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Geovisualization Techniques of Spatial Environmental Data Using Different Visualization Tools

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Abstract: The appearance of online map services and frameworks (e.g., KML, QGIS) has increased the possibilities to easily, quickly and—in many cases—cost-effectively publish spatial data stored in databases. The aim of this study is to present the geovisualization of spatial databases of a Hungarian settlement on the web, using the open source webGIS system and Google application programming interfaces (APIs). The interactive point and interpolated distribution maps available online provide a detailed picture of the level of contamination, the spatial distribution of the ground water supply of the investigated settlement, and the changes which have occurred following the establishment of the sewage system. In the case of PO_4^{3-} we determined that in the year before the sewage system was constructed, most of the area of the settlement could be considered contaminated, with the highest level of contamination measured in the central area of the settlement. Five years after the construction of the sewage system, the ratio of the contaminated areas had significantly decreased. In the case of NO_3^- we found a high level of contamination before the construction of the sewage system with a concentration increase in a North–West direction. After the establishment of the sewage system, the increase in concentration was the most intense in the central parts of the settlement, while the characteristic spatial distribution could no longer be observed. The geovisualization techniques developed are able to provide information about the different spatial data for users in a visual way, and also help to understand better the spatial information using a cognitive approach. The advantage of interactive web maps created with the technologies applied over traditional static maps is a new approach, which allows the user to manipulate the temporal and spatial data directly in the most appropriate way.

Keywords: QGIS; distribution map; webGIS; geovisualization; KML; CogInfoCom

1. Introduction

The development of systems providing spatial information (geoinformatics systems, GIS) was the result of the dynamic evolution of informatics and the increasing societal demands for spatial data, which was further increased by the development of the Internet [1]. During the 2000s, parallel with the spreading of network-based geoinformatics systems, the Spatial Data Infrastructure (SDI) was also in development [2]. It is increasingly common that the latest geoinformatics databases are not necessarily stored on the user's computer or in local networks, but rather on the World Wide Web in the clouds, which are visualized in the form of web maps.

WebGIS revolves around web-based visualization of objects and phenomena, technical considerations, the use and usability of web maps and the evaluation and optimization of various techniques. Furthermore, it includes web-based visualization and analysis of spatial data [3]. Even though Graham (2010) differentiates webGIS from web-based cartography, these differences are analogous to the relationship between GIS and cartography. Despite the fact that differentiating features are the same, their boundaries are not clear [4,5]. The development of webGIS technology can be classified into two periods: the early CGI (Common Gateway Interface) based Internet GIS, and the webGIS based on Web 2.0 in which dynamics is key and which is associated with concepts such as neogeography, GeoWeb or geovisualization [6].

During the 2000s, parallel with the evolution of digital culture there was a growing demand for access to geographical information using geovisualization methods [7,8]. The number of users further expanded and, alongside professional data service providers, this now includes individual users as well. To a large degree, the publication of these data was facilitated by the fact that popular map service providers (Google Maps and Yahoo! Maps, Bing Maps, MapQuest etc.) now provide systems free for the visualization of data; however, there are examples of initiatives to standardize, as well [9], the most widespread and popular of which is the Open KML 2.2 Encoding Standard, also known as OGCL KML (Keyhole Inc, Google, Mountain View, California, USA, 2004) developed by the Open Geospatial Consortium (OSGeo, Chicago, Illinois, USA, 2002) [10].

MacEachren coined the word geovisualization by contracting the expression “geographic visualization”; its essence is a new approach to the use of maps. One of its features is that a map is not created for the public but for individual use and its primary purpose is to provide new insights from the data. It supposes an intensive interaction between people and maps in the sense that we can directly manipulate the spatial data to be mapped. If we are talking about visualization, we do not use maps alone, but in combination with other visual aids (charts, tables, photographs, 3D models, etc.). In this sense visualization and communication are complementary events during map use [11].

According to the definition given in [12], cognitive infocommunications (CogInfoCom) “explores the link between the research areas of infocommunications and cognitive sciences, as well as the various engineering applications which have emerged as a synergic combination of these sciences”. This specific multidisciplinary field has already become known in many disciplines, as is proved by several scientific papers containing sections which also examine the cognitive aspects of their results [13–44]. Effective data visualization in digital environment is in the focus of many research works, not only because the amount of data keeps increasing dramatically, but also because of the demand of people who prefer visual experience more and more intensively. In our point of view, the findings of papers [24,26,28,35,38] are of high importance that are about justifying that 2D or even more 3D visualization of data enhances their cognitive interpretation. Due to the increased interest, a comprehensive overview of cognitive infocommunications is already available in the form of a book, which also provides an outstanding theoretical foundation for the topic [45].

