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The Use of Geodata in the Process of the Ventilation of the City of Krakow

Abstract: The purpose of this publication is to analyze air pollution on the example of the city of Krakow, as well as to consider the possibility of using geodata for environmental protection. In addition to case study analysis as the leading research method, the article also uses the observation, analysis, and statistical methods. The article presents the concept of using GIS spatial analyzes and spatial planning as an element of the Green New Deal in the process of ventilating the city of Krakow.

When developing a project related to city ventilation, it is extremely important to have the most accurate data on the strength, direction of the wind, type of pollution, and the number of emitters. Spatial analyzes are also able to indicate the main ventilation corridors of the city. These include, above all, areas located on the Vistula River, but also the widest city streets. Such results make it possible to more consciously manage space.

Keywords: Green New Deal, geodata, spatial management, city ventilation, environmental protection

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1. Introduction – Research Issues

The Green New Deal addresses the important problem of the appropriate management and transformation of areas that are crucial for landscape protection. For the foreseeable future, maintaining the Earth's ability to meet the global demand for its products will be of fundamental importance [1]. The level of concern raised by current trends reflects the possibility that much land conversion is in some sense land degradation [2]. Land changes were often seen as improvements by some or all land users. Change is intrinsic to human activity and use, and the goal is to encourage improvement and counter the forces that favor degradation.

2. The Literature on the Subject

Assessing the effects of a given land transformation and its consequences requires the difficult issues of forecasting (future resource needs and opportunities influenced by technical and socio-economic changes) and assessment (distribution and rights of future generations) [3]. However, we now have much more scientific knowledge of the physical extent, nature, and consequences of land conversion, which serves as the basis for any such assessment. The path indicated by scientists is a change in structure, which means the need to create accurate and up-to-date databases for planners at all levels [4]. The inherent flexibility of GIS techniques can make a significant contribution to improving the speed and qualitative efficiency of urban and regional planning [5]. The new plans make it possible to present quite complex quantitative and spatial dependencies in a graphical form and improve the transparency of the planning and decision-making process [6]. This technique is a powerful tool, not only useful for monitoring the current growth and development of regions, but also as a basis for building and using models to achieve specific development goals in a specific situation [7]. An important result of the work on changing the structure and comparing Polish and foreign models are conclusions indicating that both European and Polish experiences are convergent and follow pan-European trends, and at the same time use their own system which has been developed for decades [8]. The European experience also shows that a similar design system can not only be used in the design of rural and agricultural areas, but also in the design of cities and the conservation of monuments. Research conducted in this field seems to confirm the universality of the idea of space design based on the multi-stage design system and has the potential to become one of many voices in the European discussion on this subject [9, 10].

One of the examples of cities that do not cope with the problem of pollution is Krakow. A city famous for legends about the Wawel dragon and struggling with smog problems. Many cities in Poland [11, 12] and in the world [13, 14] have similar experiences with regard to smog. Air pollution is a growing threat to human health and well-being that we must address [2, 12, 15–33]. The location of Krakow between the highlands, in the valley, is the reason for the formation of smog. For the purpose of the conducted considerations, the author of the study analyzed how London-type smog is formed, as this is the type of smog we most often deal with in Poland, including Krakow. The shortcomings of the methodology in the field of urban ventilation embedded in the planning and management of the city mean that wind is one of the main criteria in the formation of smog, or its absence, which is clearly emphasized by research [7, 24–27, 34–43]. Air pollution translates into increased pathogenicity, mortality, and thus burdening the state health care system, also economic losses [2, 3, 6, 17, 21, 22, 44–47].

This type of smog is created when the air is moist and cool, and there is no wind. This is why we most often encounter the problem of smog in Poland in the winter from the end of November, beginning of December to the end of February [48]. In 2017, southern Poland experienced record high air pollution, where the PM10[2] and PM2.5[3] standards were exceeded by up to 3000% [49]. Such high exceeded standards prove the scale of the problem. According to the international health organization WHO, over 230,000 people died in the world as a result of excessive air pollution in just one year [50].

3. Materials and Research Methodology

When analyzing the problem of air pollution in large cities, one should focus on the sources of the emission of these pollutants [44, 51–54]. In addition to non-stationary sources (communication – cars), the largest emitter of pollution are stationary sources – so factories and, to the greatest extent, private houses are still in many cases fired with coal, causing smog. Accurate data on buildings, the number of their floors, area, as well as the type of use affect the value of emitted pollutants [55].

Focusing on the morphology of cities, the concept of density turns out to be fundamental. Density is extremely important from the point of view of research. Traditional models of urban space management turned out to be insufficient due to their lack of flexibility and inability to adapt to a number of environmental, social and economic changes [56–63]. As part of the considerations, the research area was determined using the ArcMap program, consisting of 9 polygons with dimensions of 500 m × 500 m. The research area is located in the areas of single-family houses where pollution is theoretically the highest during the heating season. The area of 9 polygons is a representative and model area for conducting research in the city of Krakow. The author took the urbanization factor into account, obtained

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[2] PM10 is a mixture of particles suspended in the air with a diameter of up to 10 nanometers.

