ANALYZING AIR QUALITY USING GIS TOOLS

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Abstract: In this article the main topic of interest is to explore the analyzing possibilities offered by the latest version of ArcGIS Pro. At the same time, we want to highlight the use the 2D and 3D products obtained, but also the means of their subsequent analysis in the established GIS environment. We chose to use several methods of data investigation.

The purpose of this work consisted in determining the air quality based on the measured values of the PM 2.5, PM 10 and NO_2 indicators, over three days, with the help of sensors mounted in Bucharest and in its proximity.

For the visualization and analysis of spacetime data, a space-time cube (STC) has been created. The trends in the Emerging Hot Spot Analysis were identified and visualized in three local scenes for a 3D visualization, based on this. The results and conclusions were extracted based on time charts, density analysis and graphs.

Keywords: ArcGIS Pro, Space Time Cube, Hot Spot Analysis

1. Introduction

The situation of urban pollution can be successfully studied using GIS tools. Time is built into ArcGIS Pro and the temporal dimension of geospatial data can be used for analysis, simulation, and modelling across the ArcGIS platform. (Figure 1) Managing time-aware data and analysing space-time data are done by using geoprocessing tools, space-time data being visualized in ArcGIS Pro, as well as in ArcGIS Online. [1]

In the specialized literature there are a series of analyses carried out on the topic of investigation based on the Space Time Cube approach. [2], [3], [4]

Space Time Cube Model was introduced by the Swedish geographer Hägerstrand at the end of the sixties.
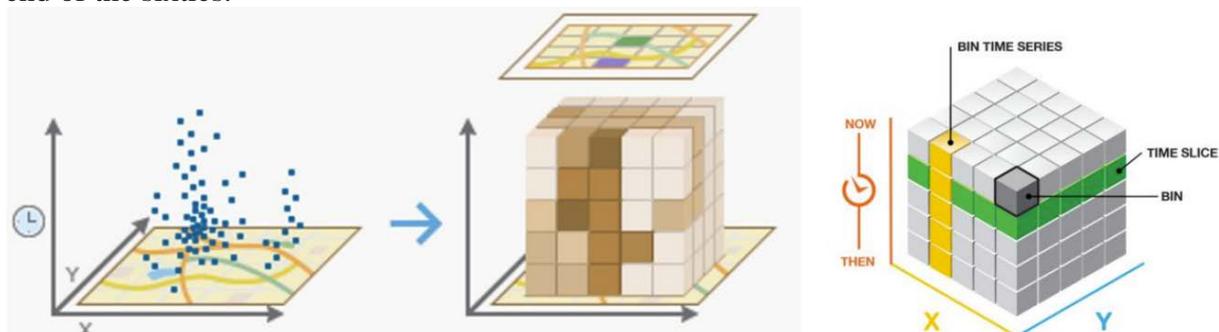

Figure 1 – Space Time Cube Concept [18]

Regarding ArcGIS Pro Spatial Statistics toolbox, there are available inferential spatial pattern analysis techniques including Spatial Autocorrelation (Global Moran's I), Cluster and Outlier Analysis (Anselin Local Moran's I), and Hot Spot Analysis (Getis-Ord Gi*).

The Hot Spot Analysis tool calculates the Getis-Ord (Gi*) statistic for each feature in a dataset and the resultant z-scores and p-values are highlighting where features with either high or low values cluster spatially. This tool is analysing each feature by comparison with neighbouring features. The main condition for a feature to be a statistically significant hot spot is to have a high value and be surrounded by other features with high values as well, so a feature having only a high value is interesting but may not be a statistically significant hot spot.

2. Materials and Methods

We chose for the study hourly air quality values from Bucharest area in a time interval when significantly high values of pollution parameters were reported (20 - 22-03-2022). The locations of the sensors were used as geospatial links.

Related data used here was downloaded from the Airly platform [11]. The attribute table associated with the layer has been processed to correspond to the definition of the date with the software requirements and includes information about the values for the main pollutants (figure 2). Over time, countries have implemented their own air quality indices differently to conduct analysis and share them with the public, corresponding to their own national standards. The same approach has been used at the continent level [15].