The mapping and correct interpretation of environmental data is of great importance in environmental science and environmental policy as well, which is a complex task due to the significant spatial and temporal variability of the data. In our study we aim to facilitate the evaluation of the data with an interactive web map created with open access webGIS tools and geoinformatics software. In this project we analyzed a spatial and temporal database regarding the ground water supply of an Eastern Hungarian settlement. Among others, the novelty of our study lies in the fact that even though the application of various geovisualization technologies are common in environmental sciences, the geoinformatics processing and complex online presentation of urban environmental data have not been investigated yet. Furthermore, the methodological comparison of applied technologies is not included in research aimed at environmental problems.

By using the example of the contamination of the groundwater supply of an Eastern Hungarian settlement, in our study we aimed to answer the question whether free geovisualization techniques (QGIS, KML, Google APIs) are suitable to create such automated methods, as a result of which—with

the publication of spatial data on the web—the end user may gain additional information on the investigated subject through their senses. In addition to the above, we investigated whether these 2D or 3D geovisualization techniques are more effective than the printed maps from various sources or not. With help of this techniques we investigated the spatial patterns of the phosphate and nitrate contents of the groundwater of the settlement and the changes which had occurred five years after the establishment of the sewage system in the settlement, compared to the baseline. Based on the above, our purpose is to publish and demonstrate the spatial visualization and processing of spatial environmental databases of a Hungarian settlement, and also highlight the power of geovisualization in terms of cognitive infocommunication, using open-access webGIS tools and geoinformatics software.

2. Materials and Methods

2.1. Study Area and Data Collection

Báránd municipality is located in the eastern part of the Great Hungarian Plain (Figure 1). According to our calculations, over the past few decades, 30–40% of the domestic wastewater generated (appr. 120,000 m³ every year) could have seeped into the soil and groundwater [46]. This significant pollution discharge has caused heavy contamination in the settlement [47]. In 2014 a sewage system was constructed in the settlement and therefore the majority of the local sources of contamination were eliminated [48]. During the data collection, 40 groundwater wells were investigated and an environmental database was created. In the sampling process—performed in the summer of 2013 (before the construction of the sewage system) and 2019 (after the construction of the sewage system)—the upper 1 m water surface of the groundwater wells was sampled. The NO₃[−] and PO₄^{3−} content of the collected water samples was determined by the appropriate procedures of the Hungarian Standard [49,50].

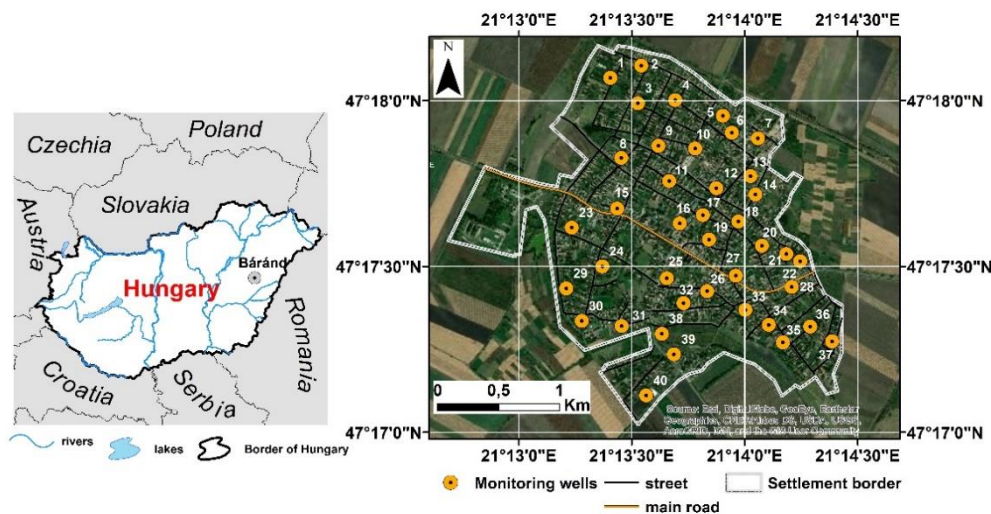


Figure 1. Location of study area and investigated wells.

2.2. Tools of Geovisualization

2.2.1. KML and Google API

The Keyhole Markup Language (KML) is an XML notation developed for describing data about features with a geospatial location, with the objective of geovisualization [51]. Most GIS software and Google Earth are capable of importing and exporting KML files, but for non-professional users it is the graphical user interface that is preferred to generate KML files. The language determining the format belongs to the family of markup languages and organizes its elements into a hierarchical class tree structure where elements can be inherited from the ancestors. The KML Version 2.2, under the name

OpenGIS KML 2.2 Encoding Standard, has been adopted as an OGC (Open Geospatial Consortium) implementation standard for presenting geographic information visually. The Google application programming interfaces (APIs) are fundamentally native JavaScript interfaces which can be used to control the functioning of the map (e.g., Map type, layer management, size, KML management, etc.). Additionally, this helps with managing the KML files so that all of its functions can be used [52].

2.2.2. QGIS and Its Geovisualization Plugin

QGIS (Quantum GIS) is a free and open-source geographic information system (GIS) that supports editing, analysis and publishing of geospatial data in numerous ways, using plugins.

