored information, and the structure may be edited quite easily. It provides the possibility for being used simultaneously by several users, but it does not maintain in parallel more than one editor for a given group of data.

4. Construction of a geodatabase for the Kutina GIS

The construction of the geodatabase for the Kutina GIS is based on the created GDB model and the defined requirements for the input information. The first step towards the construction of an integrated geodatabase of the Kutina River drainage basin for monitoring the anthropogenic impact is to prepare the input information and enter it into the geodatabase.

The constructed geodatabase comprises the time period from 1940 to 2008 and its aim is to store, manage and select objects by attributes. The structure of the geodatabase is described in the sections below, as follows:

4.1. Raster datasets

Satellite images

The satellite images are organized in raster datasets according to the year of acquisition, the type of the sensor and the spatial resolution.

- Landsat-7^{ETM+} andLandsat-5^{TM} acquired accordingly in 2000 and 2001 and 1992;
- Satellite images from QuickBird, acquired on 07.03.2007 and 31.05.2008;
- Satellite images from SPOT 5, acquired on 9 July 2004;
- Declassified satellite images from KH-7, acquired in 1967, featuring spatial resolution of 1 m.

Aerial photos

Three pieces of archive panchromatic aerial photos have been scanned which were acquired in 1940 and 1966. Concerning the modern stage of the study, 6 pieces of coloured aerial photos have been submitted, which were acquired in 2006.

Topographic maps

Topographic maps in the *System 1970* coordinate system in scale 1: 5,000 have been georeferenced for the entire Kutina River drainage basin.

4.2. Feature datasets

The feature datasets in the geodatabase for the Kutina River drainage basin are unified thematically and in compliance with the necessity of setting topological rules. The feature datasets included in the geodatabase for the *Kutina* GIS are presented in Table 4.

Table 4. Feature datasets.

Feature dataset	Feature class	Name of the feature class in the geodatabase
Drainage basins	Drainage basin of the Kutina River	basinKDB
	Drainage basin of the West and East Lake	W_E_lakes
Hydrography	Water areas	waterareas89
	Intermittent streams	streams
	Artificial linear water objects	drains
	Point hydrographic objects	hydropoints
	Coast line of the water basins	l_sides
Topography	Relief isolines	relief
	Elevations with their altitudes	elevation
Forests and soils	Forests	forests
	Soils	soils
	Sector and subsector boundaries	lines
Geomorphology	Landslide territories	Landslides
	Landslide scarps	Scarps
	Landslide lakes	Landslide_lakes
Geology	Linear geological objects	geology_lines
	Lithology	lithology
	Slopes	slope_text

4.3. Topological classes

Topological classes – for all established feature datasets, 13 topological rules are laid down which provide for advanced editing of the feature classes.

4.4. Feature classes

The feature classes which do not participate in topology and are not part of a certain thematic group have been entered in the geodatabase as independent feature classes. Such feature classes are:

- *NIMH* – represents a point feature class, containing information about the location of the *Kourilo* Rain-Gauging Station, altitude, opening and closing date.

- *Landmark_area* – test site feature class, containing the boundary of the Kutina Pyramids natural landmark.
- *Field_work* – point feature class, containing information from the conducted terrain studies and GPS measurements.

The conduct of terrain studies and measurements on the examined territory provides for on-line updating of the geographic information system with data for the environmental status.

The terrain studies and GPS measurements conducted so far aimed to map the recent landslides and the areas affected by self-ignition of the coal layers, and to verify the results from the performed visual interpretation and deciphering of the aerial photos and satellite images (Figure 7).

