Land use change and monitoring of endangered wetlands using geospatial technologies: A case study of Boyana marsh

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ABSTRACT

A specific feature of the period of transition in Bulgaria in the field of urban planning is that a large part of the newly developed urbanized territories was transformed from their previous purpose (mainly agricultural lands) via detailed urban plans that were very fragmented. When changing the purpose of the land in this way, the procedure is significantly easier than with an Urban master plan, but this leads to many negatives. Thus, the territory becomes significantly fragmented when it comes to the purpose of the properties. This leads to environmental consequences that are overlooked by the officials in charge. One such example is the basis of our present study - the attempt to destroy the Boyana Marsh so that the land can be used for building a residential complex. In this study we examine the application and integration of various types of geospatial technologies for the purpose of land use change detection and monitoring of endangered territories that should be protected. We examine the processes of collecting primary historical spatial data and their combination with two UAV field surveys carried out specifically for this purpose. Based on the collected data, specific analyzes of the affected territories were made. The data and all results are presented in a web application that aims to promote the case study and help garner wider public support for the initiative “Save the Boyana Marsh”.

1. Introduction

In his dedication to Tanyo Michev and Maya Stoynева's book “Inventory of Bulgarian Wetlands and their Biodiversity”, Dr. Petar Beron says the following: “It is enough to go back to the memorable day of April 1951, when along with Tanyo Michev we entered the Boyana Marsh - the day that determined our future as zoologists. Throng of life - birds, water inhabitants, the mystic reeds… - people come from all Europe to see them. But we? We just have to protect the colorful rug of Bulgarian nature - for all of us and mostly for our children” These thoughts of Dr. Petar Beron are particularly relevant in the context of the socio-economic development of our country and the models by which newly urbanized territories are being developed, especially in large cities, where private economic interests significantly exceed the public interest and common sense, which should be leading in the processes of defining policy in the field of territorial and urban planning. One such example forms the basis of our present study. It is about an attempt to destroy the Boyana Marsh - the last natural wetland within the city of Sofia and to use its territory to build a residential complex.

It should be noted that in parallel with the processes of growth of the capital city and the acquisition of new territories for these purposes, in recent years the interest in a number of local problems of the territory has significantly increased and a considerable number of studies have been carried out both by the municipal administration and consultant teams (within the project to development of a Vision for Sofia (an initiative launched in 2016), the
activities on monitoring the quality of atmospheric air, monitoring and managing the problems related to the urban heat island, with unregulated dumps, with the projects in within the scope of the activity of the municipal company SofiaPlan, etc.), as well as from the scientific community - for example the study of Sarafova and Petrova (2020) that investigated the ways to improve public awareness of the pm concentration, Sarafova (2020, 2021) on the green urban development units land surface temperature in urban cores of 4 Bulgarian cities, Dimitrov, Popov and Iliev (2021) on urban heat island mapping, Vaceva, Kitev, Genchev (2016) on mapping urban green spaces, based on remote sensing data. (2016), etc.

We should not miss the growing public interest in the problems of the city. A good example in this regard is the civil platform AirBG.info, which in the years before the pandemic quickly gained popularity due to the seriousness of the problem.

The problems of urban planning in the city are also not neglected in the scientific literature. A good example of a study covering the transition period (and more precisely 1990 - 2010) is Zhana Stoycheva’s book Urban Planning of Sofia during the transition (1990 - 2010). The author confirms the trend, which is specific not only for Sofia but also for the spatial planning throughout the country, namely, to work piecemeal, for small territories, and even for individual properties, using what in Bulgaria is called detailed urban plans. This bad practice continues even after that period and due to the significantly easier procedure, it leads to the implementation of a large number of investment projects, inconsistent with the public interest, tearing the structure of the urban space and leading to structural, social, and environmental problems.

The main goal of our research is to explore the different ways of applying and combining different types of geospatial technologies in this specific case of struggle for the protection of an endangered territory. To achieve this objective, we've set three main tasks, all of which contribute to protecting and conservation of the habitat. The first task is to collect, process and summarize historical data. In this way we are able to check whether the hypothesis that the Boyana marsh was formed in the last few years from sewage water is correct. The second task is to make an analysis and monitoring of the damages on the territory by using UAV technology. The third task is to gather all these information in a dynamic user-friendly platform and thus make this case open to the wide public, popularize it and gather a larger number of followers to join the cause of protecting this ecologically valuable territory. The developed GIS application also aims to provide access to up-to-date information on the state of the territory.