[3] PM2.5, so-called atmospheric aerosols with a diameter of up to 2.5 nanometers.

on the basis of the local development plan, and in the absence of a plan, it was estimated on the basis of the number of emitters. According to the innovative AERMOD atmospheric dispersion modeling system, each polygon is one of the nine emitters (Fig. 1). The data was obtained from publicly available websites such as OpenStreetMap and data provided by GUGIK, and then processed, where each of the buildings in the area separated by the training ground was reduced to a point representation. Then, using the ArcMap program, the research area was determined, consisting of 9 polygons with dimensions of 500 m × 500 m. Each of the buildings is treated as an independent emitter and on this basis emission calculations were made, assuming the average parameters regarding the height of the building at the level of 2.5 and assuming that the building is inhabited by 3 people. The adopted cubature assumptions result from information on the number of floors obtained from GIS attribute data.

The last stage of the research was to take into account the wind rose and terrain barriers. For this purpose, the area of the city of Krakow was modeled, taking into account the cubature of the city's buildings and the digital terrain model. The conducted research is presented in Figure 1.

Fig. 1. Division of the area into 9 sectors

4. Research

4.1. Calculations of Total Volume and Energy Demand

Information on buildings and their data is presented in Table 1.

Table 1. A summary of the results of the data analysis of the designated area, on the basis of which a number of calculations were made for further analysis of the demand for power and energy

Emitter ID	Number of buildings	Sum of the heights of the buildings	Average building height [m]	Number of residents	Total P_{CO} [W]
1	25	107.5	3.89	75	246,101.06
2	78	287.5		234	619,975.18
3	22	97.5		66	210,946.94
4	37	137.5		111	308,760.38
5	41	170.0		123	409,163.61
6	42	145.0		126	305,097.43
7	114	470.0		342	1,033,385.25
8	17	57.5		51	149,814.75
9	61	230.0		183	486,251.15
Sum	437	1702.5		1311	3,769,495.56

For the calculations, the height of a floor was assumed as 2.5 m, it was assumed that one building is inhabited by 3 people.

Calculation of the building volume is as follows:

$$V_B = a \cdot b \cdot c \cdot cor \ [\mathrm{m}^3] \tag{1}$$

where:

V_B – volume of one residential building [m^3],
a – building area [m^2],
b – number of floors,
c – average height of one floor of the building [m] (assumed 2.5 m)
cor – correction factor, determines the percentage of the object area that is not heated; founded 0.8 (which means that 20% of the building area is not heated).

The demand for power and CO energy is expressed by the formula:

$$P_{CO_i} = \frac{1.6}{\sqrt[6]{V_B}} \cdot V_B \cdot \Delta T \ \ [\mathrm{W}] \tag{2}$$

where:

P_{CO_i} – demand for central heating power for 1-residential building [W],
V_B – volume of one residential building [m^3],
ΔT – difference between indoor and outdoor temperatures ($T_i - T_o$) [K] (assumed 40 K).

The total power demand of the city is as follows:

$$P_{CO} = \Sigma P_{CO_i} \ \ [\mathrm{W}] \tag{3}$$

where P_{CO} – total power demand of the locality for CO purposes [W].

The formula describing the demand for central heating power supply is presented below:

$$E_{CO} = \frac{P_{CO} \cdot n \cdot t}{10^9} = \frac{2{,}438{,}814 \cdot 0.25 \cdot 8760}{10^9} = 5.34 \text{ GWh} \rightarrow 19{,}228 \text{ GJ/year} \tag{4}$$

where:

E_{CO} – demand for central heating energy [GWh],
P_{CO} – demand for central heating power [W],
n – conversion factor of the annual demand for CO in relation to the maximum demand (assumed 0.3),
t – time [h] (calendar year 8760 h).

Calculation of demand for DHW power and energy is as follows:

$$P_{DHW} = V \cdot C_p \cdot \rho \cdot \Delta T \ \ [\mathrm{kW}] \tag{5}$$

where:

P_{DHW} – domestic hot water power demand [kW],
V – water stream [m^3/s] (about 110 liters for 1 person per day, 3 person/house),
C_p – specific heat of water [kJ/(kg·K)] (equal to 4.19 kJ/(kg·K)),
ρ – density of water [kg/m^3] (equal to 998 kg/m^3),
ΔT – temperature difference ($T_{hot\ water} - T_{cold\ water}$) [K] (equal to 51 K).

The energy demand for the preparation of domestic hot water (DHW) was determined as follows:

$$E_{DHW} = \frac{V \cdot M \cdot T_{year} \cdot C_p \cdot \rho \cdot \Delta T_{av} \cdot f}{10^6} \quad \text{[GJ/year]} \tag{6}$$

where:

E_{DHW} – energy demand for domestic hot water [GJ/year],
V – water stream [m^3/person],
M – number of inhabitants of the estate [persons],
T_{year} – total number of days of operation of the installation [d/year] (equal to 340 d, 25 days a year I am on vacation],
C_p – specific heat of water [kJ/(kg·K)] (equal to 4.19 kJ/(kg·K), assumed in calculations),
ρ – density of water [kg/m^3] (equal to 998 kg/m^3),
ΔT_{av} – temperature difference ($T_{hot\ water} - T_{medium\ water}$) [K] (equal to 40 K),
f – coefficient of hourly non-uniformity of distribution of demand for domestic hot water:

$$f = 1.08 \cdot n^{-0.322} = 1.08 \cdot 1440^{-0.322} = 0.104 \tag{7}$$

where n – number of large draw-off points (one per building).

