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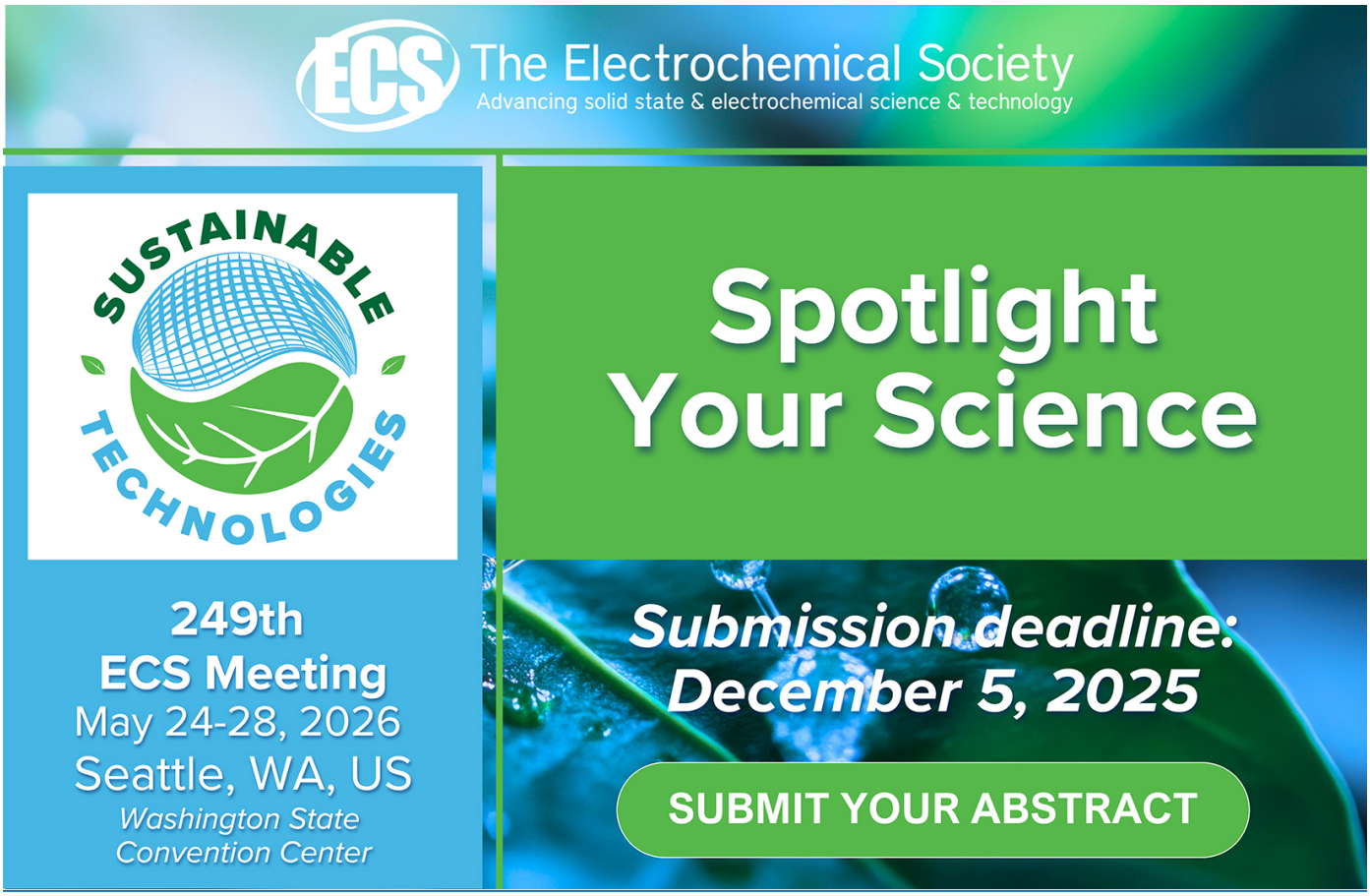

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Principles and methods of integrating geospatial analysis into the school geography course

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Abstract. Geoinformation analysis is associated with the search for spatial patterns and relationships in the distribution of geographical objects, processes, and phenomena, resulting in new geoinformation that is of high practical importance. The use of geospatial analysis in the educational context includes several key components and approaches that help to make traditional geography lessons in the school curriculum more modern, effective, and interesting. The main principles of implementing geospatial analysis in a school geography course using various methods and technologies for research, analysis and visualization of geographic data are developed.

1. Introduction

Today, geographic information technologies are considered as an effective tool for understanding geographic space. According to most researchers, its use makes it possible to study and analyze the spatial differentiation of various processes, objects and phenomena, which solves practical problems in various fields of human activity: ecology, agriculture, transport, urban planning, etc. [1]

Geoinformation technologies are especially important in the educational process. Teaching based on these technologies makes it possible to study the peculiarities of spatial changes in natural and anthropogenic objects, processes and phenomena, i.e., to conduct geospatial analysis. This not only develops students' digital competencies and skills, but also significantly deepens their general and geographical knowledge [2].