QGIS qgis2web: This plugin generates a web map from the current QGIS project, either as OpenLayers or Leaflet. It replicates as many aspects of the project as it can, including layers, styles (including categorized and graduated), and extent. No server-side software required [53].

QGIS Cloud: This plugin is a webGIS platform for publishing maps, data and services on qgiscloud.com with the public. It can create and edit professional maps with all the capabilities from QGIS [54].

QGIS Qgis2threejs: This plugin visualizes DEM (Digital Elevation Model) data and vector data in 3D on a web view. It can build various kinds of 3D objects with simple settings panels and generate files for web publishing in a simple procedure. In addition, it can save the 3D model in glTF format for 3DCG (3-Dimensional Computer Graphics) or 3D printing [55].

2.3. Data Mining and Geoprocessing

The implementation can be divided into three separate parts (Figure 2). During the data collection phase, we performed laboratory measurements on the samples collected from 40 wells in Báránd settlement. This was followed by the geoinformatics processing of the data, which was performed using QGIS version 3.12.12. Since the water chemistry properties of the wells were recorded in table format with coordinates, it was therefore necessary to import them into a geoinformatics environment. After converting the data into a .shp file and defining the appropriate symbols, we exported them into a KML file.

From the water chemistry properties, we created a regional distribution map using kriging interpolation which was saved as a raster file in GeoTiff format. In earth environmental sciences, interpolation can be considered as primary form of geostatistical analysis, which is often used to predict values in unobserved locations based on the values in observed locations. Ordinary kriging, a type of interpolation, has become a widely used interpolation method for assessment of spatial variation of groundwater quality [56–61]. From this raster file, we created an overlapping map and placed a map legend on it using Screen Overlay. The last phase of the work was running QGIS visualization modules and the inset of Google maps and KML management functions into the website. The mash-up site was created using five different technologies. The visualization of the map and geographical data was implemented using Google Maps Api V3 and KML tools. In order to create the website, we used the Bootstrap front-end framework created by the developer of Twitter and the interactive interface of Sufee Admin. The Bootstrap is primarily based on HTML5 and CSS3 technologies. In order to use the full version jQuery is required, jQuery is a popular framework which emphasizes the connection between the HTML code and client-side JavaScript. The aim of jQuery is to detach the JavaScript code from the HTML as much as possible and to communicate with the HTML items of the webpage through various event controllers and identifiers.

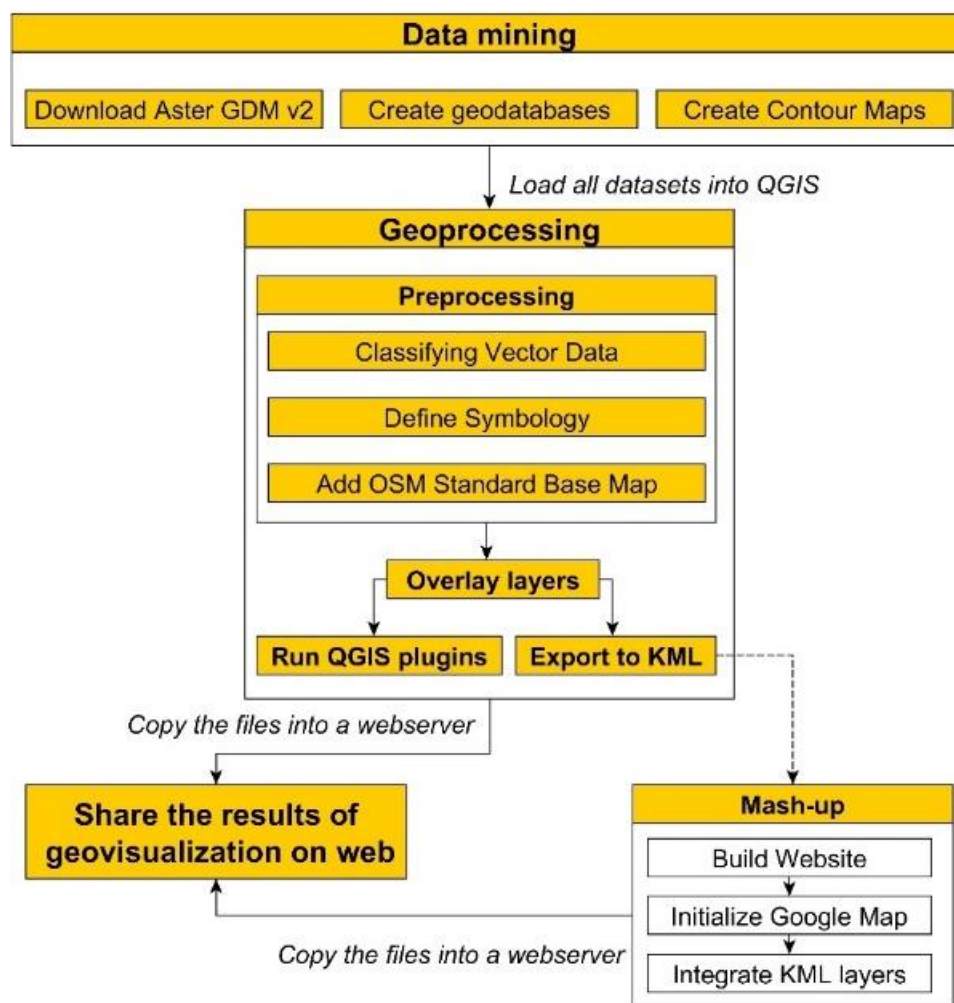


Figure 2. Process of geovisualization.