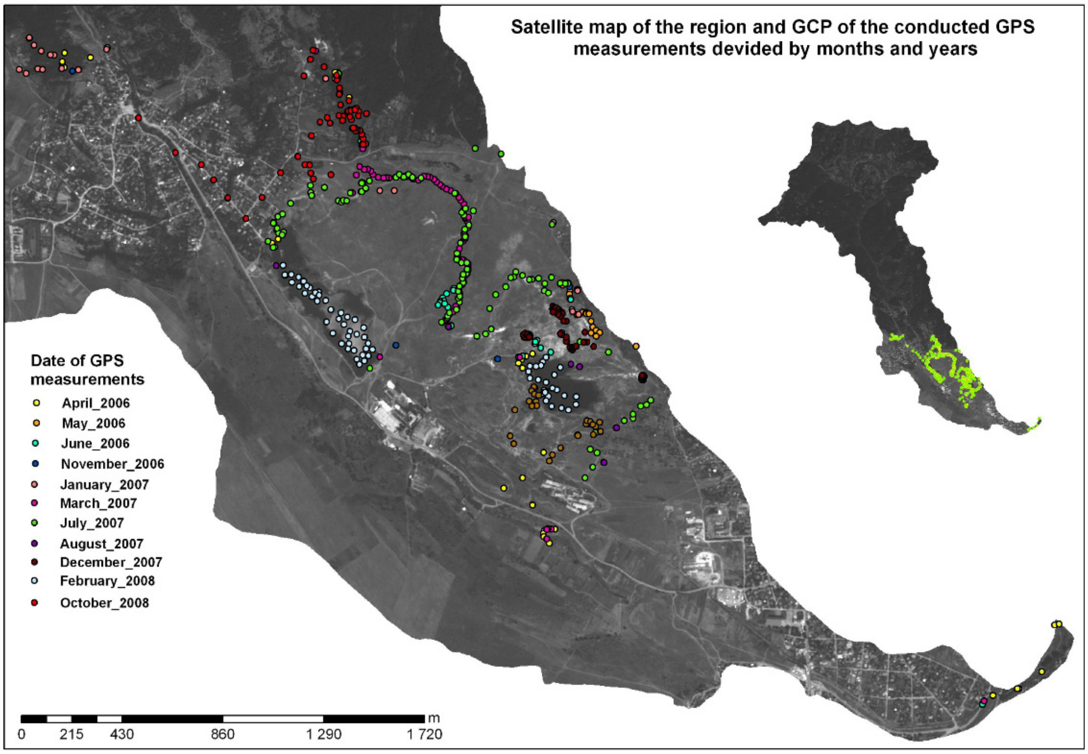

Figure 7. Spatial distribution of the conducted GSP measurements.

4.5. Raster data as a feature class attribute

For the territory of the two test areas and the Kutina Pyramids natural landmark, archive photos from the beginning of the last century and more than 500 modern ones have been collected and entered in the thematic database as attributes of the feature class *field_work.*

4.6. Tables

Each spatial object is related to specific attribute information, which describes its major characteristics and properties. For two of the feature classes – *Forests* and *NIMH*, additional tables have been entered in the database, containing information about forestation, wood cuttings, species composition of the sections and subsections, etc. and the individual characteristics of the precipitations climatic element for the time period from 1949 to

2005. The tables are stored outside the feature datasets and are related with the spatial objects by relational rules.

4.7. Relationship classes

12 relationship classes have been established, linking the climatic data and forests spatial objects with the additional attributive information presented in tables. The set cardinality is *one to many*.

The constructed file geodatabase for the *Kutina* GIS contains 7 feature datasets with 21 feature classes, 1 raster catalogue with 385 images, 19 raster datasets, 14 tables, 3 stand-alone feature classes and the relevant topological and relational classes. To perform various types of spatial analyses and modelling, a geographic information system should be constructed.

The *Kutina* GIS under development is of integrated type, since the two types of data (spatial and attributive) are stored in a common geodatabase, which results from the fact that the detail level is a micro one. The *Kutina* geographic information system has the following functional options, which are available in the used software ArcGIS 9.2:

- Visualization of spatially referenced information in raster and vector format;
- Thematic mapping;
- Drafting of cartographic models;
- Queries to the constructed geodatabase based on attributive characteristics;
- Performance of spatial and statistical analyses using raster and vector data based on the instruments laid down in the software product of ArcGIS;
- Possibility for using additional scripts, models and extensions, created with various program products.

The main extensions used for the analysis in this paper are Spatial Analyst, 3D Analyst, some additional scripts - Spatial Analyst Plus and Convert Graphics to Feature, which are freely available on the ESRI web page. The created geographic information system is open and can be updated and extended by new data and additional functionality.