In this study, we combined different geospatial technologies as data sources (unmanned aerial vehicles (UAV), satellite data, historical cartographic data) and as tools for their processing and representation. Combining these data, which are different in their actuality and genesis, allowed us to follow both the changes that have occurred in the studied territory over the years, and by using significantly more precise current data from the aerial surveying of the territory done twice with UAV to examine in detail the damage, which was inflicted during the attempts to illegally destroy the Boyana marsh.

The representation of the processed data in an online GIS application allowed us to reach many people and allow them not just to look at a static map of the territory, but also to use the collected and processed data and the toolkit provided in the online application to carry out additional and detailed analyses.

2. Materials and methods

2.1. Case study area and its ecological significance

More than ten years ago, Boyana Marshes was a complex of two wetlands - Upper Boyana Marsh with an area of about 13 000 m² and Lower Boyana Marsh with an area of about 5500 m². The complex of the two marshes was located on the territory of the neighborhood called “Gardova Glava” at the northern foot of Vitosha mountain (Fig. 1.).

![Figure 1. Location of Boyana Marshes](image-url)
After the restitution of agricultural lands (restitution of rights to forcibly confiscated property during the period of the communist regime in Bulgaria) in the 1990s, since the year 2000, these territories have been gradually transformed to territories for residential purposes (Fig. 2). With the update of the urban plan of Sofia in 2008, these territories were designated as part of a new residential zone with low-rise construction (up to 8.5 m on height).

Thus, in the period 2005 - 2010, the Lower Boyana Marsh was declared dry and was destroyed, in the same way as now the owners of the property, where the Upper Boyana Marsh is situated, are trying to cover it with a mass of earth and subsequently develop the terrain for construction of a residential complex. From an engineering point of view, this type of approach is not scientifically sound. Although there is a lack of in-depth geological and hydrogeological studies of this territory, it is considered that the two marshes are supplied by high groundwater with a significant flow rate. This is also the reason that after the construction of a large part of the new buildings in the area, it is necessary to continuously pump the water from their underground floors.

From the point of view of the nature protection status of the territory in the scientific literature, the Lower Boyana Marsh is indicated in the Red List of Wetlands in Bulgaria as 'disappeared' in Stoineva and Michev (2007). In the same paper, the Upper Boyana Marsh is categorized as a critically endangered wetland. The same conclusions were reached by the team that prepared the report on the state of the Boyana Marsh commissioned by the municipal enterprise Sofiaplan. In the final part of this report, the team states that the studied area is the last wetland within the city of Sofia, which, according to the authors, most likely fulfills its ecological functions as a habitat for higher plants, amphibians, reptiles, and birds. As a result of the field research carried out in June 2021, the condition of the marsh has been assessed as extremely deteriorated. However, the authors point out that it could be restored if the factors leading to the strong eutrophication of the reservoir found on site are removed.

In terms of species diversity, the most observations were made in the field of birds. This is largely due to the peculiarities of the terrain around the marsh itself, which make it difficult to study certain species, such as fish, for which observations have not been made at that point. There is also a lack of data on conducted more in-depth research on amphibians. The only modern studies of these two groups have been done by the Sofiaplan team. In terms of birds, the research is much more. From a conservation point of view, they are also the most significant group of species in the marsh area. Since 2019, Georgi Kamov has been actively doing his research in the area. His regular observations show that during the nesting period and during the periods of migration and wintering, 116 species of birds were observed around Boyana Marsh, which is nearly 40% of those found in the territory of Sofia Municipality. During the one-time observations carried out by the SofiaPlan team, 20 species were observed (on 03.06.21 by Lyubomir Profirov) and 13 species (on 11.06.21 by Nevena Ivanova). As part of the Global Big Day initiative held on 05/14/2022 on the eBird platform, 19 species of birds were registered around the marsh.

Figure 2. Development of the territories around Boyana Marshes.

Figure 3. View of the Geocartfund portal when searching on the map for available datasets.
2.2. Initial historical data

To carry out part of the task, namely, to prove the historical existence of the marsh, it was necessary to select appropriate archival data on which it was mapped. For this purpose, a study of the archival materials available in the State Geodetic, Cartographic and Cadastral Fund (Geocartfund) of the Geodesy, Cartography and Cadastre Agency (GCCA) was carried out. The study began in the online portal for administrative services of Geocartfund at https://gkf.cadastre.bg/ (Fig. 3).

