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USING HISTORICAL AERIAL PHOTOGRAPHY FOR MONITORING OF ENVIRONMENT CHANGES: A CASE STUDY OF BOVAN LAKE, EASTERN SERBIA

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Highlights

- By analyzing historical aerial photography we can get useful and important information for the spatial, ecological and many other changes in the environment.
- With a comparative analysis of aerial images from the past and contemporary aerial images, we can get information about the nature and trends of the observed phenomena.
- This paper gives the obvious demonstration of the possibilities of the usage and the quality of the historical aerial images for the spatial analysis and the other researches that include the living environment in total.

Abstract. Useful and important information for the spatial, ecological, and many other changes in the living environment may be obtained using the analysis of historical aerial photography, with comparison to contemporary imagery. This method provides the ability to determine the state of elements of the space over a long period, encompassing the time when it was not possible to acquire the data from satellite imagery or some other contemporary sources. Aerial images are suitable for mapping spatial phenomena with relatively limited spatial distribution because they possess a high level of details and low spatial coverage. With a comparative analysis of aerial imagery from the past, contemporary aerial imagery, and other sources of aerial imagery, we can obtain information about the nature and trends of the observed phenomena as well as directions of future actions, considering changes detected in the environment, whether they are preventive or corrective in nature. This paper gives the methodological framework for the appliance of the existing knowledge from various fields, intending to use historical aerial photography for monitoring of environmental changes of the Bovan Lake in Eastern Serbia.

Keywords: environment, landscape, historical aerial photography, photography processing, mapping, remote sensing, spatial analysis.

Introduction

The detection of previous and analysis of the current state, scope, and prediction of changes, is a method commonly used for exploration of a given area. Usage of aerial imagery provides a solid base for numerous researches e.g. in the landscape and living environment generally (Gong, 2012; Liu & Yang, 2018; Melnyk, 2008). Concerning other data acquisition methods, including satellite imagery, the advantages are obvious – e.g. full autonomy in work, the cost, and the possibility of analysis of the elements of space from the notably earlier date (Lillesand & Kiefer, 2000; Tobak et al., 2008). Photo interpretation is one of the fundamental tools for environment and landscape ecology (Van Eetvelde & Antrop, 2004; Pinto et al., 2019).

This kind of research is present for a long time and is actual nowadays too, e.g. as in given examples (Morgan et al., 2010; Szatmári et al., 2016) in the up to date analysis of the environment, e.g. aerial photogrammetrical remote sensing in present (Newton et al., 2009; Van Eetvelde &

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Antrop, 2004). The aerial imagery from previous and present day's epoch, together with equipment for processing and visualization of geospatial data e.g. give the multipurpose ability (Collier et al., 2001; Dyce, 2013). Thus, by analyzing the aerial imagery, important and high-quality spatial information can be acquired (with high accuracy), e.g. its previous and actual state (Kull, 2005; Tucker, 1979). An aerial image gives a great opportunity for analysis of surface spatial elements such as soil, vegetation, urban areas, transportation, hydrography, etc. (Morgan et al., 2010).

The area of interest treated in this paper is a narrow area around Bovan Lake and the main goal is to get the answers about changes considering land use, vegetation, extent, and type of transportation, and the degree of hydrographical changes over time. The secondary goal is to show the way of preparation and possibilities of usage of historical aerial photography for environmental analysis and other fields of the research.

This paper covers the period of over 40 years through the three epochs of the camerawork: 1969, 1980, and 2010. For the research purposes, aerial imagery in possession of the Military Geographical Institute [MGI] was used. In the first part of this project, it was necessary to digitize the aerial imagery from the first and the second epoch. For that purpose, well-known methods of digitalization were used (Bakrač et al., 2018; Wrobel, 1991). The further procedure of processing all aerial images (all 3 epochs) implied the creation of the orthophoto. After the creation of the orthophoto (standard activities were carried out), we started the mapping process according to well-known methods (Redecker, 2008; Sonnentag, 2009; Wolf et al., 2014). Mapping of the content for every given epoch was conducted through processes of 3D and 2D photogrammetrical plotting, with the usage of adequate software and standard methods, respective up-to-date approaches, and tendencies (Conte et al., 2014; Firoz et al., 2018; Li et al., 2016). For the mapping purposes, basic spatial features were chosen: hydrography (rivers, lakes), main roads, local roads, residential and vegetation, similar to (Butt et al., 2015; Haque & Basak, 2017; Valta-Hulkkonen et al., 2005). Possibility of usage of the more thorough data model is also an option, but it requires additional fieldwork, desktop research, and redefinition of the main goal of the monitoring (Jackson et al., 2016; Rawat & Kumar, 2015; Szatmári et al., 2016). For every individual epoch and according to every feature mapped, the results are shown both graphically and numerically (tabular), similar to the examples (Alphan, 2003; Pflugmacher et al., 2012; Salinas-Melgoza et al., 2018). The analysis of the results of the treated features was conducted both separately and by the comparison between each epoch, like in (Cissel et al., 2011; Daigle, 2010; Liu & Yang, 2018).

We assume that the methodology used and the results presented would cause, and potentially initiate, more thorough analysis and the monitoring of the Bovan Lake, as well as other areas.

1. Method and materials

Location description and choice of materials

The Bovan Lake is located in the eastern part of the Republic of Serbia, near the Bovan settlement, in the region called Sokobanjska Moravica. The lake itself is an artificial accumulation, which was formed by the creation of a dam on the Moravica River. The reason for the building of such a dam was the regulation of the Moravica River basin, with the main goal of flood control, prevention of the accumulation of sludge and dirt from the Mountain Rivers, and the water supply of the larger settlements that are located in the vicinity (Aleksinac, Soko Banja, Ražanj).