Geospatial analysis is the process of applying analytical methods and tools to study geospatial data, identify trends and relationships. It is closely related to geospatial thinking. Geospatial thinking provides the cognitive framework for understanding geographic concepts, and geospatial analysis provides the tools and techniques to explore geospatial data. Together, they create a powerful set of skills for solving a variety of spatial geographic problems.

Currently, there are no national or state standards for spatial thinking content course [3]. Consequently, there is no incentive to advance educational materials to develop students' skills in geospatial thinking and, consequently, in geospatial analysis. However, in twentieth-century global educational practice, one can find examples of projects in which enthusiasts have

developed GIS-based resources that can be used to introduce geospatial analysis into the existing school geography curriculum.

For example, the Saguaro project has developed modules on cyclones, hurricanes, and the dynamic Earth. The KanCRN project provides two modules: one spatially links tornadoes and the mean position of the jet stream, and the other studies leaf samples to estimate ozone levels. ESRI has developed lessons for teachers that use ArcGIS to explore various aspects of spatial analysis of the geographic envelope.

The active introduction of geospatial research into the practice of modern schools began in the early 21st century. Indeed, the fundamental research of George Kerski [4] showed that geospatial analysis in various forms can be used at all levels of primary and secondary education, however being more effective in high school. Further research [5–10] was aimed at developing the theoretical and practical component of geospatial analysis in the educational process using GIS.

According to several authors, GIS can be a useful tool to help students develop their spatial abilities and solve spatial problems, develop their spatial reasoning, improve their map-related skills, and enhance their critical thinking, communication, and analytical skills [11]. But besides GIS, Earth remote sensing (RS) data can also be a technology to improve students' spatial reasoning concepts. Remote sensing provides real-world data that allows you one to analyze natural disasters or other phenomena in reality [12]. Also in addition, Flynn [6] proved that the use of educational geocaching in the learning process has improved certain areas of spatial thinking in students.

Today, most scientists [13–15] are convinced of the need to introduce geospatial analysis into school geographic education, which, in their opinion, will improve the quality of geography learning and promote a deeper understanding of the phenomena and processes of the geographic environment. This, in turn, requires technological, logistical, pedagogical and administrative support. As noted by Kerski, technological problems include Internet bandwidth, availability of spatial data, and the cost of software [4]. Logistical support includes building the necessary hardware (computers, interactive whiteboards, scanners, etc.). Pedagogical challenges include teaching using web-based geospatial analysis tools and the necessary methodological materials [16, 17]. Administrative issues such as competition for teaching time and funding create additional obstacles to the introduction of geospatial technologies in the educational process.

This is confirmed by experiments that have been conducted in schools around the world when teaching geography. For example, van der Schee et al. [18] conducted a series of three geography lessons for students of one class using geospatial analysis, and for another class – in the traditional form of presentation of the material. Tests conducted at the end of the experiment demonstrated that lessons with geospatial technologies contribute to a much deeper learning of the educational material.

Thus, the issue of using geospatial analysis in the educational context is of high theoretical and practical importance, which confirms the relevance of this study.

The objective of the study is to define and substantiate the principles and methods of integrating geospatial analysis into the school geography course.

2. Results and discussion

Geospatial analysis exists at the interface between humans and computers. Both play a key role in it – on the one hand, human intuition, and on the other hand, formal and mathematically accurate calculation of geospatial data. Therefore, the teacher's task is to ensure effective and comfortable interaction of students with computers within the framework of the school geography course program.

Based on the analysis of scientific and methodological literature as well as on our own experience, we have formed the main principles of introducing geospatial analysis into the school

geography course:

1. It is important that geospatial analysis is not viewed as an addition to an already overcrowded school curriculum, but as a technology in the curriculum that helps to look at traditional course material in a completely new way. Thus, geospatial technologies should be integrated into existing topics of the school geography course, which contributes to a deeper learning of the material, development of analytical skills and preparation of students to solve real problems related to geospatial data analysis.

The analysis of the content of the school geography course leads to the conclusion that it is possible to integrate geospatial analysis for most of the course topics. Here are a few examples of how geospatial analysis can be used in geography classes:

- *Studying demographic trends.* Students can use geospatial analysis to examine population density, age group distribution, ethnicity, or urbanization in different regions. This could be related to migration or historical trends.
- *Exploring environmental issues.* Students can analyze the spread of air pollution in a city or measure the decline in forest cover in a particular region.
- *Geography of biological resources.* Geospatial analysis can be used to study the distribution of distinct species of plants and animals, their habitats, and the environmental factors that affect their distribution.
- *Climate data analysis.* Students can use geospatial analysis to examine climate data such as temperature, precipitation, or climate change over time. This could be related to the study of global warming, meteorological phenomena, or the impact of climate on agriculture.
- *Study of mineral resources.* Geospatial analysis can be used to explore the relationship between the location of a mineral deposit and the geological structure of a region.

For example, figure 1 shows a model of a map with an overlay of layers of earthquake locations with a magnitude of more than 5.7 and the boundaries of the Earth's tectonic lithospheric plates, created by students when studying the topic "Lithosphere" in the school course "General Geography" (grade 6).