4.2. Emission Index Calculations

Calculations were made for:

- energy demand,
- building volumes,
- demand for power and energy in the central heating installation,
- DHW power and energy demand (Table 2).

Table 2. Calculation results

Parameter	Emitters									Unit
	1	2	3	4	5	6	7	8	9	
P_{CO}	246,101	619,975	210,947	308,760	409,164	305,097	1,033,385	149,815	486,251	W
N_{houses}	25	78	22	37	41	42	114	17	61	number
$N_{residents}$	75	234	66	111	123	126	324	51	183	number
E_{CO}	0.65	1.63	0.55	0.81	1.08	0.80	2.72	0.39	1.28	GWh
	2328	5866	1996	2921	3871	2887	9777	1417	4600	GJ/year
V	8250	25,740	7260	12,210	13,530	13,860	37,620	5610	20,130	L/d
	8.25	25.74	7.26	12.21	13.53	13.86	37.62	5.61	20.13	m^3/d
	9.549E-05	2.979E-04	8.403E-05	1.413E-04	1.566E-04	1.604E-04	4.354E-04	6.493E-05	2.330E-04	m^3/s

Table 2. cont.

Parameter	Emitters									Unit
	1	2	3	4	5	6	7	8	9	
P_{DHW}	20.364	63.534	17.920	30.138	33.396	34.211	92.858	13.847	49.687	kW
E_{DHW}	180	389	162	235	251	256	503	138	329	GJ/year
f	0.383	0.266	0.399	0.338	0.327	0.324	0.235	0.434	0.287	–
$P_{CO} + P_{DHW}$	266.465	683.510	228.867	338.899	442.560	339.308	1126.243	163.662	535.938	kW
	0.266465	0.68351	0.228867	0.338899	0.442560	0.339308	1.126243	0.163662	0.535938	MW
$E_{CO} + E_{DHW}$	2508	6254	2161	3156	4122	3142	10,279	1556	4929	GJ/year
E_{DHW}/E_{CO}	0.08	0.07	0.08	0.08	0.06	0.09	0.05	0.10	0.07	–

Explanations: P_{CO} – demand for central heating power [W]; N_{houses} – number of houses [number]; $N_{residents}$ – number of residents [number]; E_{co} – demand for central heating energy [GWh]; V – water stream [L/d], [m^3/d], [m^3/s]; P_{DHW} – domestic hot water power demand [kW]; E_{DHW}- energy demand for domestic hot water [GJ/year]; f – coefficient of hourly non-uniformity of distribution of demand for domestic [–].

The next step was to calculate the emission of gaseous pollutants to the atmospheric air from the combustion of hard coal and other fuels (Tables 3, 4, Figs. 2, 3).

Table 3. List of emission factors of selected air pollutants for the combustion process

Fuel	PM10 [g/GJ]	NO_x [g/GJ]	SO_2 [g/GJ]
Coal (W1)	404	110	600
Firewood (W2)	695	75	20
Fuel oil (W3)	1.9	51	70
Natural gas (W4)	1.2	51	0.3

Table 4. List of results of calculations of E_c emissions of dust and gaseous pollutants into the air from the combustion of solid fuels in individual household furnaces for all substitute emitters

Fuel	PM10 [kg/year]	NO_x [kg/year]	SO_2 [kg/year]	PM10 [kg/h]	NO_x [kg/h]	SO_2 [kg/h]
Coal (W1)	25,658.90	6986.33	38,107.28	10.02	2.73	14.89
Firewood (W2)	44,140.93	4763.41	1270.24	17.04	1.86	0.50
Fuel oil (W3)	120.67	3239.12	4445.85	0.05	1.27	1.74
Natural gas (W4)	76.21	3239.12	19.05	0.03	1.27	0.0E1

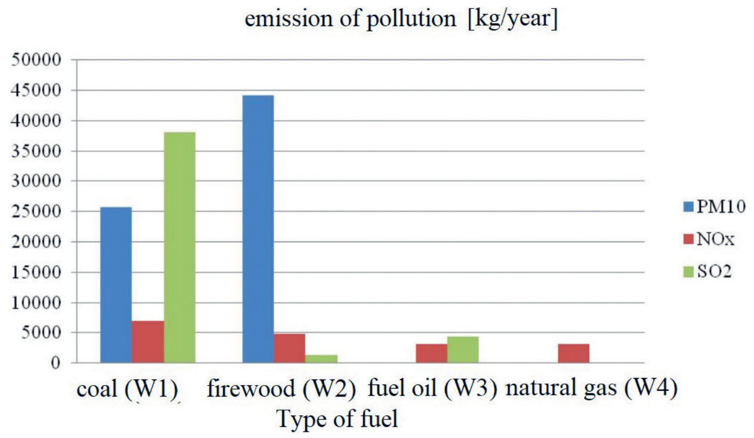

Fig. 2. Diagram of annual E_c emissions of dust and gaseous pollutants into the air from the combustion of solid fuels in individual household hearths