The Bovan Lake is 14 kilometers away from the Aleksinac town and 9 kilometers from the Soko Banja. It is located near the regional road Aleksinac-Soko Banja-Knjaževac. The lake is 8 kilometers long with its maximum width of 500 meters and 50 meters depth. At the Bovan Lake banks, there are two settlements – Bovan and Trubarevac, and a number of weekend resorts. The body of the dam is constructed by laying the stone with the central core made of clay and it possesses additional filtration layers. The dam itself is 52 meters high, with 151 meters of length at its top and 6 meters of crown width. The total gross capacity of accumulation is 58.75 million m^3, with a useful capacity of 19.5 million m^3. Since the creation of accumulation, the analysis of the impact on the living environment was not performed, except for the part that considered the quality of the water and the amount of deposited mud. The water quality is not at the required level and if this trend continues with the same intensity, the accumulation filament will reach a normally slowed level in 93 years. By analyzing the aerial imagery from the archive of the MGI for the area of the interest, aerial images that meet the given criteria, which means epoch, scale, and quality were chosen (MGI). The aerial imagery from three epochs were chosen and those are aerial images from 1969, 1980, and 2010. Imagery that originates from 1969 are panchromatic images taken at 1:32500 scale using an RC-8 camera with the focus of 153.3. Imagery from 1980 is also panchromatic, at 1:26000 scale taken by RC-10 camera with the focus of 115.24. The most up-to-date imagery from 2010 were taken with an UltraCamXP digital photogrammetric camera, with a 40 cm resolution. It is worth mentioning that all of the listed aerial images were collected for topographic map creation purposes.

2. Data preparation and processing model

For the epochs of acquisition from 1969, and 1980, it was necessary to scan aerial images. Aerial images taken during these two epochs were in the form of analogue aerial images so they had to be transformed into digital form in order to conduct the analysis. For those purposes, well-known digitalization methods were used (Bakrač et al., 2018; Wrobel, 1991) together with the DeltaScan-6 scanner. The main goal of primary processing is the creation

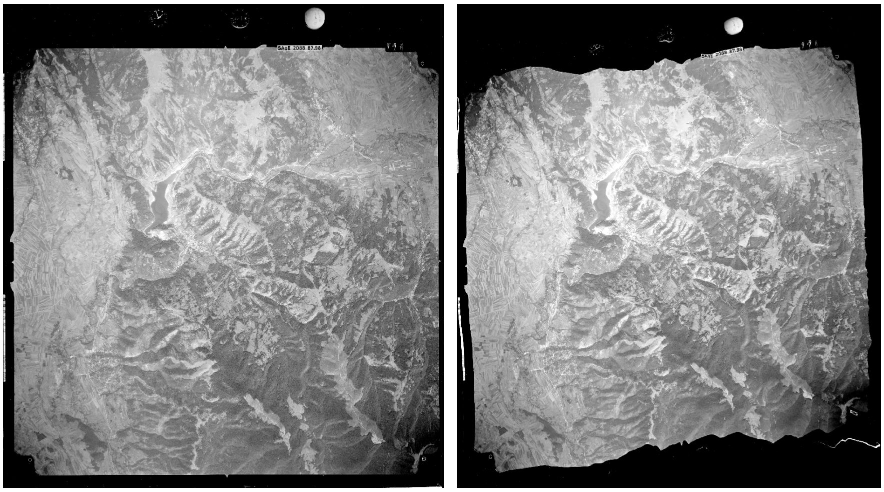

Figure 1. The appearance of the „raw“ image (left image) and orthorectified image (right image) from 1980 (source: MGI, 2020)

of orthophoto images for the given epochs of acquisition (Figures 1, 2, and 4). The entire procedure was conducted through the following activities: provision of the digital elevation model, provision of the control points, orthorectification of individual lines of the imagery, the radiometric correction of digital orthophotos, mosaicking of the orthorectified images, assembling of the orthophoto map and finally, quality control of created orthophoto map (Wolf et al., 2014).

The orthophoto images were produced in the LPS (ErdasImagine software package) using a similar workflow and method as in (Pinto et al., 2019). The results are given in Figure 1.

3. The data modelling in 3D and 2D restitution

The photogrammetrical 3D processing was conducted for the purpose of the creation of the elevation terrain model (Wolf et al., 2014) in form of the digital terrain model (DTM) and the acquisition of the information about the relative height of the features. 2D processing was performed in order to acquire planimetrical orthorectified data from the images (Linder, 2009; Pinto et al., 2019). Based on the stereo models created in the phase of preparation of these data for the photogrammetrical 3D mapping, the extension for ArcGIS – ERDAS Stereo Analyst for ArcGIS was used.

For the purpose of the 2D processing, from the base DTM, height points and lines were generated and, the content created in the 3D restitution was adapted for the usage in the 2D restitution in the central geodatabase environment. Data processing is conducted according to the existing data model, with respect to basic cartographic and topological rules as well as the symbology for mapped elements.