3. Results of Visualization

The third and fourth generation web maps published with various geovisualization techniques regarding the contaminants of the groundwater of the investigated settlements were made freely accessible on the Internet, and can be accessed from a mash-up site [62].

3.1. Static and Interactive Geovisualization of Environmental Data Using QGIS Modules and KML

We attached an optional OSM (OpenStreetMap) Standard basic map to the visual representation of the vector and raster databases imported into the QGIS environment equipped with unique symbols (Figure 3). After setting the parameters of the modules, we generated two classic third-generation web maps. The classified vector layers show the nitrate and phosphate values according to the Hungarian Standard with graduated symbols in a third-generation web map (Figure 4A,B). As the default setting, the loaded web map shows the classified database which can be freely zoomed in and out, and the length of the specified routes can be calculated. In addition to navigating on the map, we can control the visibility of each layer. Furthermore, there is a Search by location function integrated into the interactive surface which we can use to navigate to the desired geographical location in the web map, thereby informing the user about the spatial distribution of the pollution level. The visibility of the layers can also be controlled by use of the menu located in the right upper corner. Information about the layers can be queried by clicking, and results showing the appropriate data from the attribute table are visible to users in a window and in the interactive query interface.

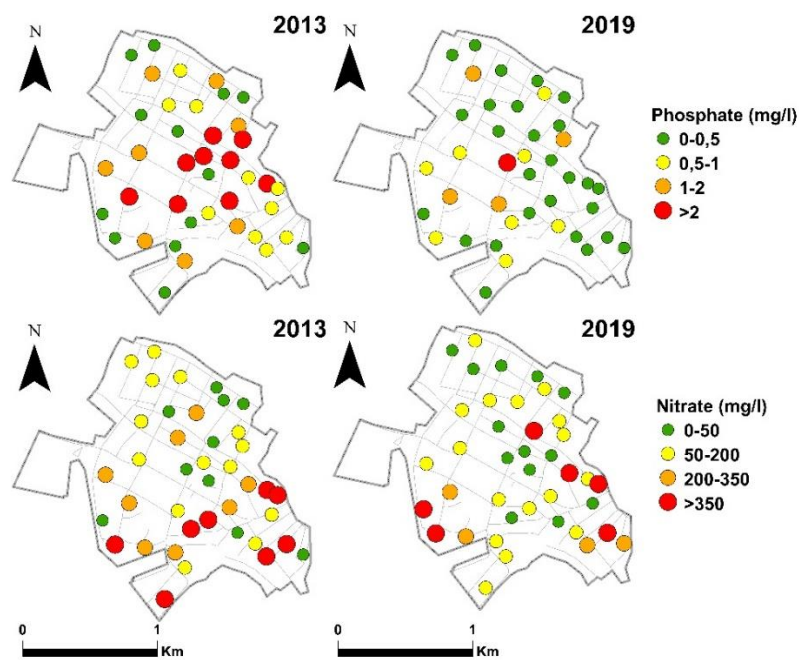


Figure 3. Spatial distribution of phosphate and nitrate values in the investigated wells.