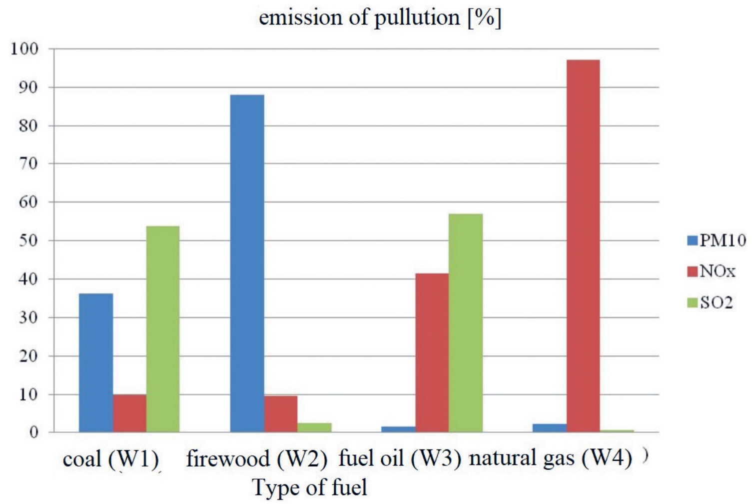

Fig. 3. Diagram of E_c emissions of dust and gaseous pollutants into the air from the combustion of solid fuels in individual household furnaces for everyone on a daily basis, expressed as a percentage

4.3. List of Emission Index Results

Analyzing the results obtained, it can be seen that coal, compared to wood, fuel oil and natural gas, is characterized by the highest SO_2 emission and the highest NO_x emission per year in kilograms (Figs. 2, 3). Only wood has a higher emission of dust compared to coal, but a much lower emission of sulfur compounds. Heating oil and natural gas have the lowest dust emissions. Gas is characterized by the overall lowest emission of compounds. The highest emissions with gas firing are NO_x emissions, and the lowest emissions are dust and SO_2. In the case of fuel oil, the highest emission is related to SO_2 and the lowest to dust. Wood has the highest emission of dust, while hard coal has the highest emission of SO_2. The percentage chart allows the determination of the percentage of pollutant emissions in relation to the emissions of all substances of a given fuel. Here, too, it can be seen that fuel oil and natural gas have the lowest PM10 emissions, and wood has the highest emission. Natural gas has the highest emission of nitrogen compounds, and wood has the lowest. The highest emission of SO_2 is shown by fuel oil and hard coal, and the lowest by natural gas (Table 5).

Table 5. List of the results of calculations of WE_i indicators of dust and gas pollutants

Substitute Emitter ID	PM10	NO_x	SO_2
	[g/m²/s]		
1	9.052E-06	1.822E-06	5.186E-06
2	2.257E-05	4.544E-06	1.293E-05
3	7.798E-06	1.570E-06	4.467E-06
4	1.139E-05	2.293E-06	6.525E-06
5	1.488E-05	2.995E-06	8.524E-06
6	1.134E-05	2.283E-06	6.497E-06
7	3.710E-05	7.469E-06	2.126E-05
8	5.615E-06	1.130E-06	3.217E-06
9	1.779E-05	3.582E-06	1.019E-05

Explanation: WE_i – i-th emission factor.

The analysis of the results and graphs shows that the highest emissions occur in areas of dense development. The correctness is maintained for each of the pollutants tested (Figs. 4–6). The emissivity results are strongly correlated with the number of emitters (buildings), the greater the number of emitters, the stronger it translates into the level of pollution, which is illustrated by the red color in Figures 4–6. The result is not only influenced by the number itself, but also by the density of objects, which is the highest in the lower left sector (sector 7). The density of objects makes air migration difficult, minimizing the influence of western winds (Fig. 7).

While the problem of defining the phenomenon itself is not too difficult, it should be noted that it is necessary to have up-to-date data on the number of buildings, their volume or number of floors, etc. From a pragmatic point of view, it is more important than defining the problem itself to define a method aimed at reducing the negative impact of pollution on the environment, and, if possible, eliminating it (at least partially).