5. Monitoring the impacts of coal mining at water drainage level

5.1. Assessment of the anthropogenic fragmentation for the entire drainage basin of the Kutina River

The assessment of the anthropogenic impact for the entire drainage basin of the Kutina River is performed by determining the anthropogenic fragmentation of potential semi-natural and natural areas, caused by various economic activities. The impact of urbanization, industrial areas, agriculture, and transport infrastructure on potential semi-natural and natural areas, such as forests, bushes, open semi-natural lands and wetlands is taken into account.

To determine the land cover/land use classes for the entire drainage basin of the Kutina River, a satellite image acquired by SPOT 5 in 2004 was used. Computer-aided visual deciphering and interpretation was carried out for the purpose.

The aggregated land cover types and the assigned impact index according to the methods of Steenmans, C. and Pinborg, U. have been used to assess anthropogenic fragmentation. Their spatial distribution for the territory of the Kutina drainage basin is shown in Figure 8, where a relatively high share of the territories sensitive to pressure, such as the natural and semi-natural complexes, is witnessed. Nearly 14% of the territory of the drainage basin has been allocated to the class affecting the neighbouring territories. It includes mainly urbanized territories and agricultural lands, and a smaller share represented by road network. The disturbed anthropogenic territories and water objects are assumed to be neutral since they do not have strong impact.

The next stage from the anthropogenic fragmentation assessment is the defining of the buffer areas. The artificial anthropogenic areas, such as urbanized territories and territories with intensive agriculture put pressure on wildlife. Steenmans, C. and Pinborg, U. [22] assume that pressure areas impact the natural complexes at a distance of at least 500 m. The infrastructural objects and, more specifically, the transport network crossing certain natural complexes, are also deemed to impact fragmentation and have a barrier effect. The barrier effect is hard to assess, therefore, a buffer area surrounding the object is used. Steenmans, C. and Pinborg, U. [22] adopt a distance of 500 m for each side, not isolating the different territories susceptible to impact.

The barrier effect is not the same for all types of infrastructural objects. It is substantially higher at highways and heavily loaded road arteries and railway lines, than at small and less loaded roads and arable lands [22].