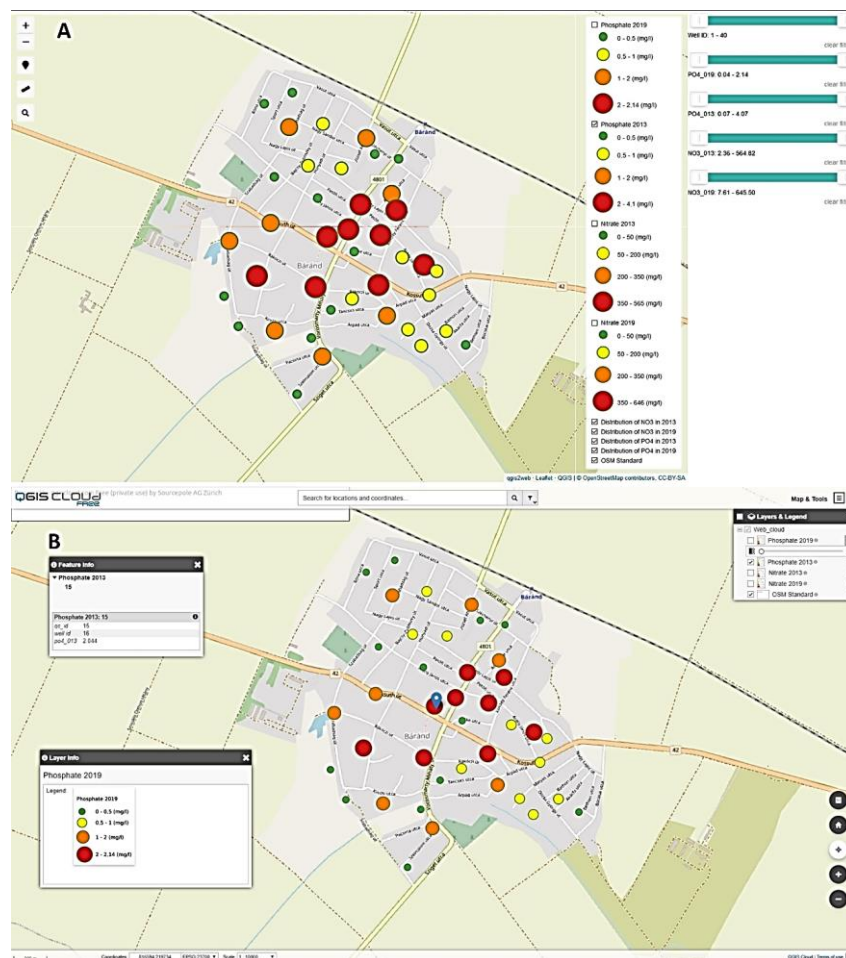


Figure 4. Interactive web maps from the study area (A) Results of geovisualization using QGIS Cloud, (B) Results of geovisualization using QGIS qgis2web.

The temporal data to be displayed on the map are represented by creating KML files. The nitrate and phosphate distribution maps of the area from 2013 and 2019 are displayed in the form of overlapping pictures, while the data points are represented as location indicators on the satellite image of Google Maps (Figures 5 and 6). By clicking on the symbol indicating the location of the selected well on the map, we can see the information panel of the given layer, and the HighCharts interactive diagram attached to mash-up site visualizes the distribution of the soil chemistry properties of the wells stored in the databases, thereby allowing the comparison and assessment of nitrate and phosphate values.