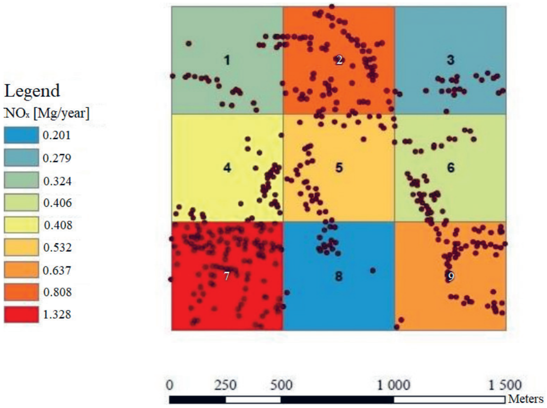

Fig. 4. NO_x emission

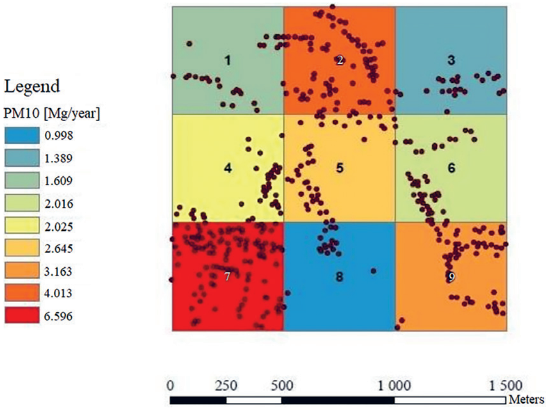

Fig. 5. PM10 dust emission

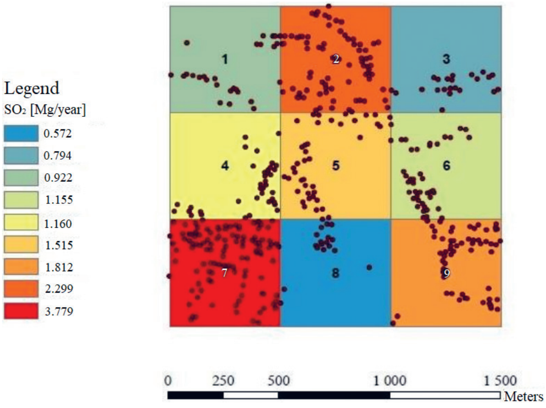

Fig. 6. SO_2 emission

One of the scenarios is a way to reduce pollution by replacing heating devices with those that emit significantly less harmful dust and, thanks to thermal insulation, cause less energy loss. Another way may be the active monitoring of the phenomenon, and through proper spatial management, increasing or creating corridors for the ventilation of the city.

4.4. Wind Rose and Terrain Barriers

When developing a project related to city ventilation, it is extremely important to have the most accurate data on the strength and direction of the wind. Such data were obtained from the Institute of Meteorology and Water Management in Krakow, and their elaboration is as follows (Fig. 7).

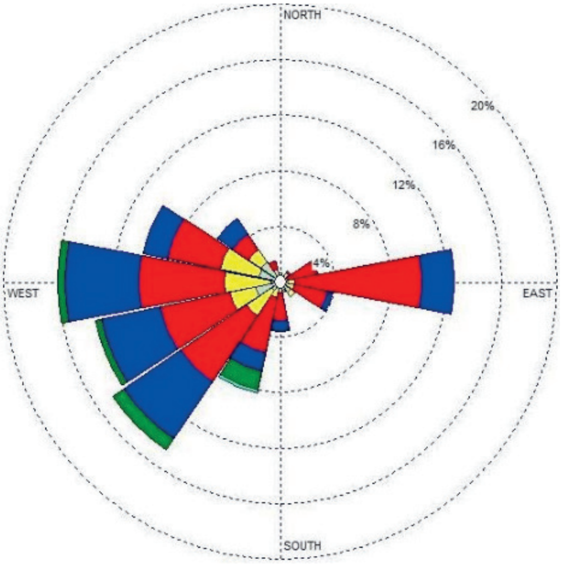

Fig. 7. Wind rose, direction and speed

Annual data allows the determination of the direction and strength of the winds as a percentage. It transpires that the direction of the wind is essentially latitudinal, with the prevailing winds being westerly and south-westerly. Winds with an average strength of up to 20 km/h prevail. The data also shows that there are many more days with virtually no wind than those with strong winds.

A three-dimensional Numerical Terrain Model of the city of Krakow was generated for a full analysis of the air corridors in Krakow and the possibilities of improving the ventilation of the city. The model was created on the basis of data available on the SRTM Internet. The created terrain model enabled a more reliable analysis and made it possible to perform a simulation showing the way smog is formed and spreads. The relief was the first element that prevented the free circulation of air (Fig. 8).

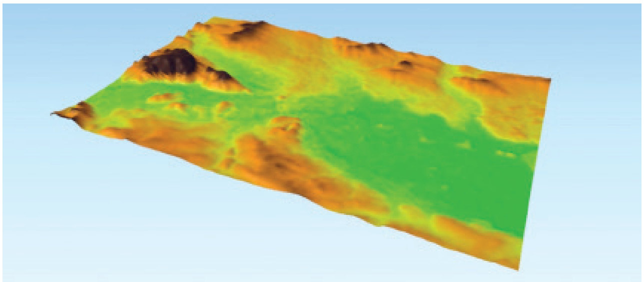

Fig. 8. Digital terrain model for the city of Krakow

In addition to the existing natural barriers, there are also many architectural barriers in Krakow. These are the tall buildings located on the outskirts of the city, and those located in the center. The city center is particularly compact, which is mainly due to the development of the city in the historical aspect. Currently, the very center is not only recognized as historic and important in national terms, but also by global organizations such as UNESCO. Belonging to the most important and valuable monuments of architecture determines the impossibility of changes in the city center, in turn affecting air circulation, or rather the lack thereof, in narrow, crowded streets (Fig. 9).