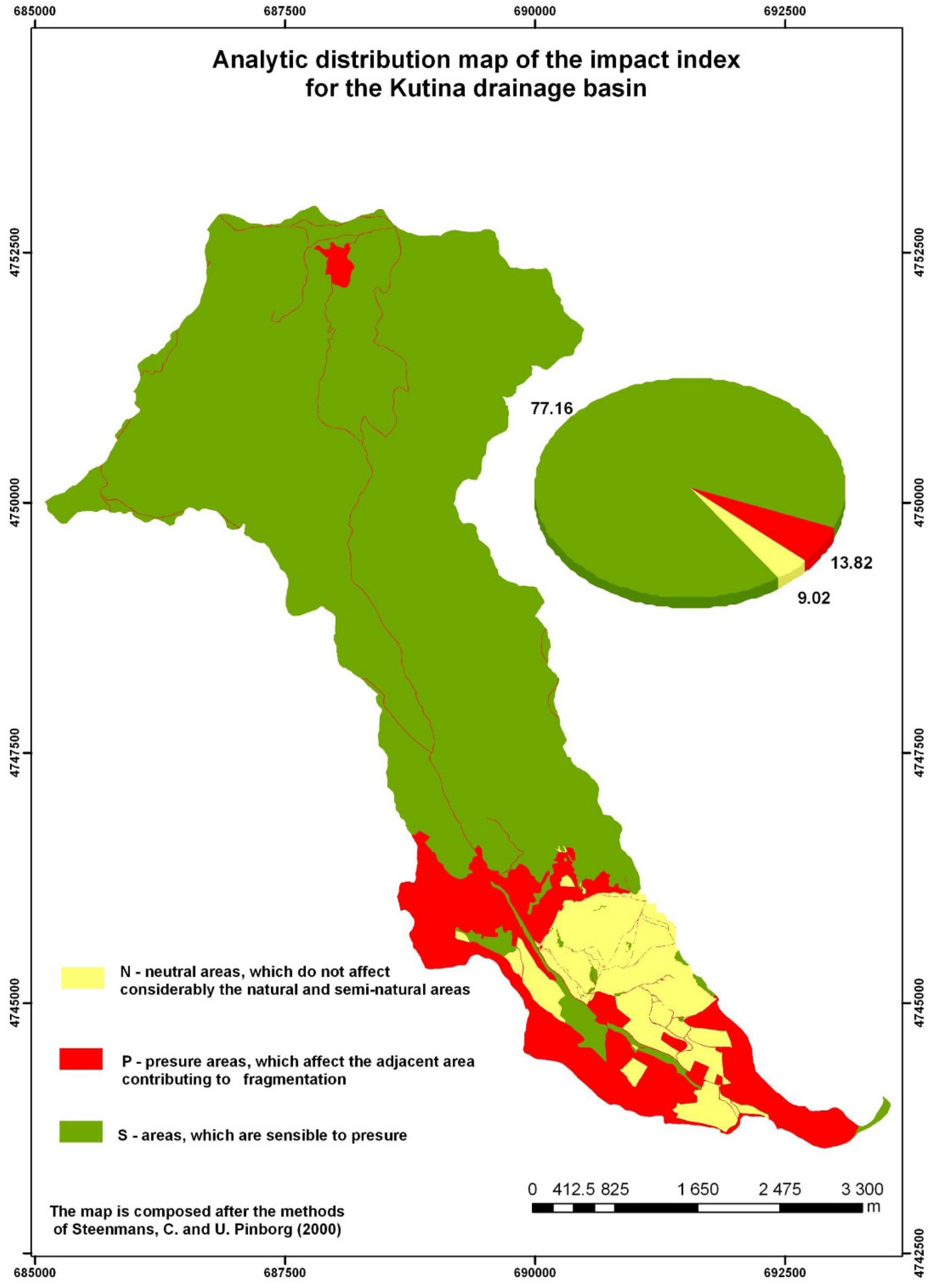

Figure 8. Map and diagram, showing the distribution of the impact index of the Kutina drainage basin, Bulgaria.