Its analysis allows the teacher to illustrate the following conclusions for students:

- the largest earthquakes with a magnitude of more than 8 are localized in subduction zones of convergent lithospheric plate boundaries (the Pacific Ring of Fire, Chile, Japan, Indonesia, etc.);
- most strong earthquakes occur along the boundaries of the Pacific Eurasian and Indian lithospheric plates;
- intraplate earthquakes are rare and usually associated with ancient faults in the lithosphere.

Exploring the connection between earthquake localization and plate boundaries allows students to better understand the mechanisms of seismic events.

It is of particular interest to use geospatial technologies in various practical activities. In this case, it becomes possible to conduct classes based entirely on geospatial analysis using mapping services such as *Google Earth, OpenStreetMap, ArcGIS Online, etc.* This will allow students to explore geographic objects and phenomena on their own.

2. One of the key elements of introducing geospatial analysis into the school geography course is **working with real geospatial data**. This makes learning more interactive, relevant, and focused on the practical application of knowledge, which contributes to the comprehensive development of students.

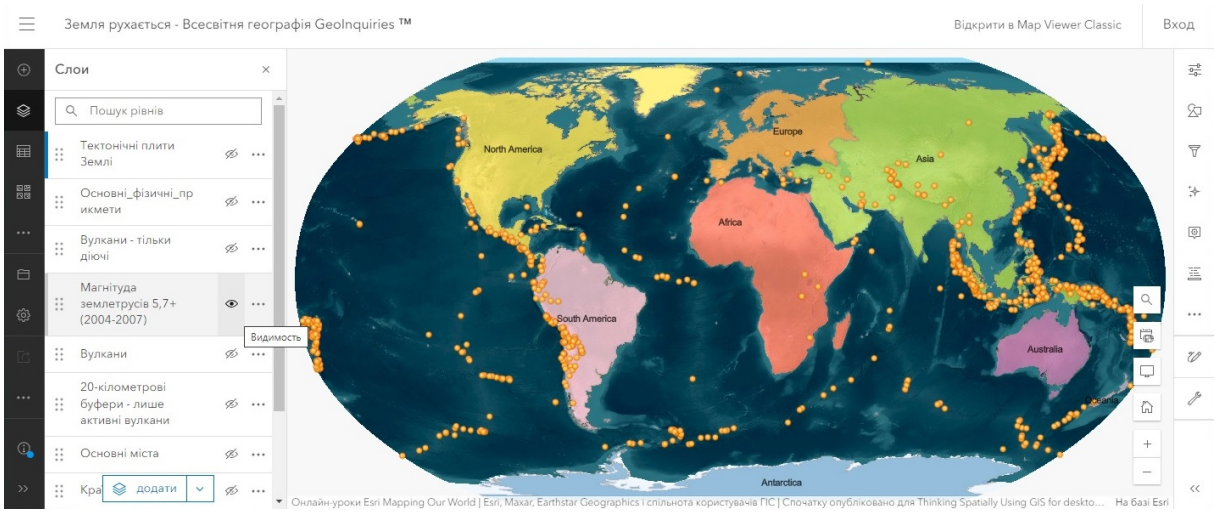

Figure 1. Map with overlay of layers of earthquake locations with magnitude greater than 5.7 and boundaries of tectonic lithospheric plates of the Earth (obtained using the GeoInquirie platform).

For this purpose, students can use geodata from various sources. First, these are various international and national statistical databases (*NASA Earth Observing System Data and Information System, GeoNetwork, WHO, Ukrstat, etc.*), mapping databases (*Google Earth, OpenStreetMap, Natural Earth, GISFile, etc.*).

Students can also collect geospatial data on their own during field research. This may include measuring environmental parameters, using GPS devices to collect location data, taking photos and recording objects on the ground [19]. It is interesting to collect data through interviews/questionnaires with residents, which can be part of projects related to social or economic geography.

Students can use GIS to analyze the collected data and create their own thematic maps that reflect the phenomena under study (for example, a map of the distribution of certain plant species, a map of natural disaster risks, a map of the socio-economic development of the region, etc.)

Figure 2 shows an example of a map built by students from the Kentucky College of Agriculture, Food and Environment based on detailed long-term observation of the distribution of fires in the Kingdom Come Park. Based on the results of the geospatial analysis, the fires were linked to the distribution of certain types of vegetation.

Spatial research is also possible without the use of GIS. But in this case, the tasks should be simplified. Here are some examples:

- *A map of the local environment showing biodiversity.* Students can collect data on biodiversity in the study area (e.g., trees, including their species, height, and trunk diameter). Then, they can draw a map labelling the identified features and adding photos (figure 3).
- *Pollution map around the school.* Students can research noise, air, and water pollution in the school's vicinity and create a map that shows the level of pollution at different points.
- *A map of students' routes to school.* Students can record their routes to school on a bicycle using a GPS tracker and then create a map with the routes and dangerous areas marked.
- *Map of sports fields and recreation areas in the neighbourhood.* Students can study the existing sports fields and recreation areas in their neighbourhood and create a map with