After analyzing the content of the different data arrays that cover the studied territory, we focused on three of them as potential sources of primary information for our purposes.

- **Balance of the territory** - as a data array is a set of topographic maps at a scale 1:25 000, on which the boundaries of the administrative and territorial units (existing at the time of the preparation of the maps - district, neighborhood, land boundaries etc.) are marked by a manual drawing method, as well as the main types of land use. For the studied territory, two maps with the nomenclature K-34-59-Б-а are registered in the system, from 1956 and 1969, respectively. Both maps were prepared based on a topographic map with a scale 1:25 000, prepared in 1935 and published 1953.

- **Topographic maps at a scale of 1:5000** - Two relevant scanned map sheets are available in the online system - a 1990 offset print (issued 1991) in 1970 coordinate system (CS) and another from 1957, issued 1959 in CS 1950.

The rest of the available materials were rejected from the selection at this early stage of the study, because by definition they do not contain the information we need.

The survey continued on-site at the GCCA Geocartfund, where a meeting was held to review the materials themselves. Very useful materials were found as a result from the meeting - a map of the balance of the territory from 1967 (Fig. 4), showing clearly the lower Boyana marsh. Probably due to the smaller scale of the topographic map that served as the basis of the 1967 balance of the territory, only the Lower Boyana marsh was marked on it, and now it doesn't exist for more than 10 years. Furthermore, there are two topographic maps in a scale of 1:5000, proving that the existence of the marshes dates back as early as 1957 (Fig. 5).

At our meeting at Geocartfund, we also found a topographic map from 1978 with the same content as the 1990 map (a high-quality color image on which both marshes are mapped) (Fig. 6). Unfortunately, this map has not been scanned and for now is paper only.

The selected images were georeferenced and added to the other datasets in the geographic database. Based on those maps (Fig. 6) the extent of the Upper Boyana marsh was digitized.

A problem in providing the necessary historical data turned out to be the scale of the study. Most of the materials that can be provided and cover the surveyed territory are developed on a smaller scale that does not allow the mapping of such a small object as the marsh.

![Figure 4. Part of the balance of the territory map (1967).](image-url)
Figure 5A. Topographic maps - Scale 1:5 000 from 1990.
Figure 5B. Topographic maps - Scale 1:5 000 from 1957.
2.3. UAV mapping of the affected area

Within two weeks in the first half of May, we completed two aerial surveys of the study area with an UAV. The machine used for the survey was DJI Mini 2, equipped with a 1/2.3” CMOS 12-megapixel sensor.

The missions that the UAV completed to photograph the territory of the marsh were manually piloted and took 15 minutes each. The two flights were carried out at the same height - 50 m, and the average flying speed of the UAV was 4.5 m/s. (Fig. 7)

The first aerial survey took place on 02.05.2022 at 17:30. Weather conditions were favorable for the purpose. The sky was covered with clouds, resulting in clear footage without sharp shadows, and the result was a homogenous orthophoto image with good contrast.

The second flight was carried out two weeks after the first, on 16.05, in the same time slot. The clear sky and strong sun caused the photos to have sharp contrast and strong shadows.

The total number of photos for each mission was about 150, and this number allowed a good overlap of the individual images (Fig. 8) and resulted in obtaining a high quality orthophoto.
The processing of the images was carried out in the photogrammetric software Drone Deploy. The program reads the geographic coordinates in the metadata of the photos and creates a spatially referenced orthophoto mosaic.

The accuracy that was achieved during the survey of the study area is as follows:

- pixel size of orthophoto mosaics 16 mm.
- average measurement accuracy of 41 cm, with an average variation along X - 28.6 cm, along Y - 21.3 cm and along Z - 61 cm.
- positional accuracy of the whole model 10 m, due to lack of RTK / PPK corrections.

**Figure 8.** Overlapping of the photos, 02.05.
3. Results

3.1. Historical overview of the study area

The archival geospatial data collected from the GCCA Geocartfund and through Google Earth Pro clearly prove the existence of the two marshes on the territory of the neighborhood long before the beginning of the urbanization of this part of the city. The review of the scientific literature regarding the species diversity within the research site shows the presence of many species, a significant number of which are protected under the Bulgarian legislation. The number of bird species observed is the largest. For some of the other species, such as fishes, more extensive research should be done to show the current status. The research carried out by ecologists in recent years clearly indicates that the condition of the marsh has greatly deteriorated, which necessitates the taking of urgent measures for its protection.