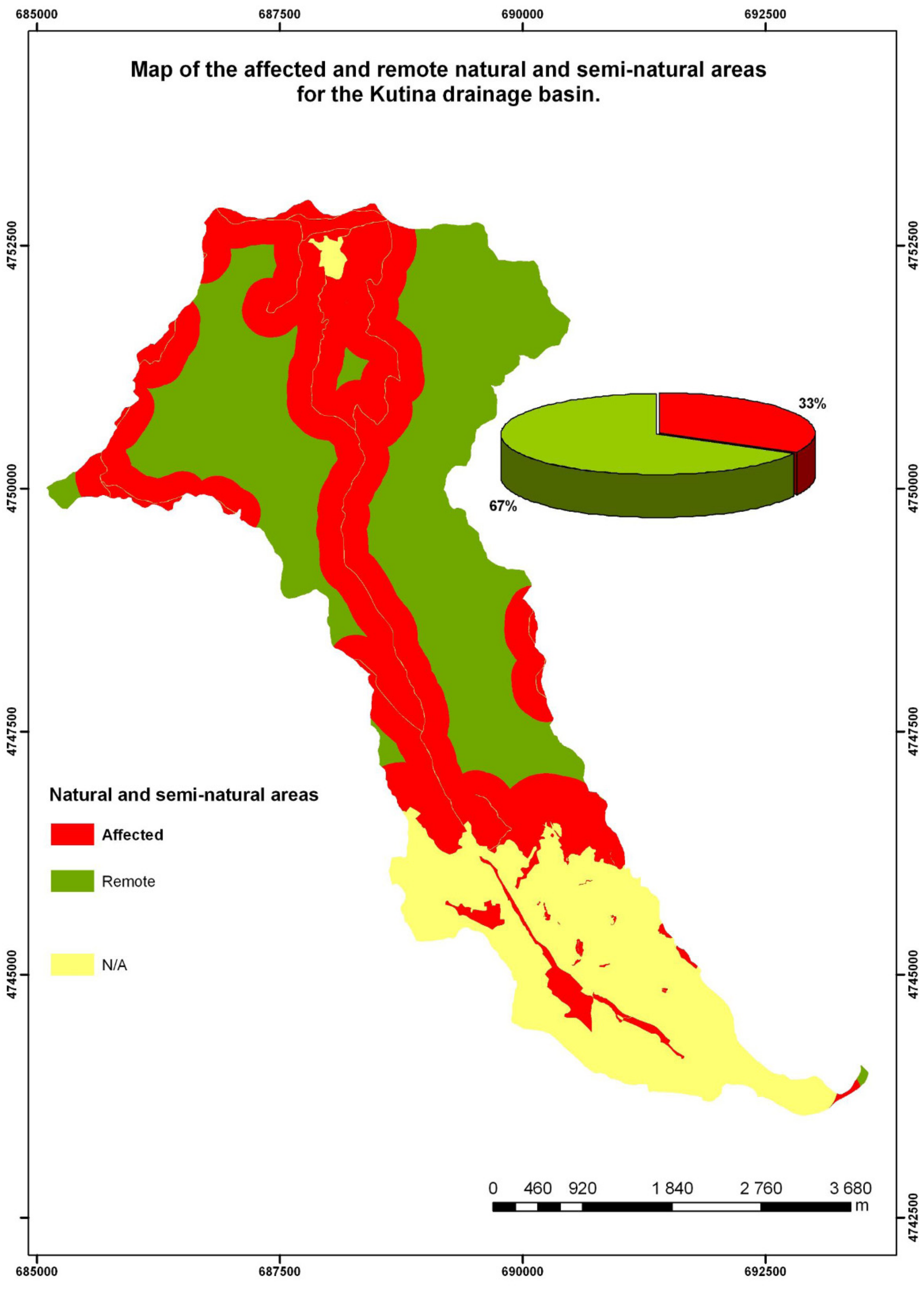

Figure 9. Map and diagram of the affected and remote natural and semi-natural areas for the Kutina drainage basin, Bulgaria.

On account of the lack of highways and heavily loaded road arteries, in this study we assume that all infrastructure objects with 2 or more traffic lanes enjoy the same rights, therefore, they are assigned a buffer area of 500 m. The large-scale mapping and the greater details laid down in this study have resulted in taking into account the non-asphalted road network as well, but since it has less than 2 traffic lanes, it is assigned a buffer area of 250 m on each side.

Following the assignment of the buffer areas, the natural and semi-natural territories are classified in two groups:

- affected – those that are influenced by pressure areas or infrastructure lines
- remote – the remaining part of the natural and semi-natural territories, on which no pressure has been exerted.

The spatial distribution of the affected and remote territories is presented in Figure 9. As a result of the analysis it was established that 33% of the natural and semi-natural complexes of the Kutina drainage basin are affected and most of them are located in the mountainous territory. The territory of the Kutina Pyramids natural landmark falls almost entirely within the affected natural and semi-natural complexes, while an insignificant part of it is represented by the territories having impact – mainly built-up lands and perennial plants.

5.2. Dynamics of the test areas' land cover/land use

Analysis and assessment of the effects of coal mining on the dynamics of land cover/land use for the territories of the two test areas – the drainage basins of the technogenic West and East Lake, have been made for the three time periods, using the aerial photos and satellite images available in the geodatabase. For the period before starting lignite coal extraction, archive aerial photos from 1940 have been used. For the period during lignite coal extraction, archive aerial photos and a panchromatic declassified satellite image from 1966 acquired by KH-7, featuring spatial resolution of 1m have been used. For the present day, aerial photos from 2006 have been used.

The results obtained from computer-aided visual deciphering have been additionally entered in the geodatabase of the constructed *Kutina* GIS. Using the functional options for thematic mapping of the constructed GIS, 2 matrices of land cover/land use areas' change for level 1 have been constructed (Table 5 and 6).

Exclusively dynamic change of land cover/land use over the studied 68-year time period has been identified. The characteristics and features of the established three time periods have been identified, the most important of which are as follows:

- The first stage (until 1945) is related with the territory's natural course of development. Before the start of coal extraction, the territory was occupied mainly by arable lands, grass vegetation and barren land, and a very small percent of forests (3.5%). The land cover classes affecting the natural complexes during this period are represented mainly by croplands occupying 58% of the territory. The percent share of low-stemmed vegetated land and barren land is also relatively high (18.3% and 17.3%), (Table 5).