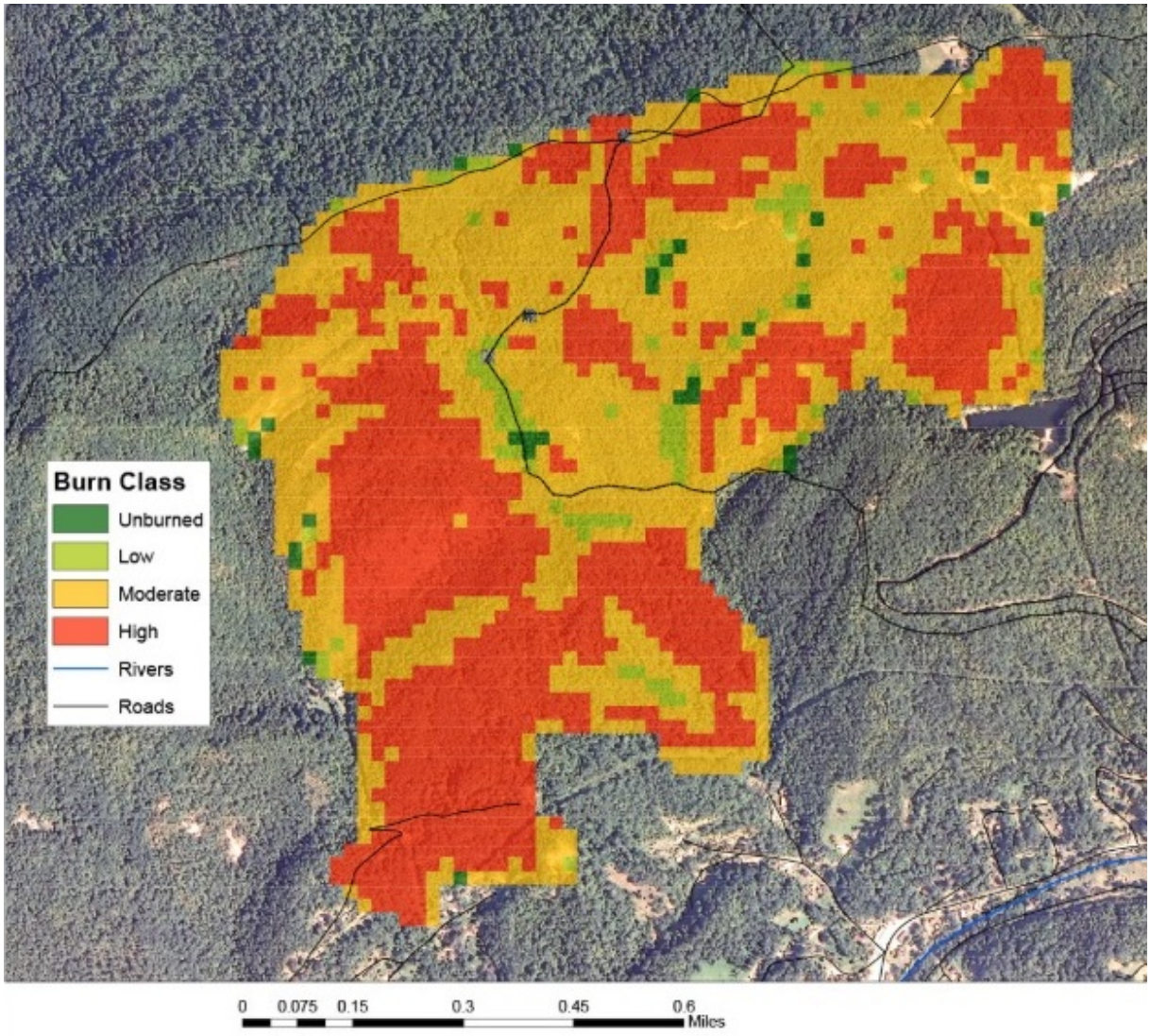

Figure 2. Analysis of forest fires in the Kingdom Come Park (according to `https://geography.as.uky.edu/sites/default/files/FOR330_KyleHoward_Fall2014_FinalProject.jpg`).

their locations and descriptions.

- *A map of where students in the class live*, showing their favourite places in the neighbourhood. Students can create a map showing their homes and add labels for their favourite places in the neighbourhood, such as parks, cafes, or shops (figure 4).

Involving students in researching and solving real-world problems in their local area or region helps to increase motivation and demonstrates the practical value of geospatial analysis.

3. *The development of project activities in the implementation of geospatial analysis in the school geography course* is an effective means of activating the learning process, developing critical thinking, and forming skills in working with modern technologies. Project activities allow students to apply the acquired knowledge in real-life situations and contribute to the development of skills of cooperation, research and presentation of results.

Figure 3. An example of mapping the biodiversity of the local environment (according to `https://www.heritageinschools.ie/online-tutorials/how-to-make-a-biodiversity-map-of-your-garden`).

When planning projects, students should have a clear plan for project implementation, including the definition of the goal, objectives, research methods, distribution of responsibilities in the group and setting deadlines. Various sources can be used to collect geospatial data, such as maps, satellite images, statistics, surveys, and field research. Analyzing this data allows you one to gain new knowledge and draw reasonable conclusions.