Since 2006, there has been a Common Air Quality Index (CAQI), in Europe, with the purpose of facilitating comparisons between countries and to have a common landmark, this index also being operational on the website www.airqualitynow.eu since 2006 [14].

The workflow for determining CAQI includes the values for nitrogen dioxide -NO_2, particulate matter less than or equal to 10 µm in diameter – PM 10 and ozone - O_3 as mandatory.

Airly sensors are small devices that measure the level of outdoor air pollution, by reading a series of air parameters (PM 1, PM 2.5, PM 10, temperature, pressure and humidity) in a particular location, in real time [11].

As EU standard for fine particulates such as PM 10 and PM 2.5, the European Union has established as acceptable levels for PM 10 - 50 µg/m3 (daily) and 40 µg/m3 (annual average), and for PM 2.5 - 25 µg/m3 (annual average)[12]. The World Health Organization has recommended in 2021different maximal levels of daily concentrations: 45 µg/m3 for PM 10 and 15 µg/m3 for PM 2.5 [13], [15] and the data is shown in figure 3.

Qualitative name	Index or sub-index	Pollutant (hourly) concentration in µg/m³			
		NO_2	PM_{10}	O_3	$PM_{2.5}$(optional)
Very low	0–25	0–50	0–25	0–60	0–15
Low	25–50	50–100	25–50	60–120	15–30
Medium	50–75	100–200	50–90	120–180	30–55
High	75–100	200–400	90–180	180–240	55–110
Very high	>100	>400	>180	>240	>110

Figure 2 – Main Pollutants in the Airly Platform (left side) - CAQI (right side) [11]

POLLUTANT	AVERAGING TIME	WHO 2021 AQG	WHO 2005 AQG	CHANGE
$PM_{2.5}$ ($\mu g/m^3$)	Annual	5	10	-50%
	24-hour	15	25	-40%
PM_{10} ($\mu g/m^3$)	Annual	15	20	-25%
	24-hour	45	50	-10%
O_3 ($\mu g/m^3$)	Peak season	60	N/A	Newly introduced
	8-hour	100	100	Unchanged
NO_2 ($\mu g/m^3$)	Annual	10	40	-75%
	24-hour	25	N/A	Newly introduced
	1-hour	200	200	Unchanged

Figure 3 – Extract from WHO 2021 Air Quality Guidelines (AQG) by Comparison with WHO 2005 AQG (adapted from [15])

Particulate matter (PM 2.5 and PM 10) consists of airborne liquid and solid particles and there can be emitted from a direct source, including power plants, vehicle traffic, construction sites, and indoor stoves and heaters as primary particulate matter, and as secondary particulate matter, because of chemical and physical reactions with various compounds, including Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ammonia (NH3)[15].

Ground-level ozone is a secondary pollutant, O_3 levels typically peak in the summer due to the heat and sunlight. O_3 levels are influenced by outdoor human activities including vehicles, fossil fuel power plants, oil and chemical refineries, the agricultural sector, and by indoor sources like copiers and laser printers.

There are specialized studies that address the scientific investigation of existing trends in air quality [8]. There are currently major initiatives, including the provision of open data through geoportals of spatial data [9]. The literature specifies that in winter is the worst air pollution period for Europe and China and air pollution in Europe reaches seven cigarettes per day equivalent, a pack a day in India and China. [10] (Figure 4)
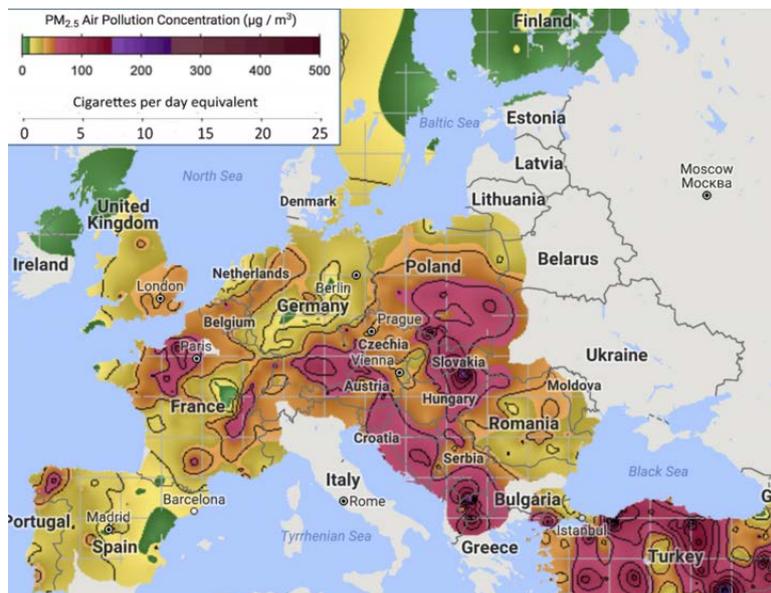