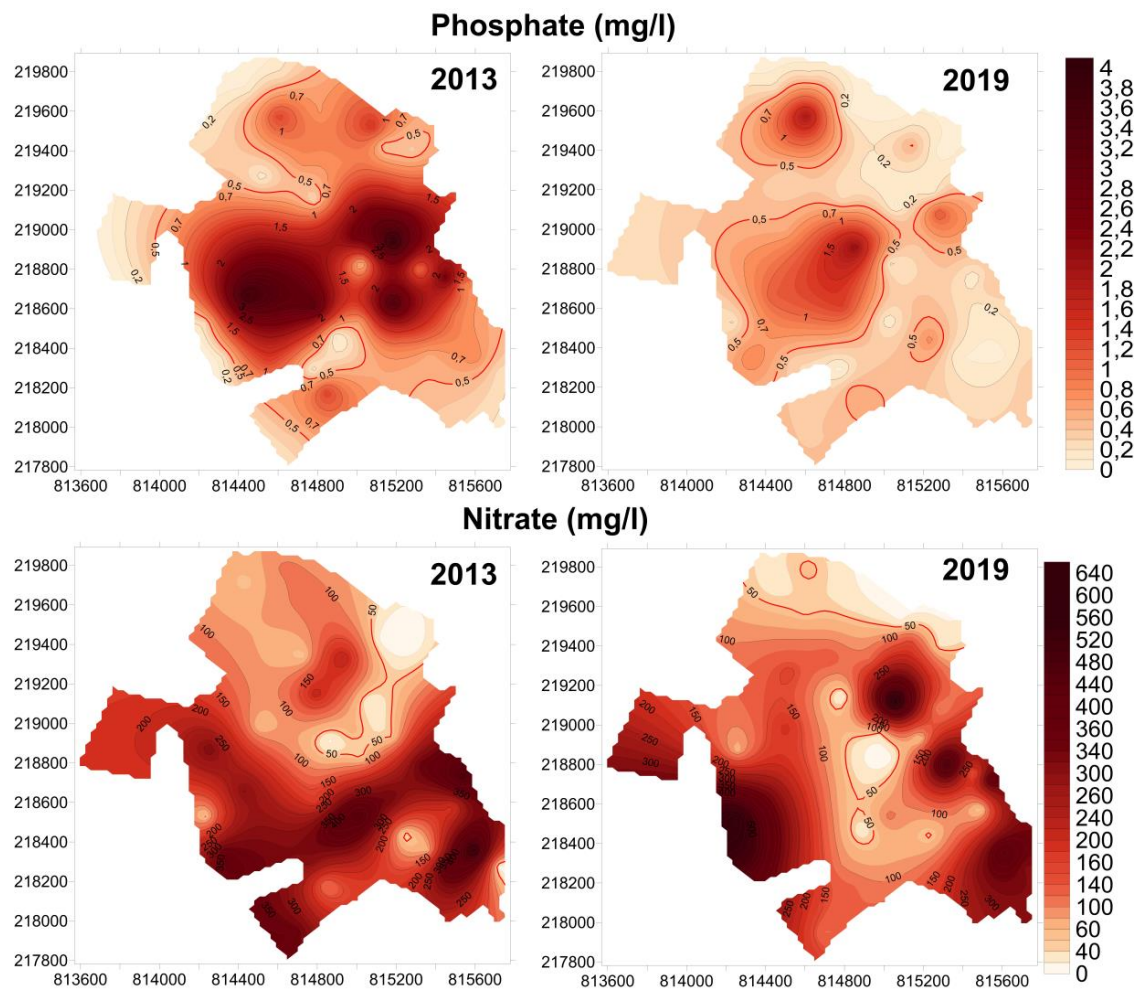


Figure 5. Distribution map of investigated parameters.

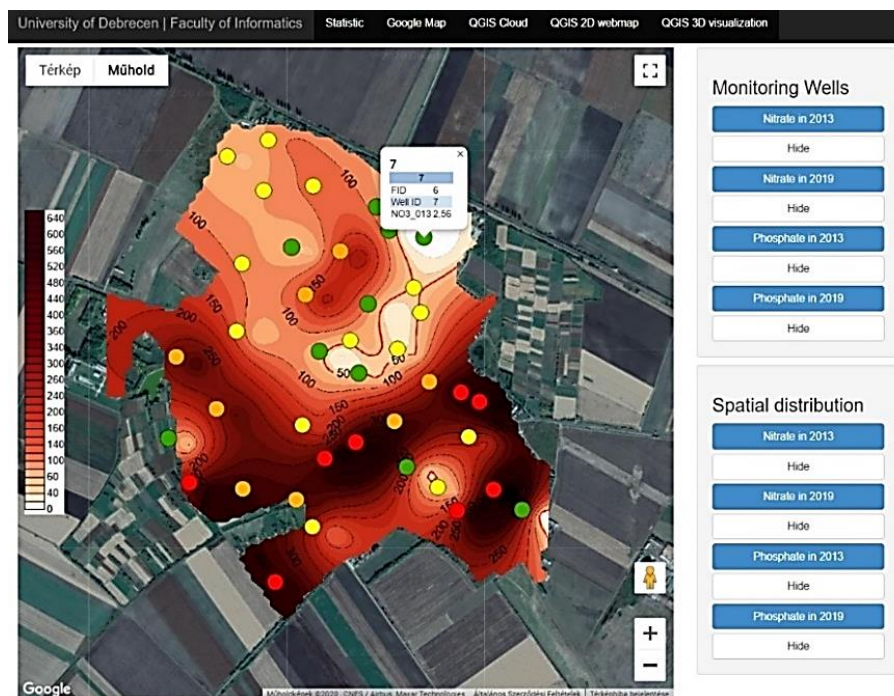


Figure 6. Mash-up webmaps.

3.2. Static and Interactive 3D Geovisualization of Environmental Data

The base of the 3D interpretation was the ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) raster digital surface model. The distribution map and monitoring wells storing the investigated water chemical properties were inserted onto this model by time points projected onto the model, which can be rotated arbitrarily, as well. Information about the layers can be queried by clicking, and results showing the appropriate data from the attribute table are visible to users in a window. The visibility of the layers can also be controlled by use of the menu located in the right upper corner (Figure 7).