Table 5. Matrix of land cover/land use area (in %) change at level I (1940-1966).

Land cover/land use classes for 1940	Land cover/land use classes for 1966: Water areas	Forest land	Built-up land	Agricultural land	Low-stemmed vegetated land	Barren land	Total area (%)
Water areas	0.061	0.020	0.006	0.393	0.014	0.964	1.458
Forest land	0.089	1.619	0.000	0.269	0.392	1.173	3.542
Built-up land		0.000	1.442	0.023	0.000	0.001	1.467
Agricultural land	0.190	0.206	1.524	26.790	1.016	28.172	57.899
Low-stemmed vegetated land		7.818	0.000	0.487	9.774	0.212	18.292
Barren land	0.015	3.172	0.000	0.054	3.466	10.636	17.342
Total area (%)	0.355	12.835	2.972	28.017	14.662	41.159	100.000

Table 6. Matrix of land cover/land use area (in %) change at level I (1966-2006).

Land cover/land use classes for 1966	Land cover/land use classes for 2006						Total area (%)
	Water areas	Forest land	Built-up land	Agricultural land	Low-stemmed vegetated land	Barren land	
Water areas	0.197	0.008		0.148		0.003	0.355
Forest land	0.003	12.181	0.026	0.587	0.005	0.034	12.835
Built-up land	0.480		1.373	0.972	0.093	0.055	2.972
Agricultural land	2.979	0.605	2.585	17.704	0.504	3.640	28.017
Low-stemmed vegetated land	0.038	12.438	0.157	1.965	0.033	0.031	14.662
Barren land	2.706	9.434	0.610	16.865	0.485	11.058	41.159
Total area (%)	6.403	34.665	4.750	38.240	1.120	14.822	100.000

- The second stage (1945–1973) is characterized by active coal extraction during which the anthropogenic activity played a leading role in the territory's development. Land cover change was exclusively dynamic, with new classes appearing, such as disturbed lands, reservoirs and lakes and coniferous forests. The greatest percent share is represented by disturbed lands (29.5% of the territory), while coniferous forests amount to 6.9%. This occurred at the expense of reduced cropland and barren land (Table 5 and 6). The third stage started upon termination of coal extraction (1973 – to present). During this stage, partial technical reclamation of the West Lake territory was carried out. Significant land cover change is recorded, compared to previous periods. The greatest percent share of the territory is occupied by forests (coniferous or deciduous) and pastures (34.7% and 35%) (Table 5 and 6). The percent share of bare ground with no or little vegetation has dropped to 1.4%, and no arable land class is recorded. The current development stage of the territory is characterized by restoration of the environmental processes' natural course.

  The conducted monitoring shows that mining activity has impacted directly on the neighbouring territories only during the second stage. While assessment of anthropogenic fragmentation for 2004 was made, the territory on which coal was extracted was occupied by land cover classes which do not impact the natural complexes and are assumed to be neutral.

The performed mining activity has affected some processes taking place on the territory of the test areas. The major effects from mining activity observed in the study area are mapped and shown in Figure 10. The relief has been seriously affected by the extraction of lignite coal and the hydrographic network has been significantly changed. During the first period, the hydrographic network was formed in a natural way and no development of landslide processes or availability of natural or artificial lakes was observed [18]. During the second period, dynamic changes in the configuration of the hydrographic network were recorded, one of them being the correction of the riverbed of the Kutina River (Figure 10).

Steep unstable technogenic slopes were formed and a great number of technogenic lakes appeared [18]. Nowadays, landslide processes may be witnessed on the territory and the hydrographic network is entirely transformed (Figure 10). The active manifestation of landslide processes in the region is typical for the period following lignite coal mining; they are further enhanced by the incomplete technical reclamation [18]. Landslides cover 14% of the territory of the test sites. Two technogenic lakes are formed and a great number of landslide lakes appear. On a great part of the territory of the East Lake drainage basin, active processes of burning coal layers are observed and mapped during the conducted terrain studies (Figure 10). Their self-ignition occurs as a result of the mining activity, but the incomplete terrain reclamation also contributes to it. The change in the hydrographic network as a result of the performed coal mining impacts directly the erosion change basis on the territory. The increase of the erosion basis enhances lateral erosion at the expense of depth. This is one of the major reasons for the degradation of the *Kutina Pyramids* natural landmark.

