Application of the GIS Visual Interpretation Technique in Monitoring Air Pollution and Changes in Land Use During Urban Development

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Abstract

Geographic information systems (GIS) have gone through many phases of development since their inception several decades ago. GIS is a tool for analyzing and representing the geographic features of the Earth's surface and the events taking place using a computer system. The article concerns the presentation of the potential of GIS software and the increase in its use in scientific research. The first research area is the issue of air pollution, which is the main problem of highly urbanized regions. This research part presents a spatial analysis of changes in the level of pollution in the European Union countries.

The second research area aims to present the functionality of GIS software in the field of mapping land use and socio-economic activities in the strongly changing process of urbanization and development of large urban agglomerations. Research in this area is a useful tool for visualizing dynamic changes related to urbanization changes in areas that can be used in spatial planning. The article presents the process of creating spatial development maps based on SPOT-5 covering the years 2000 and 2012 in order to develop spatial development maps and monitor changes in land use. Time series of SPOT-5 2000/2012 images will be compared to detect changes. This example was based on Sungai Petani from a selected city in Malaysia.

Keywords: *GIS, air pollution, urban development*

Introduction

The dynamic development of civilization results in excessive consumption of natural resources in selected areas of the globe, threatening the balance of ecosystems. The uncontrolled and excessive negative impact of human activity on the environment must be stopped and controlled at present in order not to lead to an ecological catastrophe for future generations. The perspective of sustainable development is the only possible development path for securing natural resources for future generations as stated in the report of the World Commission on Environment and Development: Our Common Future published in 1987 and setting reduction targets until 2000 [1-4]. Currently, The European Union aspires to become the first climate-neutral continent [5]. Actions taken in the last twenty years in European countries were related to the energy transformation of economies, which enabled significant reductions in gas emissions [6-7]. The main sector of economies undergoing profound changes is the hard coal mining industry [8 -9]. The production of electricity and heat from coal is the main cause of the emission of the following air pollutants, such as: particulate matter (PM10 and PM2.5), sulfur dioxide (SO2) and nitrogen oxides. The article undertakes research in the area of monitoring the levels of selected emissions of harmful substances such as: PM2.5 and nitrogen oxides that have a negative impact on the life and health of societies living today in large agglomerations using the functionality of GIS software.

Another area of research related to economic development and dynamic urban changes is the example of using the visual GIS interpretation technique in monitoring changes in urban areas. The direction of this research area is currently a new area that is dynamically developing along with the increase in the availability of scanning and image recognition functionalities in GIS. Recent geographical information systems (GIS) developments have continuously introduced new and powerful techniques [10]. GIS likewise permits specialists to guide progressions in the spatial conveyances of social groups, social products, and events over time, allowing researchers to outwardly test hypotheses that make predictions about these changing spatial distributions [11]. The most vital way GIS can help analysts re-conceptualize spatial relationships and natural settings is by permitting researchers to move repeatedly between exchange representations of physical space [12] to pick the GIS method so that parameters on the ground could be modeled, hence, made to be utilized to its re-conceptualized spatial relationship and natural setting, such as addressing the modifiable areal unit issue [13-

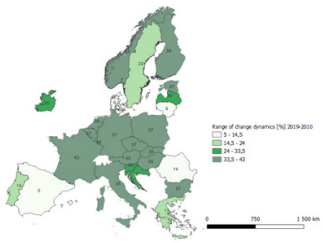

Fig. 1. Dynamics of changes in PM2.5 emission levels 2010–2019
Rys. 1. Dynamika zmian poziomu emisji pyłu PM2,5 w latach 2010–2019

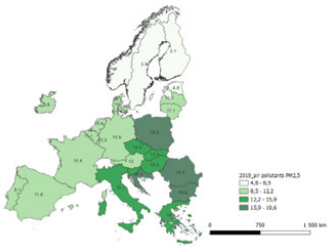

Fig. 2. Classification by PM2.5 emission levels in 2019
Rys. 2. Klasyfikacja według poziomu emisji PM2,5 w 2019 r.

14]. These systems permit consolidating census information from diverse decades without fusing or dropping census observation [15]. The system can access raster and vector precisely, thus, converting one format to another. Such a system might be utilized within visualization, prediction, simulation and projection for the future [16]. Consequently, to precisely measure environmental settings, researchers must be able to model physical space as a continuous, unbounded surface in which variable values can shift persistently instead of being fixed to particular units of analysis [17-18].