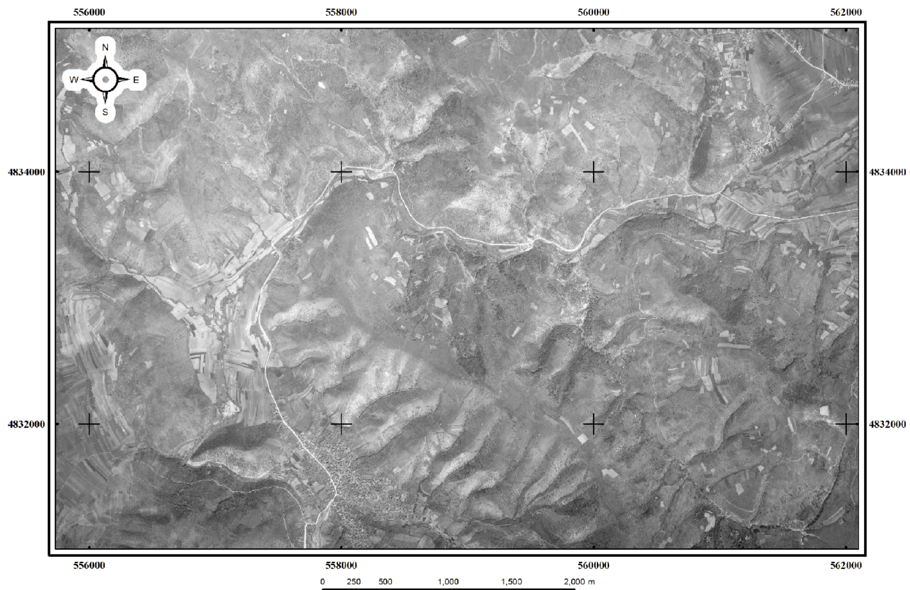

Figure 2. Orthophoto based on the historical aerial photographs from 1969 (source: MGI, 2020)

3.1. 3D restitution method

The goal of data acquisition for spatial features in 3D is the information about the terrain height or the feature heights related to terrain (Linder, 2009). For the purpose of this research, the DTM, which is generated based on the vector level lines shown on the topographic maps created by MGI at 1:25000 scale, was used (MGI) (Figure 3).

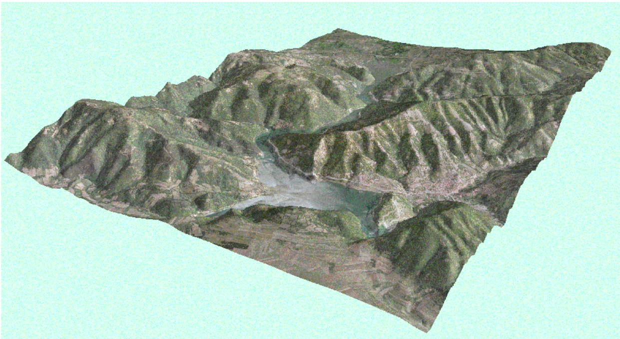

Figure 3. Perspective view of the Bovan Lake area (ortophoto from 2010 over the DTM) (source: MGI, 2020)

The level of detail and the accuracy of this model fully meet the requirements which are necessary for conducting this analysis. For example, if analysis of the influences and the estimation of the potential flood damage is required (Kourgialas & Karatzas, 2011), this model would be able to provide good estimation, but, for the purpose of undertaking measures for flood protection, more accurate and detailed DTM would be required. The contemporary tendency is, that for the creation of the more accurate DTM, LIDAR systems are to be used (Firoz et al., 2018; Liu et al., 2007). Such data, taken from the LIDAR sensors, in the combination with the aerial photogrammetrical data, would be able to provide accurate, three-dimensional information about the spatial features and their behavior, whether they are natural (land surface, vegetation) or artificial features.

3.2. 2D restitution method

After the phase of the 3D restitution, the 2D restitution phase (mapping) was performed. The first step was the adjustment of the 3D data, which were taken from their natural 3D environment, for usage in the 2D environment. The second phase considered mapping and processing of the rest of the elements according to the adopted logical data model, physical data model, and the corresponding symbology in the ESRI software. The required attributes for the corresponding elements were also stored in the geodatabase. In this phase of the 2D restitution, previously mentioned cartographic sources were used with the respect to the standard cartographic rules (Robinson & Kimerling, 1995), elements of the hydrography were mapped first, followed by the road structure as well as the other communications and the features related to them followed by the anthropological constructions and the vegetation coverage. In order to group all of the collected data in one single