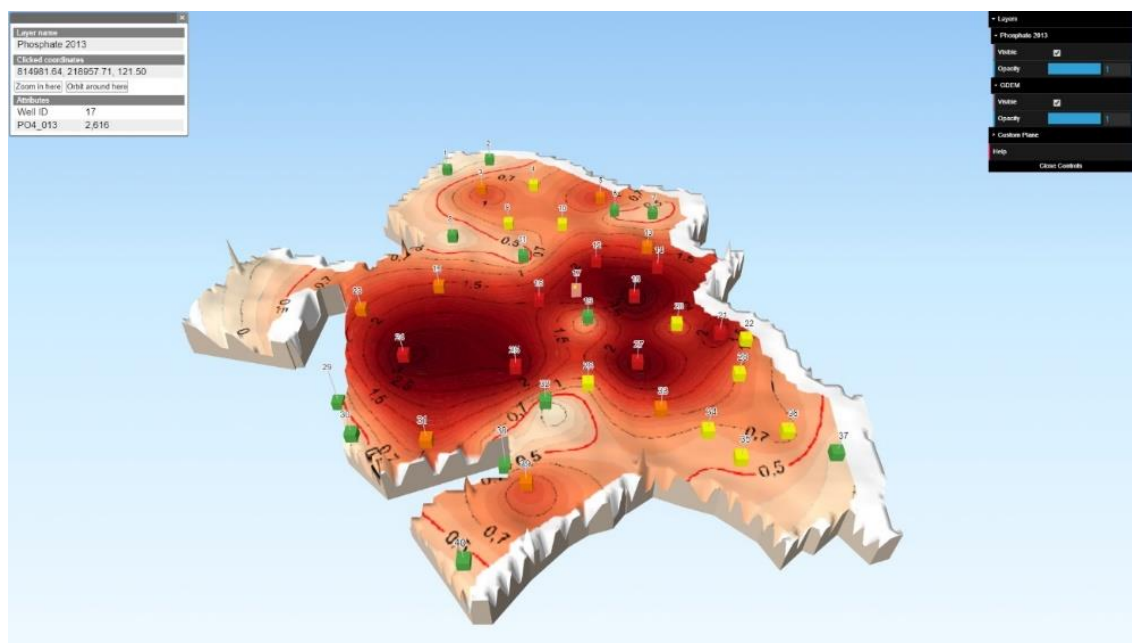


Figure 7. Visualized interface of monitoring wells with description data.

3.3. Advantages and Disadvantages of Tools

The most important benefits of 2D or 3D spatial data visualization performed via QGIS modules that the geoinformatics processing and publication of spatial environmental data imported into the system (database management, styling, layer handling, analysis) can be performed using one interface and there is no need for post-processing on another platform or in a different software environment. A further advantage is that it can interpret most of the raster and vector file formats and carry out the conversions between systems, as a result of which, users are able to visualize complex spatial analyses without coding skills. Since in the case of Cloud module, a server is not required for web publication, the results are available for everyone after processing, however due to a limit for upload, the visualization of large databases is possible only by paying for a greater storage capacity. In the case of Qgis2threejs module, there is no such data limit, however, a web server is required for the publication of data. In the context of 3D data visualization, we considered a drawback that beside the installation of the extension needed for displaying the contents in the browser, it is important that the size of the input data makes loading the data slower.

The advantage of using KML for 2D data visualization in addition to Google Earth and Google Maps is that, it is supported by other geoinformatics applications. Google Earth processes a KML file in a similar way that web browser process HTML and XML files. Similar to HTML, KML also applies indicators with name and attributes for specific displaying purposes. In this aspect, Google Earth act as a browser for KML files, however, Google Maps cannot display every item of KML. Google maps—beyond the general browsing functions—allows users to insert web maps into their own website or link this own database to the contents of the map. To make the best out of this feature, freely accessible APIs (Application Programming Interfaces) are provided for the user as long as he/she possesses basic JavaScript coding skills. Google APIs are fundamentally a native JavaScript interface which can be used to control the functioning of the map (e.g., map type, layer management, size, KML management etc.). Also, its helps managing the KML files so that all its functions can be used. The drawback of its application is that the visualization of data requires programming skills, complex analyses cannot be performed and similar to QGIS, a web server is necessary for the web publication of data.

With regards to the environmental data used and processed in the study, it should be emphasized that thanks to the raw data from the measurements and the freely accessible databases (OSM, ASTER GDEM) the end user can query the attributes of the investigated wells, thereby facilitating the local interpretation of the studied phenomenon creating a new, innovative perspective of map usage.

Beside the numerous advantages of the technologies presented (event management support, no need for extension for insertion etc.) we can also find factors which limit the visualization of KML items (formatting limitations, default display, etc.) and raster data. Despite the uploading/displaying data limits of the devices, these allow the publication of smaller databases, especially the resource-intensive server-side application and services offered for payment. Considering the above, it can be concluded that the application of freely accessible geovisualization tools nowadays is sufficient for the web publication of geographical data. Table 1 summarizes the evaluation aspects of the tools.

Table 1. Evaluation of tools.

Viewpoint	Tool			
	KML	QGIS Module		
		<i>qgis2web</i>	<i>Cloud</i>	<i>Qgis2threejs</i>
Appearance	2D and 3D	2D	2D	3D
Supported raster format	Yes	Yes	No	Yes
Browser needs plugin	No	No	No	Yes
Event management	Supported	Supported	Supported	Supported
Require coding	Yes	No	No	No
Feature/Data Limit	Up to 10,000 lines, shapes, or places Up to 50,000 total points (in lines and shapes) Up to 20,000 data table cells	Depends on hardware	50 MB upload data limit	Depends on hardware

3.4. Evaluation of Nitrate and Phosphate Distribution in 2013 and 2019

The concentration of PO_4^{3-} in the reference year before the construction of the sewage system indicated severe contamination. In 65% of the wells we measured a concentration higher than the contamination limit of 0.5 mg/L. Having investigated the spatial distribution it can be concluded that the majority of the settlement is contaminated, the highest concentration of phosphate was measured in the central areas of the settlement (2 mg/L), with a decreasing trend towards the Northern and Southern parts of the settlement.