1. Research Methodology

The article concerns the presentation of the potential of GIS software and the increase in its use in scientific research. The first research area is the issue of air pollution, which is the main problem of highly urbanized regions. This research part presents a spatial analysis of changes in pollution levels in the European Union countries. In this research part, the authors seek answers to the following problems:

- Does the way air pollution levels are monitored and reported affect air quality?
- Are the air quality standards introduced in European countries effective?

The second research area aims to present the functionality of GIS software in the field of mapping land use and socio-economic activity. Research in this area is a useful tool for visualizing dynamic changes related to urbanization changes in areas that can be used for spatial planning. The article presents the process of creating spatial development maps based on SPOT-5 covering the years 2000 and 2012 in order to prepare spatial development maps and monitor changes in land use. Time series of SPOT-5 2000/2012 images will be compared to detect changes. This example was based on Sungai Petani of a selected city in Malaysia.

2. Results of visual GIS interpretation technique

2.1. Air quality analysis in European countries using GIS

The article analyzes two key compounds for human health, i.e. nitrogen oxides and PM 2.5 particulate matter, selected due to the availability of data in the appropriate time period. These harmful atmospheric pollutants are produced by the burning of fossil fuels and other industrial processes. Measures to combat air and natural environment pollution are most important to industrial entities, which are responsible for the majority of emissions. It is in these enterprises that it is necessary to implement innovative and ecological solutions in order to achieve the greatest results [19-25]. The transformation of heavy industry towards greener production has already started and will bring green effects [26-27]. The main sources of nitrogen oxides and PM 2.5 emissions include: road transport, power plants, industrial plants, biomass combustion and other factors affecting the levels of these pollutants in the air. The article discusses the importance of the problem in the context of public health protection.

PM 2.5 analysis

Pollution in the form of PM2.5 particles has a number of negative effects on human health and the environment. PM2.5 is considered one of the most harmful atmospheric pollutants due to its ability to penetrate deep into the respiratory system and reach the bloodstream, which can affect various organs and systems in the body. PM 2.5 emissions (particles with a diameter of less than 2.5 microns) have many negative effects on both human health and the environment. PM2.5 can penetrate deep into the respiratory system, even reaching the alveoli. These microscopic particles can cause irritation, inflammation and damage to lung tissue. PM2.5 is associated with the development of cardiovascular diseases such as heart attack, stroke, hypertension and cardiac arrhythmias. These particles can cause inflammation in the circulatory system and lead to damage to the walls of blood vessels. Children are particularly sensitive to PM2.5 due to their developing respiratory system and increased physical activity. Long-term exposure to PM2.5 can affect children's cognitive and

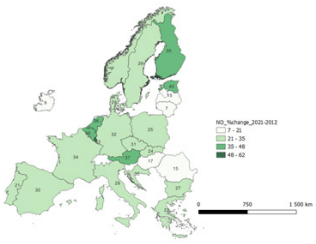

Fig. 3. Classification of countries according to the dynamics of reducing nitrogen oxide emission levels
Rys. 3. Klasyfikacja krajów według dynamiki redukcji poziomu emisji tlenków azotu

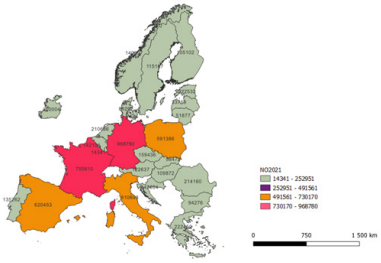

Fig. 4. Classification of countries according to emission level of nitrogen oxide in 2021
Rys. 4. Klasyfikacja krajów według poziomu emisji tlenków azotu w 2021 r.

developmental abilities and increase the risk of asthma and other respiratory diseases. PM2.5 emissions can negatively affect ecosystems, causing water and soil contamination and damage to vegetation. Therefore, limiting PM2.5 emissions is extremely important to protect public health and the environment. Actions to reduce these pollutants include controlling emissions from industrial sources, promoting low-emission transport, using air-cleaning technologies, and implementing appropriate air quality regulations and standards.

The Directive [28] on the reduction of national emissions of certain atmospheric pollutants introduced a list of reduction levels for pollutant emissions, including PM2.5. The standard indicates two time intervals, i.e. the first one covers the period from 2020 to 2029, in which the reduction level was indicated for each European Union country in relation to the base year 2005. Thus, for the analyzed countries, the highest reduction levels were set for the following countries: Netherlands (37%), Slovakia (36%), Greece (35%), Denmark (33%). The lowest emission reduction levels were assigned to: Italy (10%), Hungary (13%), Portugal, Luxembourg, Estonia and Spain each 15%, Poland (16%).