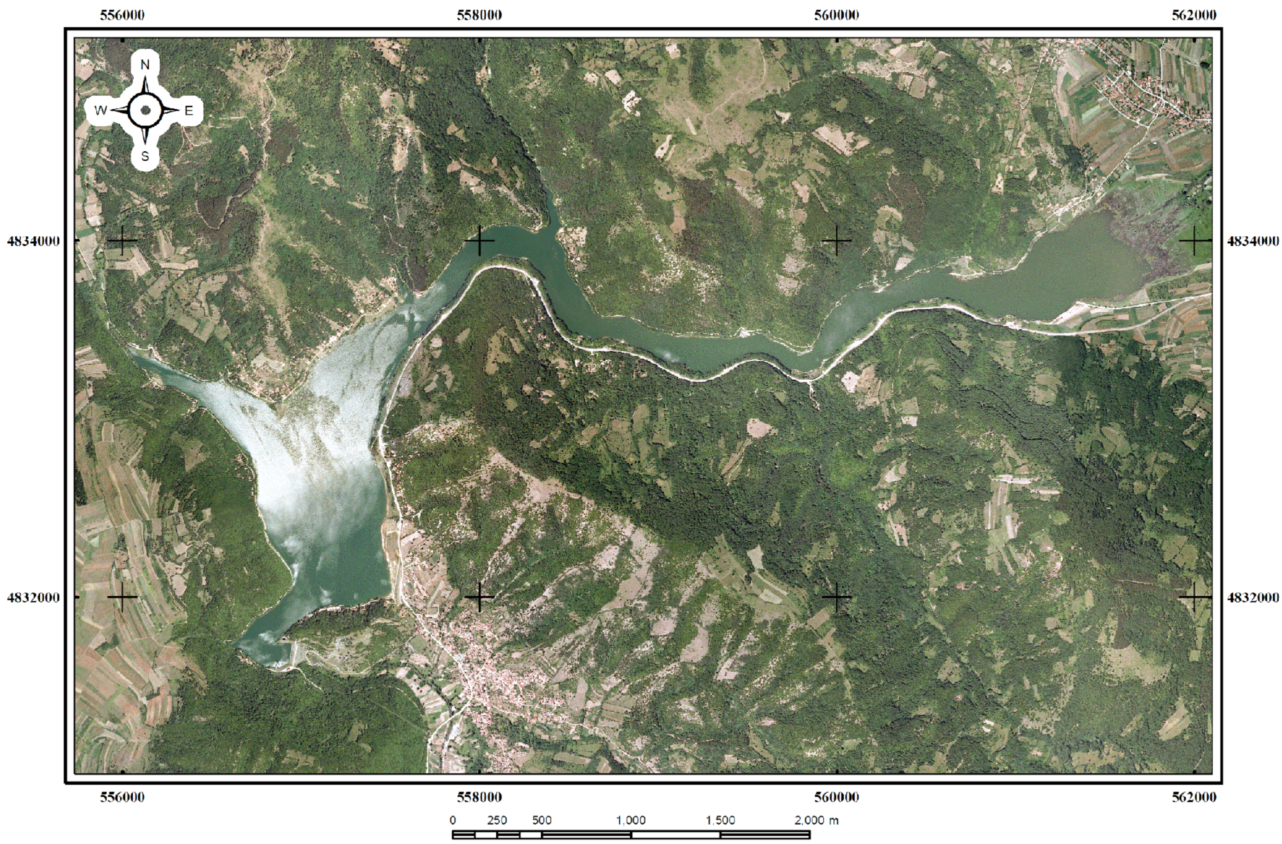

Figure 4. Orthophoto based on the aerial photographs from 2010 (source: MGI, 2020)

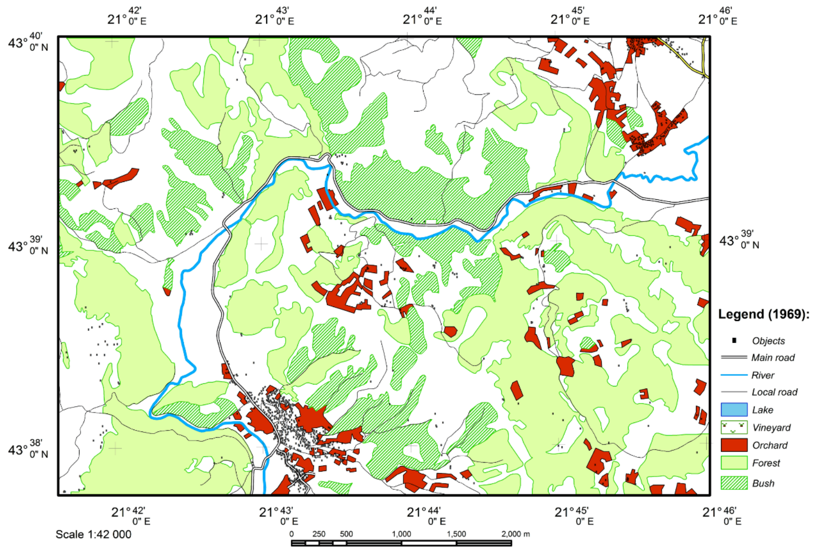

Figure 5. The mapped content from 1969 (source: MGI, 2020)

place for easier processing and additional possibilities, the central geospatial database was created, from which it was possible to generate special maps and different views. The advantages of the production process based on the central geospatial database are numerous, from which, maybe the most important are easier data access, multiscalar view, easier data administration, redundancy elimination, formalization, and standardization (Atzeni et al., 1999). This approach decreased the time necessary for the creation of special maps required for this research (Figures 5, 6 and 7).

4. Results

The results obtained by the analysis of the historical orthophoto images are shown according to the year of the acquisition (1969, 1980, 2010), graphically as well as analytically. The graphical presentation is performed through mapping, by creating special maps respectively (Figures 5, 6, and 7). Analytically, the areas and lengths of the treated entities were analyzed and presented in Figures 8 and 9, Table 5. The mapping was performed directly in a central geodatabase. By using the basic functions of the database, we were able to get numerical values for shapes (areas) and lengths for analyzed features. The data models, both logical and physical, are structured using the standard approach (Atzeni et al., 1999). The total areas of the image blocks, according to the epoch of the time of the acquisition are equivalent. From the features that were identified on the acquired images, eight were found to be significant for mapping for this research. These features are hydrography (rivers, lakes), the road network (main roads, local roads), constructions, and vegetation (forests, orchards, bushes). The same number of analyzed features were used in similar researches (Butt et al., 2015; Haque & Basak, 2017; Valta-Hulkkonen et al., 2005).

All of the features were mapped, the hydrography was limited to the Moravica River and the boundaries of the Bovan Lake. The mapped vegetation coverage was treated as the forests, bushes/low plants, and the orchards and the road network, according to their significance, as main or the local roads. The areas that were classified as the meadows, construction sites, and urban areas were not mapped since they possess very low or no impact at all on the results of this research. Nevertheless, the option for the more detailed classification of the basic features remains open, which would allow more comprehensive analysis (Fensham & Fairfax, 2002; Jackson et al., 2016; Morgan & Gergel, 2013). This approach requires a previous analysis of the features that need to be collected and analyzed. Also, it would be necessary to precisely define the goals of such monitoring, as were done in (Sun, 2000a; Szatmári et al., 2016; Valta-Hulkkonen et al., 2005). It is always possible to upgrade or change the data models according to the new requirements with (mostly) insignificant engagement of resources and adaptation of the existing data to the new data model (which requires (mostly) significant engagement of the resources).

4.1. Analysis of constructions monitoring

By analyzing the constructions (Table 1, Figure 8) it is determined that the number of constructions for the time period from 1969 to 2010 – between the first and the last image acquisition, increased from 889 (in 1969) to 1179 (in 2010) with the middle epoch (1980) showing 537 constructions.