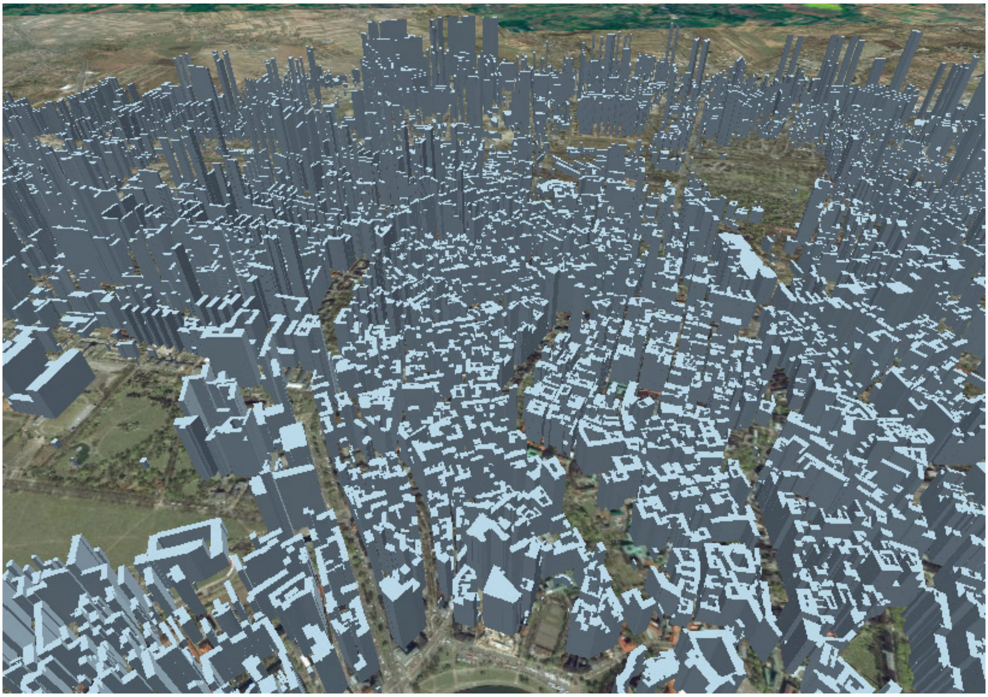

Fig. 9. 3D models of buildings in the city of Krakow

In order to conduct the most reliable data analysis possible, 3D modeling and the visualization of all of the buildings of the city of Krakow was made available by the City of Krakow for the implementation of this work, i.e. 123,883 buildings. Due to such a large number of buildings, as well as for the sake of the nature of the task performed, modeling was carried out based on the LoD2 level of detail, which allowed for significant time savings, taking into account the complexity of the computational processes. The varied height of the buildings was achieved by using the building attributes regarding the height of the buildings. Missing data was supplemented with field intelligence, as well as data from the OBSERVATORY geoportal and OpenStreetMap.

On the basis of the conducted analysis, it is possible to notice a definite differentiation of buildings in particular parts of the city. The very center of the Old Town is dominated by compact buildings, consisting of traditional and historic tenement houses.

The height of buildings located in the center usually reaches about 5 floors. Buildings located outside the city center are definitely higher. The highest of them have 24 floors and are buildings intended for offices. The tallest buildings are marked in blue – 15–22 floors, green – 9–14 floors, yellow 5–8 floors, orange 2–4 floors, red – below 2 floors (Fig. 10).

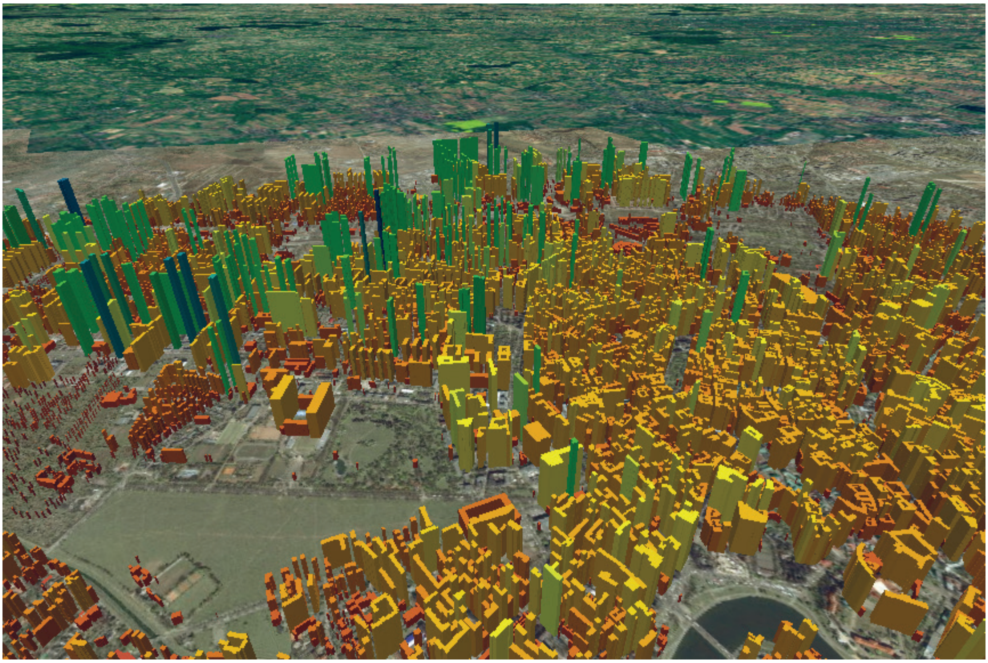

Fig. 10. Buildings and their division by the number of floors

The visualization shows air circulation, which from the west and south-west is blocked by the hills, resulting in the poor ventilation of the city. In terms of relief, this is progressively gentler on the eastern side. However, it should be noted at this point that this type of landform does not have a beneficial effect on the ventilation of the city due to the meteorological data, which indicate that prevailing western winds are typical across the country.