Figure 1 presents an analysis of data on the achieved PM2.5 emission reduction levels in 2019 in relation to the base year 2010.

Figure 1 shows the classification of European countries into four groups of countries similar in terms of PM2.5 emission reduction levels in 2019 in relation to the base year 2010. The group with the lowest reduction level includes countries that reduced emissions by a maximum of 14% in relation to 2010 and they are: Spain, Denmark, Lithuania and Romania. The second group of countries with a reduction in the range of 14.5–24% includes: Portugal, Greece, Sweden. The third group that achieved reduction levels from 24% to 33.5% was Ireland, Latvia, Slovenia, Croatia. The largest group of sixteen countries are those that have achieved reduction levels ranging from 33.5 to 43%. In this group, the highest level of reduction of 43% was achieved by France. Figure 2 presents the classification of the surveyed countries in terms of PM2.5 emission levels in 2019. Four groups of similar countries have been identified.

The emission limit for PM2.5 particles since 2008 was 25 µg/m3. This is the level of the average annual European value, which has been in force since January 1, 2015. However, from January 1, 2020, the permissible levels of average annual PM2.5 particle emissions were further reduced to 20 µg/m3 [18]. As can be seen in Figure 2, four of the 25 countries surveyed have emission levels close to the permissible limit: Poland, Romania, Bulgaria, Croatia. Other countries in 2019 were classified significantly below the upper emission limits, which should be assessed positively.

Nitrogen oxides analysis

The emission of nitrogen oxides has a potentially negative impact on human health. Nitrogen oxides are toxic gases that are produced when fossil fuels are burned in vehicles, power plants, industrial plants and other sources of emissions. The negative health effects of nitrogen oxide emissions can include respiratory problems. Nitrogen oxides can irritate the airways and worsen existing problems with asthma, chronic obstructive pulmonary disease, and other respiratory conditions. Prolonged exposure to nitrogen oxides can increase the risk of infection and pneumonia. Increasing the risk of cardiovascular disease. Nitrogen oxides can contribute to the development of inflammation in the circulatory system. Air pollution with nitrogen oxides can negatively affect the quality of life, especially in areas with heavy traffic and industrial areas. Children and the elderly are particularly sensitive to the effects of nitrogen oxides, as their respiratory and cardiovascular systems are more susceptible to damage. Various measures are being taken to reduce the impact of nitrogen oxide emissions on human health, including regulating emissions from industrial sources and vehicles, encouraging the use of public transport or other less emitting modes of transport, and promoting renewable energy sources. Improving air qual-

Fig. 5. Study Area Sungai Petani located in Malaysia
Rys. 5. Obszar badawczy Sungai Petani zlokalizowany w Malezji

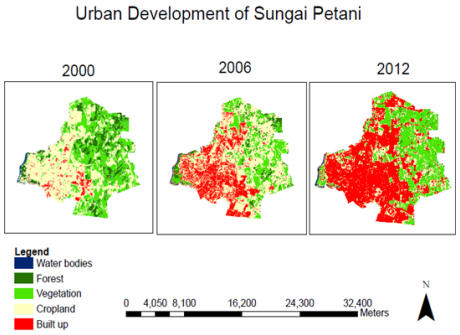

Fig. 2. Classification by PM2.5 emission levels in 2019
Rys. 2. Klasyfikacja według poziomu emisji PM2,5 w 2019 r.

ity and reducing nitrogen oxide emissions are important steps in ensuring a healthier environment for people. In the European Union, it is estimated that 40% of nitrogen oxides come from transport. The currently applicable Euro 6 regulations on nitrogen oxide emissions specify a permissible emission limit of up to 80 mg/km NOx for diesel engines and 60 mg/km NOx for petrol engines. The emission limit for both forms of propulsion according to the Euro 7 standard will be 60 mg/km of NOx. The Euro 7 standard regulates nitrogen oxide emissions from transport and is to apply in the European Union from July 1, 2025. The exhaust emission standard is an EU tool to combat gigantic emissions and pollution.

Since 2012, selected European countries have respected their emission limits for nitrogen oxides (NOx). The highest level of reduction in 2021 compared to 2012 was recorded in Luxemburg. The next group with high reductions are: Austria, Belgium, the Netherlands, Estonia and Finland.

In 2021, in absolute terms, Germany and France will be the largest NOx emitters. The second group of large issuers includes Poland, Italy and Spain. Since 2012, all selected countries have respected their emission limits for nitrogen oxides (NOx).