Table 1. Constructions in the area around the Bovan Lake during 1969–1980–2010

1969	1980	Change %	2010	Change %	Change %
Number	Number	1980–1969	Number	2010–1980	1969–2010
889	537	–40	1179	+119.6	+32

Table 2. The vegetation in the area around the Bovan Lake during 1969–1980–2010

Land use/cover categories		1969		1980		Change %	2010		Change %	Change %
		Square meters-m^2	%	Square met.-m^2	%	1980–1969	Square met.-m^2	%	2010–1980	1969–2010
Total Vegetation		1,278,3226 m^2	100	1,325,0283 m^2	100	+3.65	1,790,9614.1 m^2	100	+35	+40.1
Vegetation	forest	817,1342.1	63.9	924,6628.1	69.8	+13.2	1,575,6815.6	88	+70.4	+92.8
	bush/low plants	352,8506.2	27.6	326,0669.6	24.6	–7.6	130,2271.2	7.3	–60	–63.1
	orchard	108,3377.7	8.5	74,2985.3	5.6	–31.4	85,0527.3	4.7	+14.5	–21.5

It is evident that the incrementation in the number of the constructions is caused by an increased number of residential constructions, which are mostly located in the vicinity of the banks of Bovan Lake, which implies that those are weekend cottages.

4.2. The analysis of the vegetation coverage monitoring

The analysis of the total changes of the vegetation coverage that occurred over the analyzed period shows that in 1969, 1278 ha was under the vegetation coverage, in 1980, the vegetation coverage spread over 1325 ha of the analyzed area and, about 1791 ha in 2010. A significant increase in the vegetation coverage (over 35% increase) had occurred in the period between 1980 and 2010. The total increase of the vegetation coverage for the analyzed period is 40% (Table 2, Figure 9).

The area under the forest was growing continuously from 817 ha in 1969, over 924 ha in 1980, to 1576 ha in 2010. In the summary of the vegetation coverage, forests took the largest percent. Such as the percentage of the forests in the total vegetation coverage took 63.9% in 1969, 69.8% in 1980, and 88% in 2010. For the same time period, the lower vegetation took 352 ha (27.6% of the total area under vegetation coverage) in 1969, 326 ha in 1980. (–7.6%) and reached the level of 130 ha in 2010, which is a significant decrease (–63%) in comparison to 1969. The area under orchards has slightly recovered over the period between 1980 and 2010, compared to the time period between 1969 and 1980 when the percentage of the area under orchards was decreased by 31.4%.

When summarized, for the time period between 1969 and 2010, a decrease of 21.5% of the area under orchards is evident. This decrease in the area under orchards is considered to be the direct consequence of the inundation and the very creation of Bovan Lake and, indirectly, the consequence of the decrease in the number of agricultural households.

4.3. The analysis of the hydrography monitoring

As mentioned, two hydrography features were analyzed, the Moravica River and the Bovan Lake. After the analysis, it is concluded that the Moravica River was inundated by the creation of the Bovan Lake accumulation in a length of 9.1 km (Table 3, Figure 8). In the analyzed area, from the Moravica River, only 1.7 km of the river flow remained, which is an 84% decrease in comparison to the length which is recorded on historical aerial photography from 1969. It is important to note that, according to the historical aerial photography from 1980, the entire area of interest was partly inundated, thanks to the work in progress on the Bovan dam. The calculated area of the Bovan Lake, while in full capacity, based on the aerial photography from 2010 is 2,191,584.2 m^2 or about 219 ha.

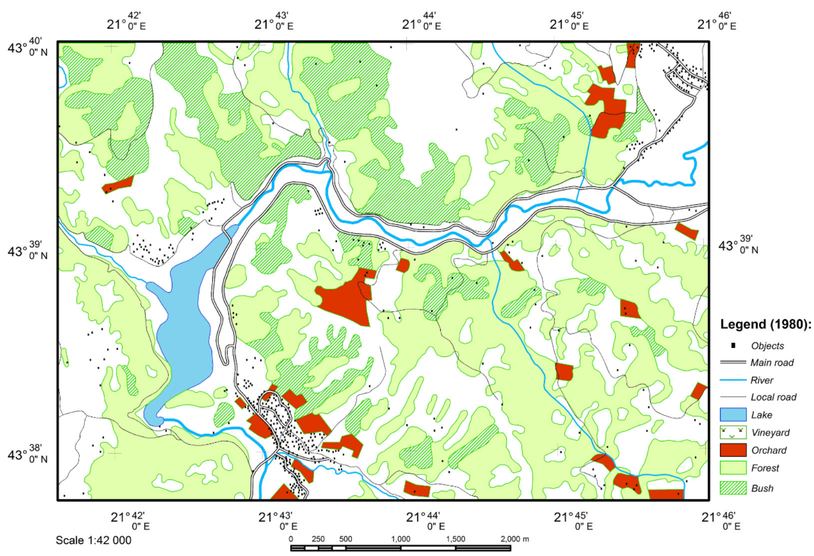

Figure 6. The mapped content from 1980 (source: MGI, 2020)

Table 3. Hydrography in the area around the Bovan Lake during 1969–1980–2010

Land use/cover categories		1969		1980		Change %	2010		Change %	Change %
		Square meters-m^2 Length-m	%	Square meters-m^2 Length-m	%	1980–1969	Square meters-m^2 Length-m	%	2010–1980	1969–2010
Hydro-graphy	Moravica River-m	10 859.2 m	100	8273.2 m	100	–23.8	1696.6 m	100	–79.5	–84.4
	Bovan Lake-m^2	0 m^2	0	54,2829 m^2	100	+100	219,1584.2 m^2	100	+303.7	+303.7

4.4. The analysis of road network monitoring

The analysis of road network was conducted based on the mapped content, considering changes in the length of the main roads (solid/asphalt base) and the local (dirt) roads (Table 4, Figure 9). The given results show that, in the road network structure, local roads are dominant over the main roads and that the total infrastructure length, for the time period between 1969 and 2010 was cumulatively increased by 11.8%. For the time period between 1969 and 1980, the total road network length was decreased by 21.2%. When summarized, for the time period from 1969 to 2010, it is noted that the length of the local roads is increased by 2% compared to the length of the main roads. It is also notable that the main road length was increased by 83.5% in the given time period, while, at the same time, the length of the local road was decreased by 36.1%. The changes in the road network structure were not linear over the given time period. From 1980 to 2010, the decrease in the main road length was almost 40% and the increase in the local road length was 75.5%.