Figure 4 - The scale of "cigarettes per day" used to make the pollution levels, calculated by comparing the known health risk of cigarettes to the known health risks of PM2.5 as estimated by the World Health Organization [10]

On the website of the European Environment Agency (EEA) it can be seen, in figure 5, that there are, for Romania, reports only from a few air quality monitoring stations. [17]

Figure 5 – Situation of the Air Quality Monitoring Stations in Romania by EEA [17]

Another possibility for investigating the air quality is to use satellite data from the Tropospheric Monitoring Instrument (TROPOMI) aboard the Sentinel-5P satellite, launched by the European Space Agency in 2017, measuring a wide range of aerosols. This spectrometer has a temporal range of 1 day and a spatial resolution of 7 km by 3.5 km (it was updated to 5.5 km by 3.5 km in 2019) [19].

We used in this study Airly urban stations where the core pollutants of the CAQI were monitored. Create STC tool (ArcGIS Pro) was used to aggregate Input Features (point type) into space-time bins and Visualize STC tool for visualizing the result. It creates a netCDF data structure (*.nc file) by aggregating data into space-time bins. Esri developed a dedicated Add-In for ArcGIS Pro, named Space Time Cube Explorer in the purpose to display the STC by interacting with and exploring the 3D analysis results. [2]

3. Case Study Results

The aim of the study is to analyze, with the help of GIS tools, the time intervals during which pollutants (PM 2.5, PM 10 and NO2) affect air quality. The values used were taken with the help of sensors, for three days, hour by hour (20.03.2022 – 00:00 A.M.-23.03.2022 – 00:00 A.M.).

After downloading the sensor data, the values for the 45 sensors were arranged according to figure 6. The dates were imported into ArcGIS Pro and represented in 1970 Stereographic Projection System (figure 7).

Sensor ID	Installation ID	PM 2.5	PM 10	NO2	De la	La	Longitudine	Latitudine	Elevatie (m)	Nord (m)	Est (m)	Tara	Oras	Strada
3042	5628	23	27	0	3/20/2022 0:00	3/20/2022 1:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	24	29	0	3/20/2022 1:00	3/20/2022 2:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	24	28	0	3/20/2022 2:00	3/20/2022 3:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	22	25	0	3/20/2022 3:00	3/20/2022 4:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	23	26	0	3/20/2022 4:00	3/20/2022 5:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	22	26	0	3/20/2022 5:00	3/20/2022 6:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	21	24	0	3/20/2022 6:00	3/20/2022 7:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	21	25	0	3/20/2022 7:00	3/20/2022 8:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	19	21	0	3/20/2022 8:00	3/20/2022 9:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	16	17	0	3/20/2022 9:00	3/20/2022 10:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu
3042	5628	19	21	0	3/20/2022 10:00	3/20/2022 11:00	44.45751	26.09715	85	329230.850	587431.920	Romania	Bucuresti	Strada Tudor Vianu