Working in groups develops students' cooperation skills, the ability to resolve conflicts and make joint decisions. Presentation of results teaches students to communicate effectively and present their work.

An example of such work is the research conducted by students in grades 10-12 at Bishop Dunne Catholic School in Dallas, Texas [3]. After receiving data from the police department on robberies in the region for a certain period, the students geocoded the locations of robberies, identified hotspot areas, and created maps of robberies. The students then analyzed the geographical patterns and made recommendations to the police department regarding the patrolling area. The result was a reduction in crime in the study area.

Here are some more possible examples of projects:

- *"Monitoring the condition of green areas in the city"* – using satellite images to analyze changes around green areas and assess the impact of urbanization on the city's ecology;
- *"Transport infrastructure research"* – building maps of road density in the region and assessing the accessibility of social facilities;
- *"Energy map of the region"* – studying the location of alternative energy facilities in the region and analyzing the efficiency of their use.

4. A powerful tool to support geospatial analysis is geographic information systems (GIS), as they provide collection, storage, processing and visualization of geographic data. GIS combines spatial technologies with statistical and spatial analysis tools to perform analytical

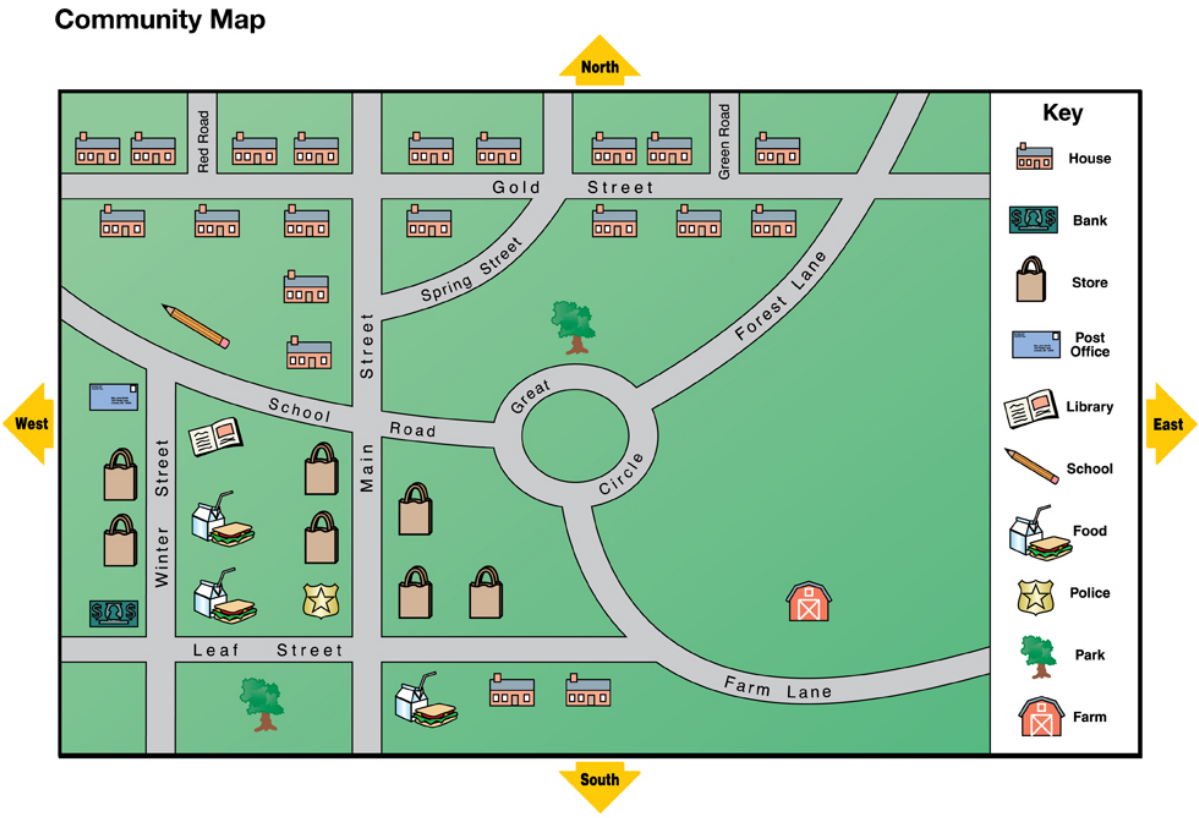

Figure 4. A map of students' places of residence showing their favorite places in the district (based on `https://images.nationalgeographic.org/image/upload/v1638889251/EducationHub/photos/community-map.jpg`.

functions by manipulating and visualizing the structural relationships between spatial geodata sets.

Introducing GIS into the educational process requires appropriate teacher training and technical resources, but the results, such as improved geospatial thinking, justify the effort. Introducing students to GIS should be gradual. Initially, one can use online maps and tools from various educational web platforms, such as *MapMaker Interactive, GeoInquirie, Google Earth, etc.* Most of these geo-resources are free or have educational licenses, which makes them accessible to schools. It is also important that they have pre-loaded geospatial data, which makes it possible to conduct geospatial analysis without additional steps. Some platforms even have developed standards-oriented lessons to integrate geospatial technologies into the learning process. For example, *ESRI's GeoInquiries* platform provides access to interactive web maps of various kinds that are designed to be used with *ArcGIS Online* without the need for a login or prior GIS experience (figure 1).