In the year 2019 significant changes could be observed. We measured a concentration above the limit value in only 32.5% of the wells, compared to 2013 when the same value was 65%. The maximum value of 4.07 mg/L measured in 2013 had decreased to 2.14 by 2019. The central part of the settlement is still considered the most contaminated part; however, in this year there was no area with a concentration above 2 or 3 mg/L, and only a small area where the concentration exceeded the value of 1.5 mg/L. The other important change was the significant increase in the extension of the areas which can be characterized by a concentration under the limit value. Whereas in 2013 we measured a concentration under the limit value only in the Northern and Southern peripheral areas of the settlement, in 2019, we measured concentrations under the limit value, except in the central area of the settlement and some smaller regions.

In 2013, before the construction of the sewage system, we measured concentrations above the limit value of 50 mg/L in 75% of the wells. Furthermore, in the reference year before the construction of the sewage system we found a characteristic spatial distribution. The Southern parts of the settlement showed a significant degree of contamination. From the central part of the settlement towards the Southern direction we measured concentrations above 200 mg/L, and in a coadjacent area, we measured concentrations above 300 mg/L. In contrast, the Northern part of the settlement was less contaminated; however, in the majority of the area we still measured concentrations above the contamination limit of 50 mg/L.

In 2019, the fifth year following the construction of the sewage system, the decrease in the concentration of NO_3^- also indicates the elimination of a significant part of the contaminant supply, since the average value decreased from 187.8 mg/L to 163.5 mg/L from 2013 to 2019. The value of the lower quartile decreased from 50.15 mg/L to 43.09 mg/L from 2013 to 2019, while the value of the upper quartile decreased from 341.7 mg/L to 244.8 mg/L. By 2019 the North–South difference had been eliminated, and significant positive changes occurred in the central parts of the settlement. The most contaminated areas were still the Southwestern and Southeastern parts of the settlement, even though their extension had significantly decreased (Table 2).

Table 2. Descriptive statistics of investigated parameters.

Parameters	Contamination Limit (mg/L)	Mean		Minimum		Maximum	
		2013	2019	2013	2019	2013	2019
NO ₃ [−] (mg/L)	50 mg/L	187.8	163.5	8.36	7.61	564.8	645.5
PO ₄ ^{3−} (mg/L)	0.5 mg/L	1.22	0.49	0.07	0.04	4.07	2.14
Parameters	Contamination Limit (mg/L)	Lower Quartile		Upper Quartile		St. Deviation	
		2013	2019	2013	2019	2013	2019
NO ₃ [−] (mg/L)	50 mg/L	50.16	43.09	341.7	244.8	164.4	170.7
PO ₄ ^{3−} (mg/L)	0.5 mg/L	0.374	0.137	1.75	0.604	1.09	0.49

The red and green cells indicate values above and under the contamination limits, respectively.

4. Relationship to CogInfoCom

The complexity of the term cognitive InfoCommunications (CogInfoCom) closely reflects its multidisciplinary characteristics, since acquiring information by observing geovisualized spatial data can support different cognitive processes. The key factor is demonstrated in the process of geovisualization, during which data were transformed into a special form enhancing the co-evolvement of cognitive processes with infocommunication devices. Human perception as a cognitive process can interact with certain artificial cognitive systems and the process itself can also be supported in the context of cognitive infocommunications. Although we have not tested directly the efficiency of our visualization, but we relied on other studies whose findings are about how 3D visualization enhances human perception [63–65]. Considering the current study, the following cognitive considerations related to the field of CogInfoCom are of high importance:

- The most important advantage of using geovisualization tools is the visualized spatial environmental data, which makes valuable information understandable both for the public and for decision-makers.
- Revealing relationships between the investigated wells and the location became easier after the geovisualization.
- Geovisualization facilitates capturing the spatial pattern of nitrate and phosphate distribution at different times.
- The general cognitive perception of digital data is supported. The more data sources are used, the greater need can be identified for supporting the appropriate interpretation of the data.

5. Conclusions

Our study provided a method showing how the QGIS geovisualization modules and KML tools can be applied to publish geospatial information on the Internet. In order to demonstrate this, we depicted the nitrate and phosphate contamination of a settlement located in East Hungary. We investigated the spatial and temporal distribution of the contamination, as well as its changes. Using the created point and interpolated maps we were able to determine the most contaminated areas of the settlement which were the central part of the settlement in the case of phosphate, and the zone located to the south of the central part of the settlement in the case of nitrate. Having investigated the differences between the assessments made before the construction of the sewage system (2013) and after the construction (2019), we concluded that significant positive changes can be observed in the case of both contaminants. In the case of phosphate, the spatial distribution remained the same; however, the concentration of the wells significantly decreased. In the case of nitrate, the most significant decrease in concentrations was observed in the central parts of the settlement, while the rate of decrease of the concentration was lower in the most contaminated parts. The open-source geovisualization tools clearly demonstrate that tools derived from geoinformatics can enhance the cognition of the data which geographers work with. The opportunities presented by visualization techniques can be used for the visualization of different spatial environmental databases, thus broadening the amount of displayable information and helping the cognitive interpretation of spatial data. The spatial environmental data used are representative in

themselves; however, by combining these techniques and publishing, we were to assess nitrate and phosphate values and their spatial configuration from a new perspective.

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