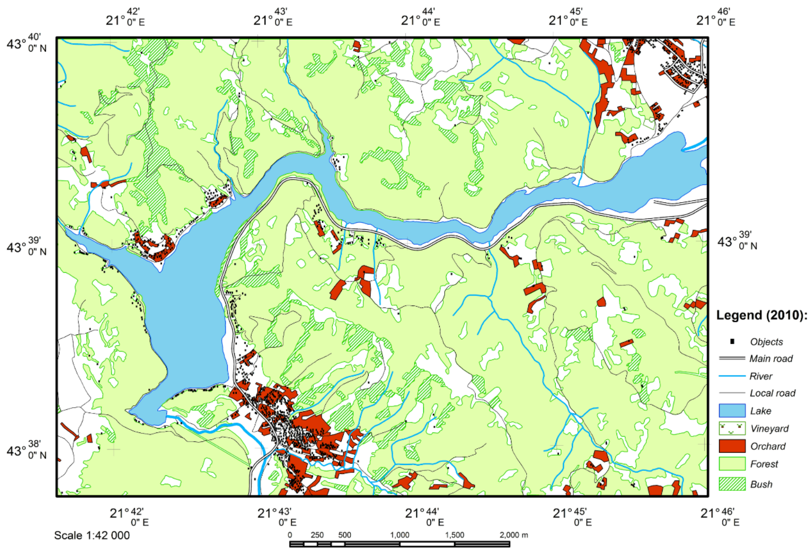

Figure 7. The mapped content from 2010 (source: MGI, 2020)

Table 4. Roads in the area around the Bovan Lake during 1969–1980–2010

Land use/cover categories		1969		1980		Change %	2010		Change %	Change %
		Length-m	%	Length-m	%	1980–1969	Length-m	%	2010–1980	1969–2010
Total Road		85,982.5 m	100	67,752.3 m	100	–21.2	96,147 m	100	+41.9	+11.8
Road	main road-asphalt	10,732.5 m	12,5	19,696.7 m	29	+83.5	11,824.2 m	12.3	–40	+10.2
	local road-macadam+ dirt road	75,250 m	87,5	48,055.6 m	71	–36.1	84,322.9 m	87.7	+75.5	+12.1

5. Discussion

Our research had presented a successful implementation of the new work process for the preparation of historical aerial imagery for monitoring changes in the environment. The local case study has been developed in Eastern Serbia, over the narrower territory of Bovan Lake. The methods applied have yielded the methodological framework, which contains multiple methods and processes. Procedures and equipment used (aerial acquisition cameras, photogrammetric scanners, photogrammetric and cartographic software, etc.) have been described. This framework had shown that the spatial information obtained may be used with the accuracy required for the description and understanding of the environmental events and processes. We believe that our methodological framework has the application for a broad range of researchers and elsewhere, for the ones interested in landscape environmental science, socio-environmental patterns and dynamics of spatial changes, long-term planning in the environmental science, and monitoring global changes.

5.1. Method and materials

During the first phase of the implementation of the photogrammetric method, selected aerial images from the MGI archive have been used for three epochs: 1969, 1980, and 2010. During this phase, we have presented the path from the collection of the raw information – aerial imagery; over their processing (scanning and ortho-rectification) to the orthophoto production (Szatmári et al., 2016).

The data obtained had high geometric accuracy (Pinto et al., 2019) and were suitable for use in further quality processing during the next phase of the combined application of photogrammetric and cartographic methods (3D and 2D restitution data modeling). This phase has been performed aiming at the production of digital maps over the narrower territory of Bovan Lake. We believe that the application of our model and methods used provides exceptional conditions for reconstruction and understanding historical patterns and processes, which are the key to understanding the emergence of present conditions (Morgan et al., 2010; Pinto et al., 2019).

The results expected and obtained indicate that our working method is well planned and successfully implemented. There are known examples of monitoring changes of the individual elements (Collier et al., 2001; Tobak et al., 2008) by the other researchers. They have, though in the lesser scope and details (individual features of the environment) similarities to our research. We believe that our methodological framework is specific for its comprehensiveness and the application of the presented methods. It is also specific for a unified presentation of the scientific disciplines applied in photogrammetric and cartographic processing.

5.2. Hydrography and Constructions in 1969–1980–2010

The captured state from 2010 shows increase in the number of constructions by 32% compared to 1969. This information does not represent a significant increase in the number of constructions for the given time period, but it is directly related to the resulting landscape change caused by the establishment of the Lake accumulation. During this research, a significant increase is identified in the constructions that are located in the vicinity of the Bovan Lake banks (Figure 8). This is related to the purpose of these objects because the landscape of the Lake has become attractive for recreational and tourist purposes. A similar case, but with a higher percentage of the construction, occurred in the example of the changes in the land use and urbanization of Adana (Alphan, 2003).