Teachers who have the appropriate training can subsequently transition to more complex software products such as ArcGIS, QGIS, MapInfo, etc. They allow for more complex and information-rich geospatial analysis tasks. For example:

- *Creation and analysis of current thematic maps.* With the help of GIS, students under the

guidance of a teacher can create maps that reflect various geographical phenomena, such as climate zones, population distribution, or economic activities, which will be based on the latest (in terms of time) geospatial data, particularly relevant for analyzing very dynamic processes and phenomena (e.g., external and internal population migration);

- *Establishing relationships in space and time between processes and phenomena* (for example, analyzing factors of spatial distribution of natural resources);
- *Analysis of transport infrastructure.* Students can assess the accessibility of various facilities, study the road network, determine the most optimal routes, and identify areas of concentration of traffic accidents (figure 5).

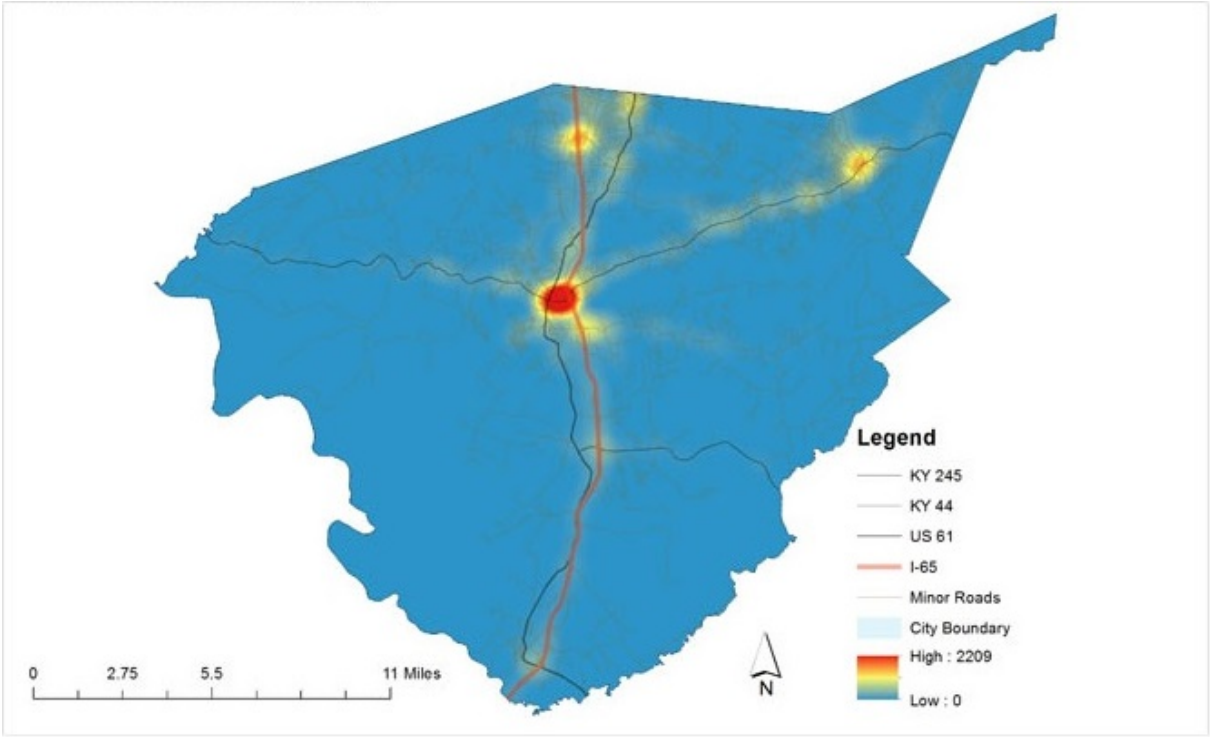

Figure 5. Map of the concentration of car accident locations, created by students at Bishop Dunne Catholic School in Dallas (based on data from `https://geography.as.uky.edu/sites/default/files/NRE355_AustinSauer_Fall2014_FinalProject.jpg`).

- *Modeling environmental risks.* GIS allows identifying areas prone to natural disasters such as earthquakes, floods, or landslides, and developing risk reduction plans;
- *Studying the terrain.* With the help of GIS, it is possible to model three-dimensional surfaces, analyze slope steepness, determine watersheds, and assess potential flood zones.

This is just a small list of geospatial analysis tasks that can be performed in the school geography curriculum using GIS.

5. However, geospatial analysis can be integrated not only into geography but also into related disciplines such as history, biology, economics, and mathematics [20]. This will contribute to the formation of **an understanding of interdisciplinarity and the significance of geospatial data in various fields**. An interdisciplinary approach to integrating geospatial

analysis into the school geography curriculum allows for the combination of knowledge and methods from various subjects, which contributes to a comprehensive understanding of complex phenomena and processes by students, as well as developing their analytical and research skills.