Figure 6 - Example for Sensor 3042

In the first stage, the values for the three pollutants were analyzed and chart representations (figures 8, 9, 10, 11) were used to investigate these parameters in the analyzed

time interval. Based on the results in Figure 7, we identified as the critical intervals 6-7 a.m. of March 21, 2022, as well as 9-10 p.m. of March 20, 2022. In figure 12 we emphasized these situations using an interpolation approach.
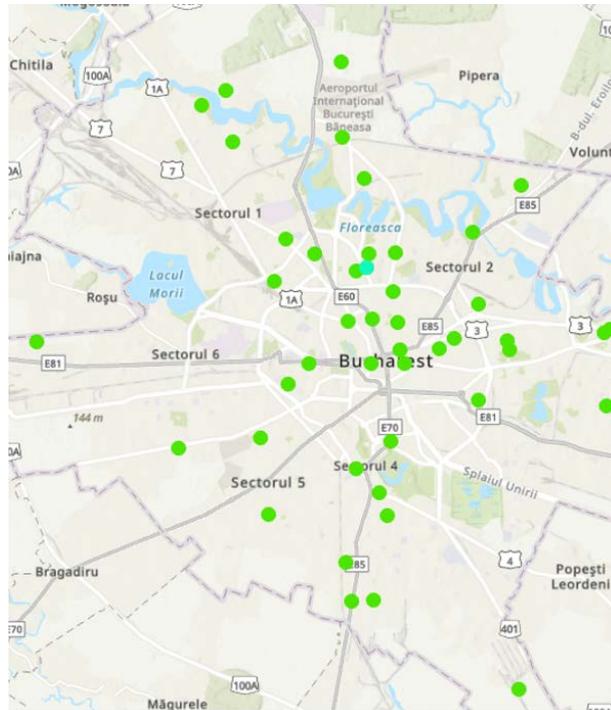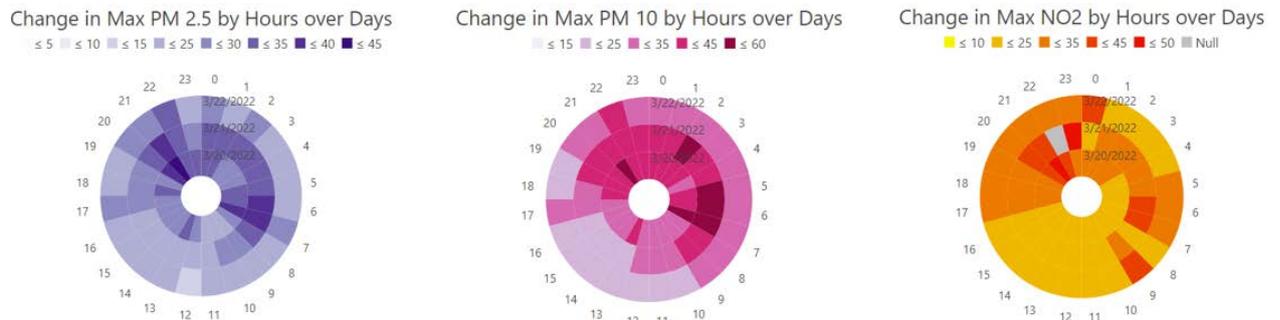

Figure 7 – Sensors Locations [11]

Figure 8 – Investigation of Data Clock Charts for PM 2.5, PM 10 and NO$_2$
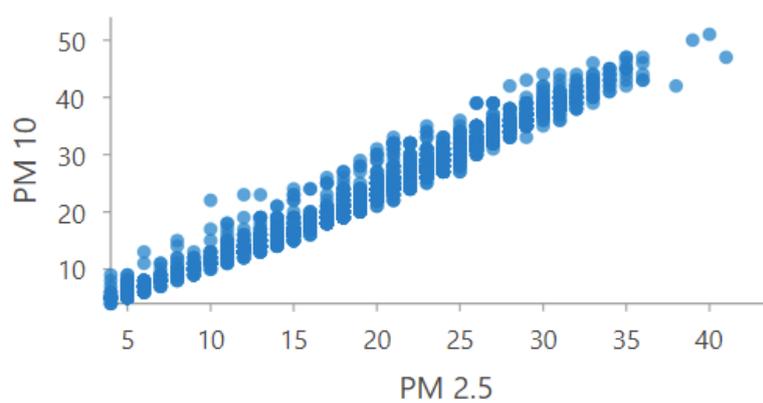