Based on the presented data, it can be seen that the restrictive emission limits for PM 2.5 bring measurable benefits in the form of significant reductions in emission levels in the European countries surveyed.

Across the European Union, a 29% reduction in nitrogen oxide emissions was achieved in 2021 compared to 2012. In terms of PM2.5 emissions, a 33% reduction was achieved in 2019 compared to 2010. Based on the data analysis performed using the classification functionality in the Quantum GIS software, the following answers to the given problem issues can be specified. Based on the diagnosis and analysis, Figures 1-5, it should be stated that the monitoring and reporting of emission levels of the tested pollutants, i.e. nitrogen oxides and PM2.5 particles, bring measurable positive effects in the form of significant reductions in emission levels in the analyzed periods of 2012-2021.

The standards for air pollutant emission limits introduced in the European Union countries have an effective impact on air quality, as the levels of pollutants of the tested substances have been decreasing.

2.2. Urban changes observations in Malaysia

Study area: Sungai Petani is the capital of Kuala Muda district and is located in the northwestern region of Peninsular Malaysia, in the state of Kedah. Sungai Petani is located about 35 km to the north of the metropolitan city of Georgetown, Penang. The district covers an area of 925 km2. Sungai Petani was a small town with a population of 254,372in 1990. However, the town has gradually developed over the years, especially after the opening of the North-South Expressway in 1991. This study area was chosen for the research because it has increased access to other areas, particularly Penang State in the south. It is one of the examples of new urban growth centers in a non-metropolitan area. In addition to that, with the rapid growth of urban extent and urban population, Sungai Petani has been categorized as a Semi-Regional Centre with a population of 358,663in 2000, which increased to 388,733 in 2005 and 421,530 in 2010 (MPSP 2013).

This section contains analyses of urban development through the years 2000, 2006 and 2012 which show the changes, the pattern and activity on land. The percentage changes in land use are shown in Table 1 for 2000 to 2006, Table 2 for 2006 to 2012 and Table 3 for 2000 to 2012. The output of the urban development map is displayed and analyzed. According to the data obtained in Table 4, there is a significant increase in job opportunities and the population's income level. Household income refers to the total income accrued to household members, both in cash and in-kind regularly in one year or more.

Tab. 1. Development changes in 2000–2006. Source: own elaboration

Tab. 1. Zmiany rozwojowe w latach 2000–2006. Źródło: własne

Change 2000-2006						
% of Change	2006					
2000	Forest	Water bodies	Vegetation	Cropland	Built up	Grand Total
Water bodies	10.5	80.2	1.3	2.1	6.0	100.0
Forest	44.8	0.8	25.6	22.0	6.8	100.0
Vegetation	26.4	0.0	36.3	27.4	9.9	100.0
Cropland	11.8	0.2	14.2	43.1	30.7	100.0
Built up	0.0	0.7	0.9	18.1	80.3	100.0
Grand Total	23.7	0.8	24.1	31.9	19.5	100.0

Tab. 2. Development Changes in 2006–2012. Source: own elaboration

Tab. 2. Zmiany rozwojowe w latach 2006–2012. Źródło: opracowanie własne

Change 2006-2012						
% of Change	2012					
2006	Forest	Water bodies	Vegetation	Cropland	Built up	Grand Total
Water bodies	4.4	81.2	0.2	8.1	6.1	100.0
Forest	35.6	0.6	36.2	16.9	10.7	100.0
Vegetation	18.8	0.0	71.0	5.1	5.0	100.0
Cropland	17.5	0.0	23.8	34.7	23.9	100.0
Built up	2.8	0.5	2.1	29.9	64.8	100.0
Grand Total	19.2	0.9	33.7	22.2	24.0	100.0

Tab. 3. Development changes in 2000–2012. Source: own elaboration

Tab. 3. Zmiany rozwojowe w latach 2000–2012. Źródło: opracowanie własne

Change 2000-2012						
% of Change	2012					
2000	Forest	Water bodies	Vegetation	Cropland	Built up	Grand Total
Water bodies	8.9	79.9	2.2	5.0	4.0	100.0
Forest	28.8	1.0	42.3	13.6	14.4	100.0
Vegetation	20.4	0.1	45.8	17.4	16.3	100.0
Cropland	14.1	0.3	20.9	30.7	34.0	100.0
Built up	0.0	0.5	2.8	33.2	63.5	100.0
Grand Total	19.0	0.9	33.7	22.2	24.2	100.0

The quantitative case study will rely on the visual interpretation technique allowing the researcher to see the urban development change observed against the environment. This represents the first attempt to identify development and social well-being and their impacts in an urban setting. Also, the development and other factors, such as institution, geography, mobility and human capital, are significant factors in society development rather than urban growth.