3.2. Analysis of the data collected through UAV

After the first survey of the study area was taken, the prepared orthophoto image was used jointly with satellite images to identify the area of the Upper Boyana marsh, together with the adjacent territories affected by the land mass burial. Initially, the areas of the intervention carried out at that moment (02.05.2022) were identified and mapped together with the part of the marsh that was not affected. With the second survey of the territory, carried out on 16.05.2022, we found that, despite the implementation of construction works within the studied territory during the period between the two surveys, our expectations that there would be new parts of the marsh covered with earth masses were not justified. What we could assume after having also made field observations, is that additional earth masses were laid on top of the already buried parts of the territory. Unfortunately, to give a more adequate assessment of this hypothesis, a new survey with a higher-class UAV is needed. That would allow us to generate a high-accuracy DTM, needed for this analysis. After the second survey, the data of the affected area was further processed, and the information was detailed. Three types of territories were identified - Water surface with an area of 7851.87 m² and an approximate share of the total area of 71.52%, buried adjacent territories - 2780.93 m² (25.33%) and buried parts of the water surface - 345.26 m², which represents 3.15% of the total area (Fig. 9).

| Territory               | Area (m²)   | Share of the area (%) |
|-------------------------|-------------|-----------------------|
| Water surface           | 7851.87     | 71.52                 |
| Buried adjacent territories | 2780.93   | 25.33                 |
| Buried parts of the water surface | 345.26 | 3.15                 |

Figure 9. Affected territories.
The positive conclusion that we can draw from the analysis of the data from the two surveys is that indeed a very small part of the original area of the water mirror is affected. This gives hope that slowly, naturally, the marsh could recover to near its original extent.

3.3. Development of a specialized online GIS application

To achieve greater publicity of about what is happening in the study area, as well as to spread the achieved results, an interactive online GIS application was developed. The application was developed based on modern technologies provided by the online platform of the company ESRI Inc. The specific platform on which the application is developed is ArcGIS Web AppBuilder. The application uses an online interactive map that presents the orthophoto images generated as results of the two surveys, the different types of affected areas mapped, and a satellite basemap that allow the comparison of the state of the marshland before and after the intervention. It also visualizes the topographic maps purchased from the GCCA Geocartfund (Fig. 10).

While the activities on the development of the online GIS application were carried out, the results of the mapping of the Boyana marsh as a water body, commissioned by the Municipality of Sofia, were released. The coordinates of the endpoints forming the outline of the marsh were generated as a layer in the database. Based on these coordinates, the image of the map prepared by the mapping team of the potentially flooded territories at 5% and at 1% security was also georeferenced, i.e., with a probability of flooding occurring once in 20 and once in 100 years. A data layer was also generated on the extent of potentially flooded areas. This data was also published in the online application.

In terms of tools, the application offers the standard options to control the view and layers, including the basemap. An information button is included in the application interface, which includes an additional panel with brief information about the Boyana marsh and the current situation. The possibility of making measurements of areas and lengths is also provided. The application also offers several preset filters – visualizing only the water surface of the marsh, visualizing all affected areas or only those that are within the water surface. When setting a filter, the system automatically zooms in to the range of territories that are currently visualized. The application also includes a dynamic graph of the areas subject to the study, by type (Fig. 11). Through it, the data on the area of each type of territory can be examined, as well as the relative share of the total area. The set filter tools, and the area plot are functionally linked, enabling the set filters to be automatically reflected on the map as well.

Figure 10. Interface of the web GIS application.

Figure 11. Dynamic graph of the affected areas.
The last interactive tool that is integrated into the application allows a comparison to be made between the base map (satellite image) and a historical satellite image from July 2000 downloaded from the Google Earth Pro platform (Fig. 12).

4. Discussion

The combination of data different in their genesis and characteristics provide opportunities for solving different type of research problems. The historical data used in the present study categorically disprove the thesis that the Boyana Marsh was formed within the last 15 years as a result of the illegal discharge of wastewater from the newly built residential buildings. Of course, considering the type of water supply of the marsh (from groundwater) it can be expected that it has existed for a rather long period, as is also evident from the archival topographical maps. In this part of the task, other additional sources of information could be used - materials from the territorial balance maps, archival orthophoto images, etc. Here, the big problem that arises is the small size of the studied territory. For this reason, it is uncertain how well the object would have been distinguishable with imaging technology from the middle of 20th century. At the same time, the order for receiving such types of images does not include the possibility of their preliminary detailed review.