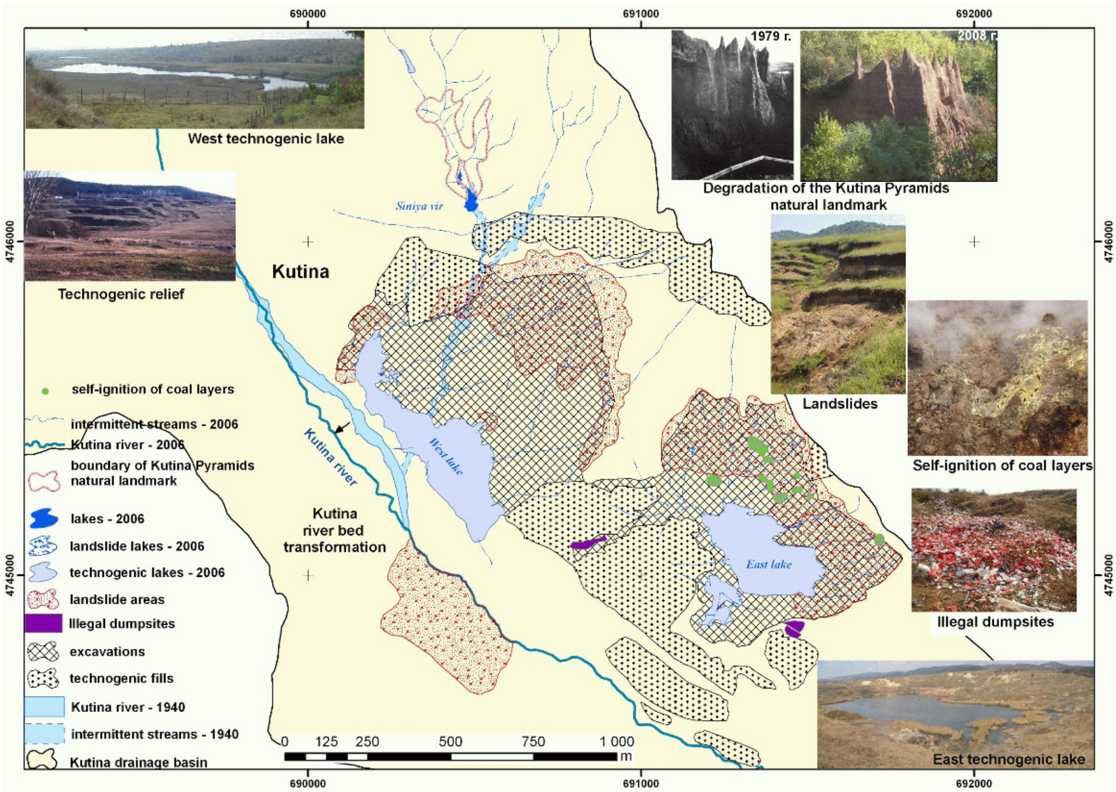

Figure 10. Effects of mining activity.

6. Conclusions

The main emphasis of the paper is the presented methods and geodatabase model for assessment of the anthropogenic impact from mining activity on land cover and relief, using a geographic information system integrating ground based data with remote sensing ones. The created Kutina GIS is open and may be updated and supplied with new information. Providing the ability to conduct regular monitoring aimed at supporting managerial decision-making at the local level. The assessment of the anthropogenic impact for the Kutina River drainage basin has been made, using the anthropogenic fragmentation method of Steenmans, C. & Pinborg, U. As a result, it was established that a significant part of the natural and semi-natural complexes are affected by the impact of urbanized territories, transport infrastructure, and agricultural lands. The observed land cover / land use changes for the two test areas as a result of mining activity during this 65-year period are quite significant. The constructed *Kutina* GIS is intended to be used for performing regular detailed monitoring of the studied territory, multi-criterion analysis of the landslides in the region and landscape-ecologic planning.

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