For example, students can use geospatial analysis to study biodiversity in different regions by analyzing data on species distribution, ecosystem status, and the impact of climate change on biological diversity. This approach helps to understand the interplay between natural and anthropogenic factors.

The integration of history with geography allows students to analyze historical maps, study changes in borders, migration processes, and so on. This contributes to understanding how historical events impact the geographical development of regions. Students can use geospatial analysis to study cultural objects, their locations, and historical changes in the landscape related to the cultural development of society.

6. The successful implementation of geospatial analysis in geography lessons requires fundamental professional training for teachers. Only well-prepared teachers are capable of effectively using geospatial analysis in the practice of modern schools.

Referring to the experience of Hauselt and Helzer [21], it is worth noting that quality training for future teachers can be achieved by including geospatial science in the curriculum for the professional preparation of modern geography teachers. Such education allows for the cultivation of a generation of young teachers who possess spatial knowledge, geospatial ways of thinking, as well as geospatial analysis technologies.

The professional development of teachers can be shaped through qualification enhancement courses (trainings, seminars, and webinars), collaboration with colleagues, participation in conferences, and so on. Most importantly, teachers can independently acquire new knowledge using Internet resources, textbooks, and literature on geospatial analysis and geography.

Despite all the advantages that teachers gain from integrating geospatial analysis into the school geography curriculum, today we have few examples of its use among practicing educators. Among the problems that hinder this process, the most significant are:

- *Limited number of hours in the school geography curriculum.* Existing geography curricula in most countries around the world do not include the use of geospatial analysis. Individual examples that can be found in the literature [3] are more of an exception than the rule.

As an option, it is possible to recommend integrating appropriate short tasks (15-20 minutes) of geospatial analysis into the existing topics of the school curriculum. For example, when studying population geography, students can use the *Map Viewer* cartographic application to create maps of demographic indicators for countries around the world (population size, density, child mortality rate, etc.). Spatial analysis of these indicators (figure 6) allows for the identification and explanation of spatial patterns, as well as the identification of factors that influence their differentiation.

- *Limited access to high-quality geospatial data adapted to educational needs.* Today, there are many sources of geospatial data available for conducting geospatial analysis. However, much of the freely available data is created for professional use and does not consider the knowledge level of school students. To address this, it is necessary to create simplified and theme-oriented datasets that are easy to understand and adapt to specific educational topics. Additionally, teachers must be able to assess the quality of these data, with key components including data completeness, logical consistency, positional accuracy, thematic accuracy, and temporal accuracy.

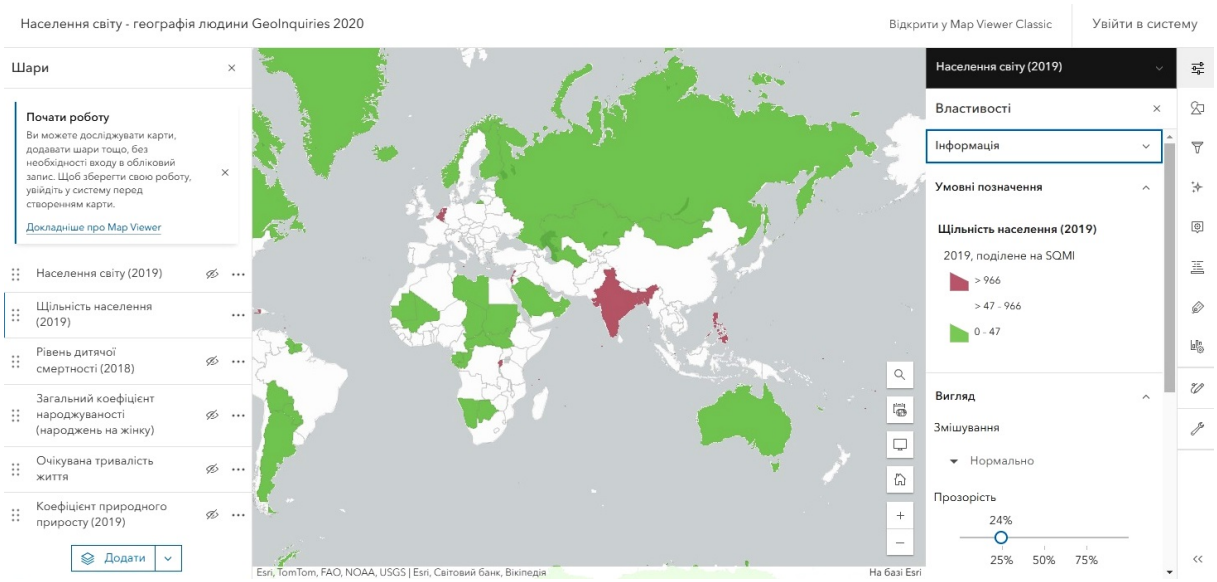

Figure 6. Population density map created on the educational platform GeoInquiries.

- *The lack of necessary methodological developments and appropriate textbooks.* The shortage of modern textbooks and manuals on the implementation of geospatial analysis in the educational process leads to teachers having to independently develop approaches to its integration, which can significantly reduce the effectiveness of learning. Organizing various courses and webinars for teachers on this issue can be considered one of the ways to address it.
- *Uncertainty of pedagogical teaching methods.* This is one of the main obstacles to the implementation of geospatial analysis in the educational process. To date, this issue remains insufficiently studied and developed.