It would be useful to evaluate the risk of the pollution from this potential source (constructions), as it was done in the following examples (Kanakiya et al., 2014; Zhang

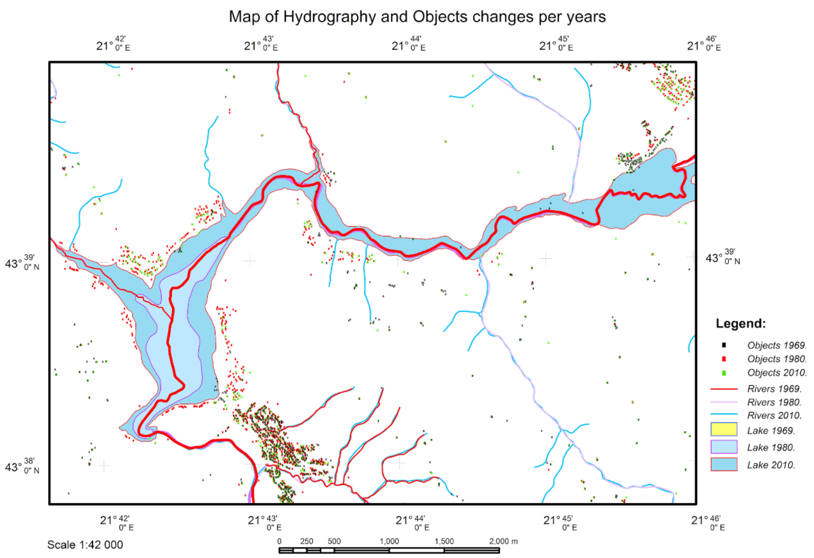

Figure 8. Map of the hydrography and the constructions change over the years (source: MGI, 2020)

Table 5. Elements and size of environmental changes in the area of the Bovan Lake from 1969 to 1980 to 2010

Land use/cover categories		1969		1980		Change %	2010		Change %	Change %
		-Number -Square meters-m^2 -Length-m	%	-Number -Square met.-m^2 - Length-m	%	1980–1969	-Number -Square met.-m^2 - Length-m	%	2010–1980	1969–2010
Total Constructions		889	100	537	100	–40	1179	100	+119.6	+32
Total Vegetation		1,278,3226 m^2	100	1,325,0283m^2	100	+3.65	1,790,9614.1 m^2	100	+35	+40.1
Vege-tation	Forest	817,1342.1	63.9	924,6628.1	69.8	+13.2	1,575,6815.6	88	+70.4	+92.8
	Bush	352.8506.2	27.6	326,0669.6	24.6	–7.6	130,2271.2	7.3	–60	–63.1
	Orchard	108,3377.7	8.5	74,2985.3	5.6	–31.4	85,0527.3	4.7	+14.5	–21.5
Hydro-graphy	River-m	10859.2 m	100	8273.2 m	100	–23.8	1696.6 m	100	–79.5	–84.4
	Lake-m^2	0 m^2	0	54,2829 m^2	100	+100	219,1584.2 m^2	100	+303.7	+303.7
Total Road		85,982.5 m	100	67,752.3 m	100	–21.2	96,147 m	100	+41.9	+11.8
Road	main road-asphalt	10,732.5 m	12.5	19,696.7 m	29	+83.5	11,824.2 m	12.3	–40	+10.2
	Local road-macadam+ dirt road	75,250 m	87.5	48,055.6 m	71	–36.1	84,322.9 m	87.7	+75.5	+12.1

et al., 2008; Gaudėšius, 2020). If the number of the inhabitants would also be considered and analyzed according to chosen epochs, together with correlation to the number of the constructions as well as other analyzed elements (Table 5), this would facilitate the acquisition of additional data and the statistical indicators.

Furthermore, mapped and analyzed data for the two observed hydrographical entities (the Moravica River and the Bovan Lake) shows that, by the building up of the accumulation, the entire area suffered from significant changes in the landscape, and, most likely other changes in the ecosystem (Figure 8). That is yet to be determined, as it was through numerous researches (Arango & Tank, 2008; Johnson & Host, 2010; Wagner et al., 2007). The analysis of the analytic map (Figure 8) shows the landscape change – the appearance of the Lake and the disappearance of the Moravica River. The area covered by the Lake ranged from 0 hectares in 1969 over 54.3 hectares in 1980 to 219.2 hectares in 2010. The loss of the river flow of the Moravica River in the length of 9.2 km is a direct consequence of the formation of the Bovan Lake as an artificial accumulation. This change in aquatic ecosystems has probably caused numerous changes in the living world therein. Also, it is considered that the appearance of the accumulation affected the increase in the number of the objects and the present water pollution, which is stated in the report on the water management strategy on the territory of the Republic of Serbia (Government of Republic of Serbia [GRS], 2015, p. 90). This research did not aim to determine the ecosystem changes and the water quality of the subject area, but it should be determined by some other research according to known examples (Battarbee & Bennion, 2011; Davidson & Jeppesen, 2013; Koff et al., 2016; Baltrūnas et al., 2020).

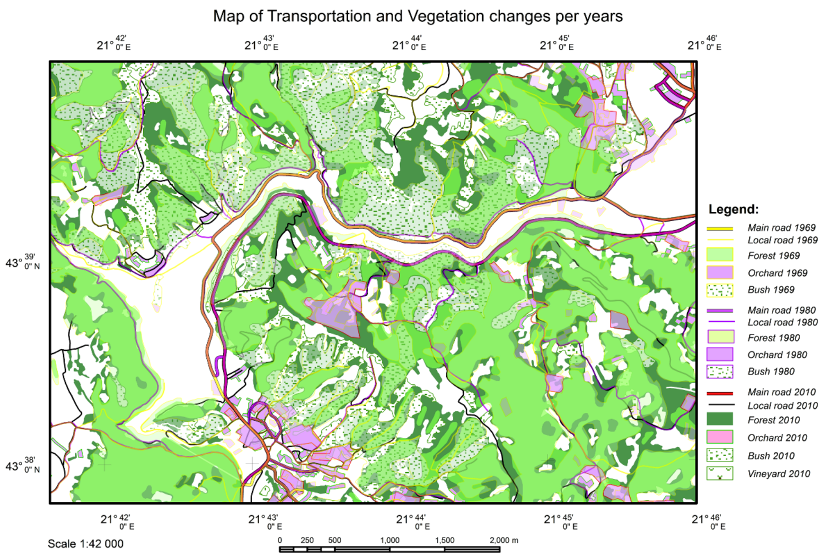

Figure 9. Map of the road network and the vegetation change per years (source: MGI, 2020)