Airborne pollutant dispersion calculations were made using the advanced AERMOD modeling system. The results of the numerical values are presented in the table below (Table 6).

Table 6. Summary of the results of the AERMOD model

Variant	Substance	Concentration [μg/m^3]		*xp*	*WO*
W1	NO_2	S_{1_max}	311.45	200	200
W2			59.91		
W3			95.82		
W1	NO_2	S_{d_max}	134.77	no data	no data
W2			42.21		
W3			55.00		
W1	NO_2	S_a	36.28	40	40
W2			9.63		
W3			15.40		
W1	SO_2	S_{1_max}	2396.94	350	350
W2			45.85		
W3			1184.82		
W1	SO_2	S_{d_max}	730.39	125	no data
W2			14.48		
W3			372.89		
W1	SO_2	S_a	168.72	20	20
W2			2.87		
W3			73.08		
W1	PM10	S_{1_max}	24,183.22	no data	280
W2			6.55		
W3			69.49		

Table 6. cont.

Variant	Substance	Concentration [µg/m³]		*xp*	*WO*
W1	PM10	S_{d_max}	1274.66 2.07 21.87	50	no data
W2					
W3					
W1	PM10	S_a	294.45 0.41 4.29	40	40
W2					
W3					

Explanations: S_{1_max} – maximum hourly concentration; S_{d_max} – maximum daily concentration; S_a – maximum annual concentration; *xp* – allowable level in the air [µg/m³]; *WO* – permissible level in the air due to the protection of human health [µg/m³].

The results were presented by means of the calculations in three variants depending on the intensity of combustion and the maximum and minimum wind strength. The aim was therefore to indicate the possible greatest pollution, focusing on their type and place of occurrence. The results were presented as part of the dispersion model implemented (Figs. 11–13).