As an example, let's consider some effective methods and technologies.

An effective means of integrating geospatial analysis into the school geography curriculum is interactive teaching methods, as they promote active student engagement in the learning process, the development of critical thinking, and analytical skills. Thus, students can use interactive maps such as *Google Maps, Google Earth, and OpenStreetMap* to study geographical objects and analyze spatial data. They can independently explore the terrain, change map layers, compare different time periods, or geographical regions.

Problem-based learning with geospatial analysis contributes to the development of students' ability to think spatially and understand the interconnections between various geographical processes and phenomena. The teacher should develop tasks that reflect real geographical problems, encouraging students to solve them using geospatial analysis. For example, the teacher asks the question: *What type of lithospheric plate boundary is characterized by the highest concentration of shield volcanoes?* Students should analyze the tectonic interactive map on the *GeoInquiries platform* (figure 7) and provide an answer.

An important role in the formation and development of geospatial thinking is played by gaming technologies, as they allow students to study spatial relationships between objects, phenomena, and processes in an engaging way. One example is geocaching – a geospatial game where students use GPS coordinates to find hidden "treasures" or objects in the terrain. This method promotes the development of navigation skills and the use of geospatial technologies in real-world conditions.

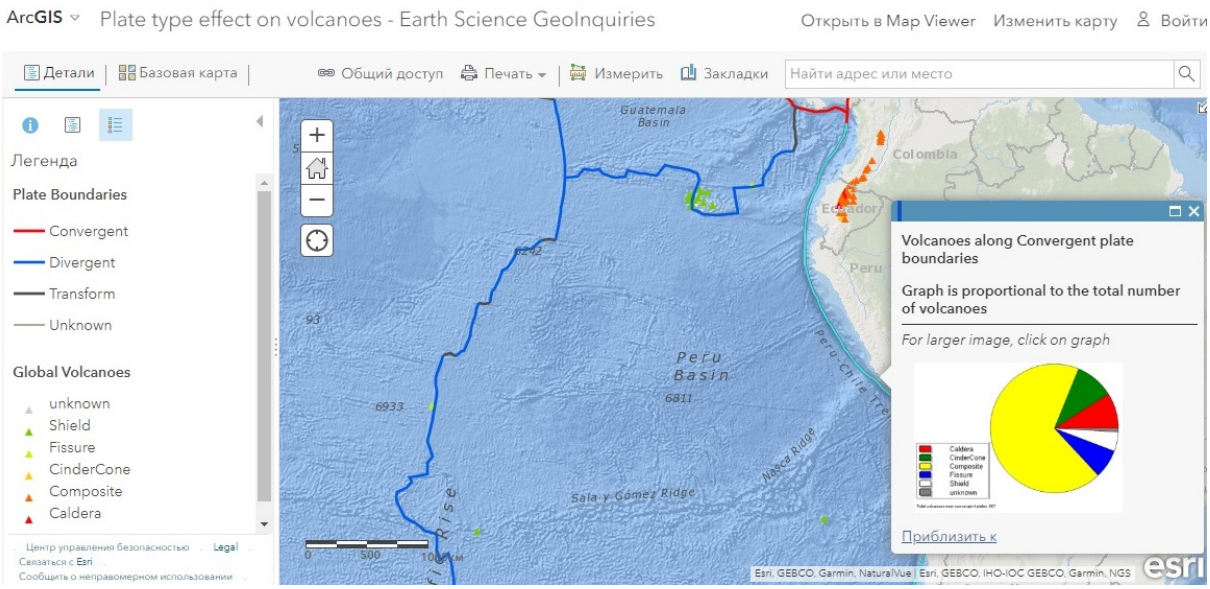

Figure 7. A tectonic map on the *GeoInquiries platform* with a summary chart showing the number and ratio of different types of volcanoes at 250 miles on both sides of the lithospheric plate boundaries.

A detailed analysis of the ways to overcome all these and other problems is a separate topic for consideration and is a direction for further research.

3. Conclusions

1. The use of geospatial analysis in an educational context includes a few key components and approaches that help make traditional geography lessons in the school curriculum more modern, effective, and engaging.
2. There is a need to include geospatial analysis in the school geography curriculum, which will ensure a deeper understanding of the various objects, processes, and phenomena of the Earth's geographic envelope.
3. The implementation of geospatial analysis in school practice is hindered by several problems that need to be addressed.
4. The main principles of implementing geospatial analysis into the school geography curriculum are:
    - geospatial technologies should be integrated into the already existing topics of the school geography curriculum;
    - geospatial analysis should be based on the use of real geospatial data;
    - the development of project activities is one of the most effective forms of integrating geospatial analysis into the school geography curriculum;
    - using GIS as a powerful tool for supporting geospatial analysis in the educational process;
    - an interdisciplinary approach is important when implementing geospatial analysis in the educational process;
    - for the successful implementation of geospatial analysis in school practice, geo-information training for teachers is necessary.

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