5.3. Road network and Vegetation in 1969–1980–2010

The analysis of the road network shows that the local roads are dominant over the main roads and that the total road length is increased by 11.8%. It is considered that the main reason for lowering the total length of the main roads was inundation caused by the building up of the accumulation. The newest captured state (2010) points to the need for the determination of the ecological impacts on the road structure (Figure 9). That should be done by direct research, as it was done in (Daigle, 2010; Spellerberg, 1998; Switalski et al., 2004). It would also be very useful to establish ecological and comprehensive monitoring over the existing roads in order to track and predict different influences, as in examples (Sun, 2020b; Drobnjak et al., 2016; Falk et al., 2007).

About the predictions of the future condition of the road network and its impact on the given area of interest, it is very difficult to calculate and give the exact prediction. It is highly likely that the current state of the main roads will stay unchanged in the close future since that further urbanization in a given area is not expected. For the local roads, especially dirt roads, it is not possible to give any serious prediction, since this category of the roads is not systematically maintained and is not of significant importance.

The evident changes in the vegetation coverage structure are mostly pointing at a noticeable increase in the area under the forest over the area under the lower vegetation. This fact is also pointing out the afflux of the overground vegetation biomass. For the confirmation of the accrual of the biomass and its exact quantities, it would be necessary to carry out additional procedures, as in Malhi et al. (2006). The presumption is that the low vegetation grew to become a forest, mostly because of the lack of active households, which is directly related to the appearance of the accumulation. Decrease of the area under the orchards by 21.5% is also directly related to the accumulation, and that decrease is due to two reasons. Over the first period, the main reason was inundation, which was initiated by the creation of the accumulation, and, in the second period, the lack of active households. The total analysis of the vegetation coverage for the time period from 1969 to 2010 also gives the prediction that in the future, the trend of the domination of the high vegetation over the low vegetation will continue, which is known from the cases of vegetation monitoring in the examples (Pflugmacher et al., 2012; Salinas-Melgoza et al., 2018). Based on the obtained data, together with the additional field check, the risk of the potential fire hazard could be identified as well, as was done in (Bańales-Seguel et al., 2018). These data point out the fact that the cultivation in this area is significantly lowered. Based on the measured values, there is a possibility of future analysis and the interpretation of the state and the structure of the vegetation coverage using both statistical and probability methods.

Conclusions

This paper shows the application of the given methodological framework for monitoring environmental changes based on the use of historical aerial photographs. The given methodological framework was established on the basis of the integrated appliance of the previously conducted researches from the various fields, such as remote sensing, GIS and cartography. The results of the applied methodology show the possibilities and potential of usage of the historical aerial photographs for the purpose of the monitoring of the spatial changes in the surroundings of the artificial accumulation – the Bovan Lake. The data that was used for the analysis dates from three different epochs and covers the time period of over 40 years. In this manner, the relevant and accurate information is gathered considering the different ways and the quantities that the creation of the artificial accumulation – the Bovan Lake, affected the chosen elements of the given area.

By this research, the following elements of space were analyzed: construction, main roads, local roads, rivers, lakes, orchards, forests, low plants (Figures 8 and 9; Tables 1, 2, 3, 4 and 5). Each of the analyzed spatial features is dominant in the observed ecosystem and, as such, can be presented as a feature, entirety, corridor, or matrix. The acquired data gives the opportunity to analyze relatively small features as well (bush, individual residential construction) and the advanced visual overview of the environment.

It is considered that by the construction of the artificial accumulation, the total ecosystem stability of the environment was lowered, the new spatial element appeared, but the diversity and the homogeneity (the larger area under forest and the water) are experiencing significant expansion. This analysis shows that the anthropogenic influence, considering most of the spatial features, is relatively insignificant and that the changes that occurred are the result of the spontaneous changes in the environment. The only significant change is in the hydrography layer (river, lake) as a consequence of dam construction and, more directly, the creation of the artificial accumulation. Regarding the observed landscape, there is a growing body of the questions, such as: how does it function, is there any communication exchange among the biotic, abiotic factors, energy, and information, and how extensive is it, which did not get the answers during this research. For these questions to be answered, additional research would be required.

It is ascertained that over the time period of over 40 years, a new landscape progressively replaced the previous one, which could be seen from the usage of historical aerial photography. In the following period, it would be useful to continue monitoring the changes of all the observed features of the given landscape.

This research gives a model for the preparation and processing of aerial imagery as well as its usage in the central database environment. The preparatory actions of the aerial photography and the orthorectification process had fulfilled the prerequisites for their further processing. In this manner, the spatial models were created according to the situation at the moment of the aerial imagery acquisition. By the implementation of these procedures, every aerial image was transformed from the central to the orthogonal projection. The primary processing of the aerial imagery was conducted through the methods of the photogrammetrical 3D and 2D data processing. Further data processing was conducted through vectorisation method in the central database environment while respecting the basic cartographic and the topographic rules as well as the symbology of the mapped elements. The data collected in that manner was used to perform the mapping process of the features in the area of interest.

It can be concluded that this paper gives the demonstration of the possibilities of the usage and the quality of the historical aerial photography for the spatial analysis and the other research that include the living environment in general. This approach should provide a better understanding and the monitoring of the spatial changes that occur over time as well as the possibility to recognize the changing patterns. The analysis showed that this model, with high scientific reliability, may be used for the research.

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