3. Conclusion

The research material presented in the article confirms the dynamic increase in the importance of using various functionalities of GIS software in scientific research. Data visualization with the possibility of simultaneous data analysis in software that is available to all users free of charge are the main advantages and benefits for scientists. The use of the possibility of interpreting changes in the spatial development of agglomerations is a potential area of modern analyzes having wide practical applications, among others, for spatial planning and predicting upcoming changes in the development of land acreage.

The article shows that the main tool for air quality management in European countries is monitoring the level of toxic substance emissions, publishing data and managing administrative activities so as to minimize the negative effects on society and the environment. Measurement results are usually publicly available and are used to inform residents about the air quality in their area and to take remedial action in the event of exceeding air quality standards. Air quality standards are set by the European Union and local regulatory authorities and are based on World Health Organization (WHO) guidelines. Thanks to air quality monitoring systems, European countries can effectively track and manage the problem of air pollution, which is crucial to protect human health and the environment. Thus, it was shown that data analysis in GIS software is a very useful tool in assessing the state of various aspects of the natural environment.

This paper examined how GIS is being used extensively in urban development in Sungai Petani and how its adoption has influenced and been influenced by the contexts of the municipality. It provided a baseline survey of GIS adoption in Malaysia, a critical examination of how the urban landscape of Sungai Petani is modeled, recorded, presented and comprehended through geographic information under the particular social contexts there. It examined to what extent and in what ways urban development in Sungai Petani is affected by its GIS adoption and vice versa. Finally, it investigated whether the meanings and significances of geographic information in Sungai Petnai are unique to particular social contexts. Besides the physical implementation of GIS in Sungai Petani, this paper heavily emphasized the role of geographic information in GIS adoption. Through understanding the flow of geographic information within the same framework of mutual relationship above, it is possible to establish a systematic understanding of how the availability of geographic information is affected by both spatial and social factors and how these factors may result in uneven access to geographic information in the municipality. Such a perspective suggests a dynamic context for the current condition of geographic information openness. It is open to contestation from technological changes (e.g., availability of online mapping services) and society (e.g., demand for increased transparency). This paper is, at best, only a beginning. A more thoughtful understanding of the issue at stake would require not only input from GIS and Social well-being but also from a wide range of fields of study, such as various conceptions of space and place.

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Zastosowanie techniki interpretacji wizualnej GIS w monitorowaniu zanieczyszczeń powietrza i zmian w zagospodarowaniu terenów podczas rozwoju miast

W Systemy informacji geograficznej (GIS) przeszły wiele faz rozwoju od czasu ich powstania kilkadziesiąt lat temu. GIS to narzędzie do analizy i reprezentacji cech geograficznych powierzchni Ziemi oraz zachodzących wydarzeń za pomocą systemu komputerowego. Artykuł dotyczy przedstawienia potencjału oprogramowania GIS i wzrostu jego wykorzystania w badaniach naukowych. Pierwszym obszarem badawczym jest problematyka zanieczyszczeń powietrza, które stanowią główny problem regionów silnie zurbanizowanych. W tej części badawczej przedstawiono analizę przestrzenną zmian poziomu zanieczyszczeń w krajach Unii Europejskiej. Drugi obszar badawczy ma na celu przedstawienie funkcjonalności oprogramowania GIS w zakresie mapowania użytkowania gruntów i działalności społeczno-gospodarczej w silnie zmieniającym się procesie urbanizacji i rozwoju dużych aglomeracji miejskich. Badania w tym zakresie są użytecznym narzędziem do wizualizacji dynamicznych zmian związanych ze zmianami urbanizacyjnymi na obszarach, które można wykorzystać w planowaniu przestrzennym. W artykule przedstawiono proces tworzenia map zagospodarowania przestrzennego w oparciu o SPOT-5 obejmujący lata 2000 i 2012 w celu opracowania map zagospodarowania przestrzennego oraz monitorowania zmian w użytkowaniu gruntów. Szeregi czasowe obrazów SPOT-5 2000/2012 zostaną porównane w celu wykrycia zmian. Przykład ten został oparty na Sungai Petani z wybranego miasta w Malezji.

Słowa kluczowe: *GIS, zanieczyszczenie powietrza, zmiany zagospdoarowania terenu*