From the point of view of the current state of the site, the data collected by UAV clearly showed the size and extent of impact on the territory, allowing certain conclusions to be drawn. It would be useful here to combine these data with data from other types of sensors - for multispectral imaging (for easier identification and evaluation of the affected vegetation cover), LIDAR (for evaluation of the amounts of land masses used and the change of relief forms, as well as for a quantitative assessment of the destroyed vegetation), etc.

5. Conclusions

Regarding the first of the tasks set before the research, we can summarize that the archival data used easily and categorically confirmed the hypothesis of the existence of the Boyana Marsh in historical terms. Of course, these materials could be supplemented with more archival data, but we believe that this would exceed the needs of the specific task.

Concerning the second task, the monitoring of what is happening with the territory of the swamp now, use of UAV provides the necessary opportunity for quick and regular collection of highly accurate from a spatial point of view data. This, in turn, allows the implementation of continuous monitoring and analysis of the affected territories and the taking of timely measures to limit the harmful impact on the territory and the plant and animal species inhabiting it.

The use of online GIS technologies allows the data collected in the field to quickly reach a larger audience, while at the allowing to those interested to examine this data in detail and to carry out their own analyzes with it. The data in the online GIS application can easily be edited and supplemented with new ones to keep its content as up to date as possible. In this way, tracking the development of a similar case in the field of environmental protection becomes easy, accessible to all interested citizens, which allows achieving greater publicity, which is of particular importance for the case to gain greater public burden. In this way, responsible institutions can be pressured to act in defense of the public interest rather than private economic interests.

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References

Dimitrov St, Popov A, Iliev M (2021) An Application of the LCZ Approach in Surface Urban Heat Island Mapping in Sofia, Bulgaria, Atmosphere, October 2021, DOI: 10.3390
Gyosheva B, Naumov B, Kazakov St, Ivanova N, Profirov L, (2021) Study of conservation-important species of fish, amphibians, reptiles, birds, lower and higher plants in the area “Gardova Glava” in Boyana and assessment of their condition and of the ecosystem as a whole, 2021, municipal enterprise Sofia plan, Sofia
Sarafova E, Petrova M (2020) IMPROVING PUBLIC AWARENESS OF THE CONCENTRATION OF PM THROUGH OPEN IN-SITU AND SATELLITE DATA. Proceedings of scientific conference
“Geography and Regional Development – Sozopol”, LOPS Foundation. September 2020.

Sarafova E (2020) How green the urban development units in Sofia are: Earth observation and population time series analysis, Journal of the Bulgarian Geographical Society, Volume 44 (2021) 25–37, DOI 10.3897/jbgs.e69814

Sarafova E (2021) Analysis and visualization of the land surface temperature in urban cores of Sofia, Plovdiv, Varna, and Burgas during the summer 2021 heatwave through Sentinel-3 data, Proceedings of scientific conference “Geography and Regional Development – Sozopol”, LOPS Foundation. September 2021.

Stoycheva Zh (2017) Urban planning of Sofia during the transition (1990-2010), “Stefan Dobre” Publishing House, Sofia, 2017, ISBN: 978619705024

Stoyneva M, Michev T (2007) Database of Bulgarian non-lotic wetlands and their biodiversity. In: Michev T. M. and M. P. Stoyneva (eds.) Inventory of Bulgarian Wetlands and their Biodiversity. Part 1: Non-Lotic Wetlands, Publ., House Svetlostrouy, Sofia, 364 pp. + CD supplement

Vatseva R, Kitev A, Genchev S (2016) Mapping Urban Green Spaces Based on Remote Sensing Data: Case Studies in Bulgaria and Slovakia. Proceedings, 6th International Conference on Cartography and GIS, 13-17 June 2016, Albena, Bulgaria. ISSN: 1314-0604

https://airbg.info/ - visited on 12.06.2022
https://ebird.org/hotspot/18810407 - visited on 23.06.2022
https://ebird.org/hotspot/18810407?yr=BIGDAY_2022a - visited on 23.06.2022
https://gkf.cadastre.bg/ - visited on 16.05.2022
https://sofiaplan.bg/projects/ - visited on 23.05.2022
https://vizia.sofia.bg/ - visited on 23.05.2022

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