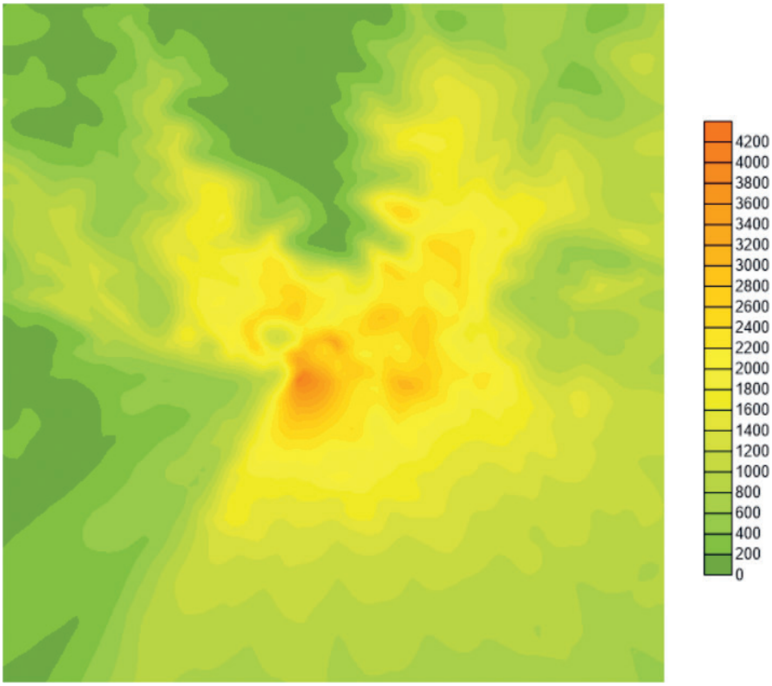

Fig. 11. Chart of maximum hourly PM10 concentrations

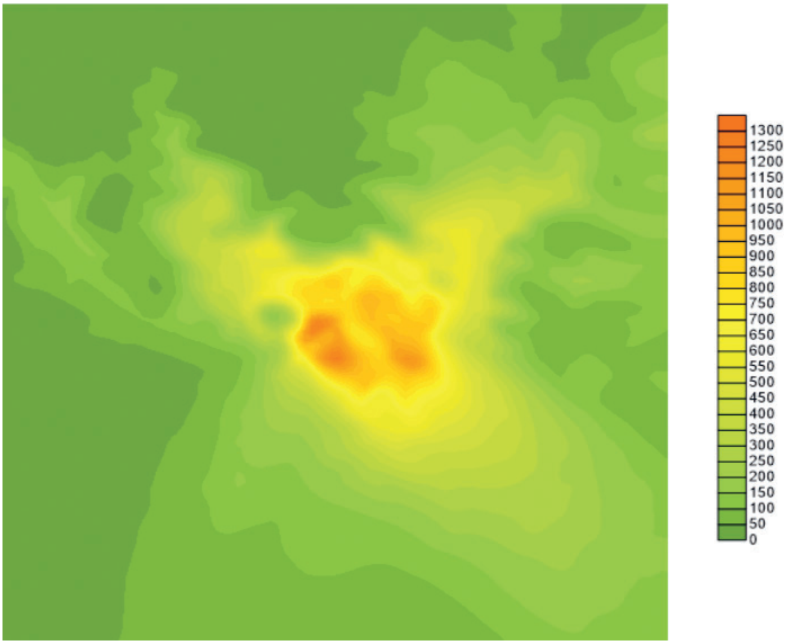

Fig. 12. Chart of maximum daily PM10 concentrations

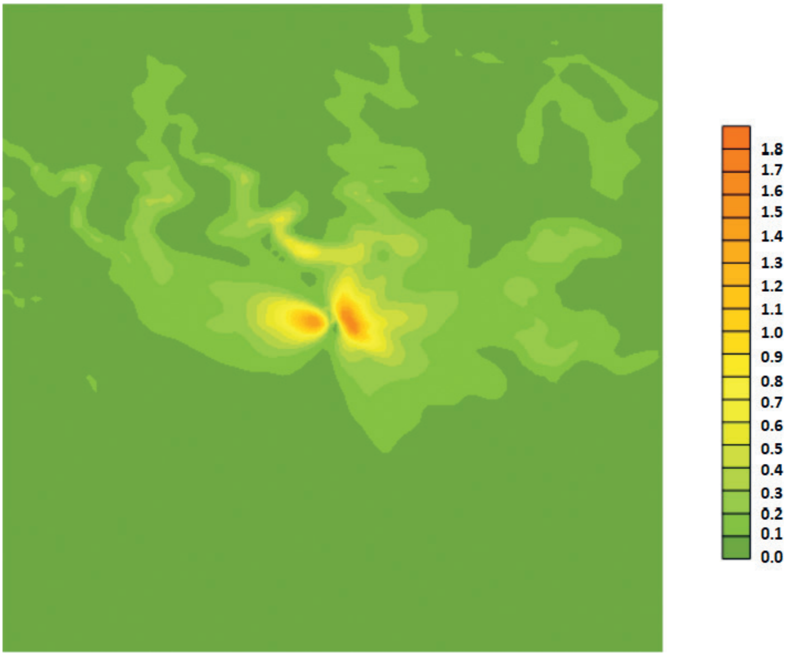

Fig. 13. Chart of maximum annual PM10 concentrations

On the basis of the considerations carried out, it should be noted that there is a need to constantly update databases on land and building records. In this case, the Digital Terrain Model also turned out to be helpful. Currently, the problem of environmental protection is being raised more and more often, the research on the analysis of the state of the air absorbs huge funds. It is worth noting that the calculation methods used are pioneering in the world, and the current geodata available contributes to a fairly accurate analysis with maximum cost reduction. It is also important that the analyzes were made using the existing ArcGIS and QGIS programs, which means that there is room for the development of more advanced programs monitoring the state of air in Krakow. Spatial analyzes are also able to indicate the main ventilation corridors of the city. These include, above all, areas located on the Vistula River, but also wide city streets. Such results make it possible to manage space more consciously. Possession of up-to-date data from the Land and Building Register and their skillful and wise use can affect areas that are seemingly independent of each other. Therefore, in this case, we can talk about the synergy of fields and exceeding previously known solutions.

5. Summary and Conclusions

On the basis of the research out, it should be noted that there is a need to constantly update databases on land and building records. In this case, the Digital Terrain Model also turned out to be helpful. Currently, the problem of environmental protection is being raised increasingly often, the research on the analysis of the state of the air absorbs huge funds. It is worth noting that the calculation methods employed are pioneering on the global scale, and the currently available registration data contributes to a fairly accurate analysis with maximum cost reduction. It is also important that the analyzes were made using the existing ArcGIS and QGIS programs, which means that there is room for the development of more advanced programs for monitoring the state of air in Krakow. Spatial analyzes are also able to indicate the main ventilation corridors of the city. These include, above all, areas located on the Vistula River, but also the widest city streets. Such results make it possible to manage space more consciously [29, 50]. Possession of up-to-date data from the Land and Building Register and their skillful and wise use can affect areas that are seemingly independent of each other. Therefore, in this case, we can talk about the synergy of fields and exceeding previously known solutions. The presented research gives the opportunity to correct the actions of local governments, indicating the need for ventilation zones. These, in the case of the city of Krakow, are located along city arteries in the form of the widest streets, the Vistula River, and common areas. This indication is unambiguous and should prevent municipal authorities from developing green areas that are key areas from the point of view of the ventilation possibilities of urban space. The results of the conducted research may also have a potential practical use in the context of designing public spaces, taking into account green areas that are the "lungs of the city". The adopted research method (case study) requires a critical look at the analyses conducted. The model method of calculations resulting from the statistical approximation of the emitters used should also be taken into account (the emission period depends on the number of people and the number of the emitters themselves). It is also worth noting that the accuracy of the AERMOD model result depends on the regular mesh size and boundary mesh conditions, so research needs to be continued in the context of mesh sensitivity in the validation part of the model. The adopted research method is therefore not perfect and makes it necessary to continue research, especially in terms of the quality of the data used. Nevertheless, the research conducted to this point can be valuable material for planners carrying out the tasks of local governments, taking into account the need for proper ventilation of the city in their activities. An undoubted advantage of the research is the possibility of universal application in other cities.

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