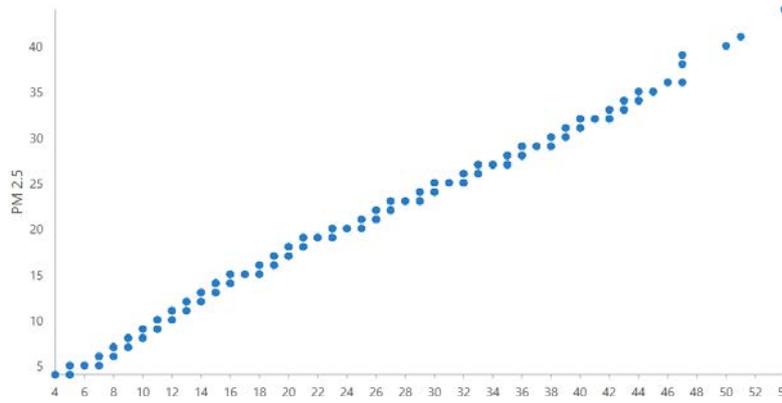Figure 9 - Scatter Plot Matrix for PM 2.5, PM 10

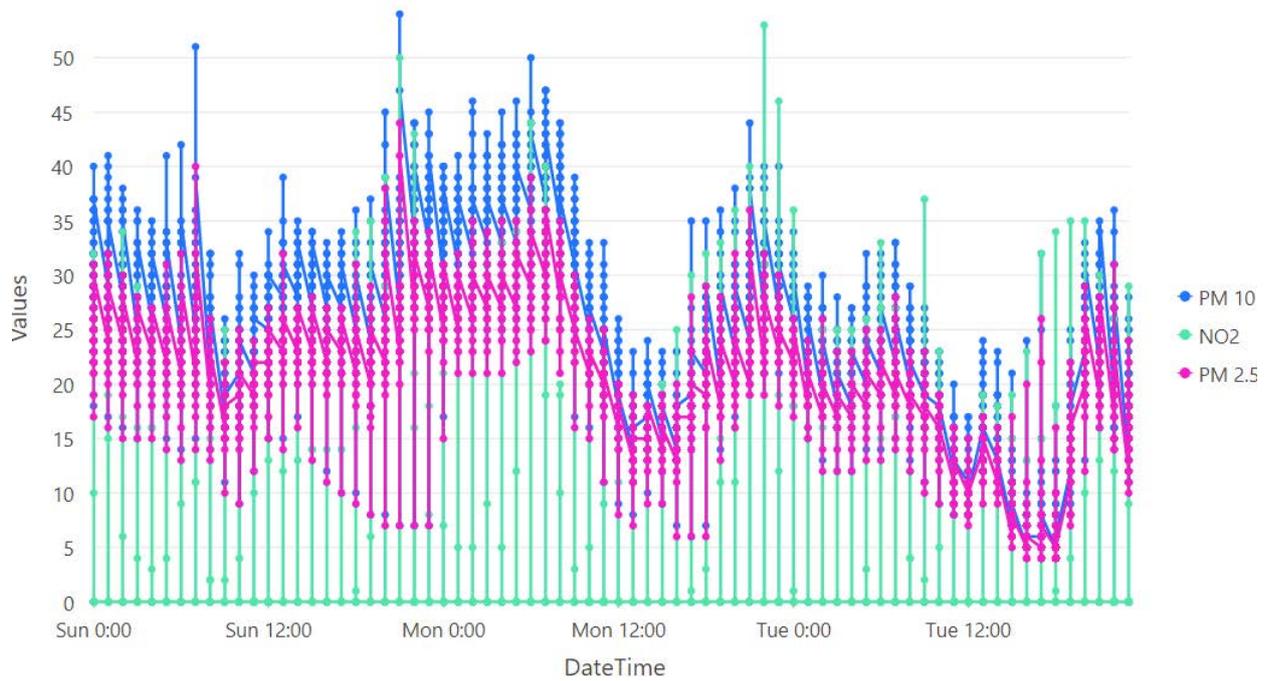Figure 10 - Comparison of PM 2.5 and PM 10 Distributions (QQ Plot)

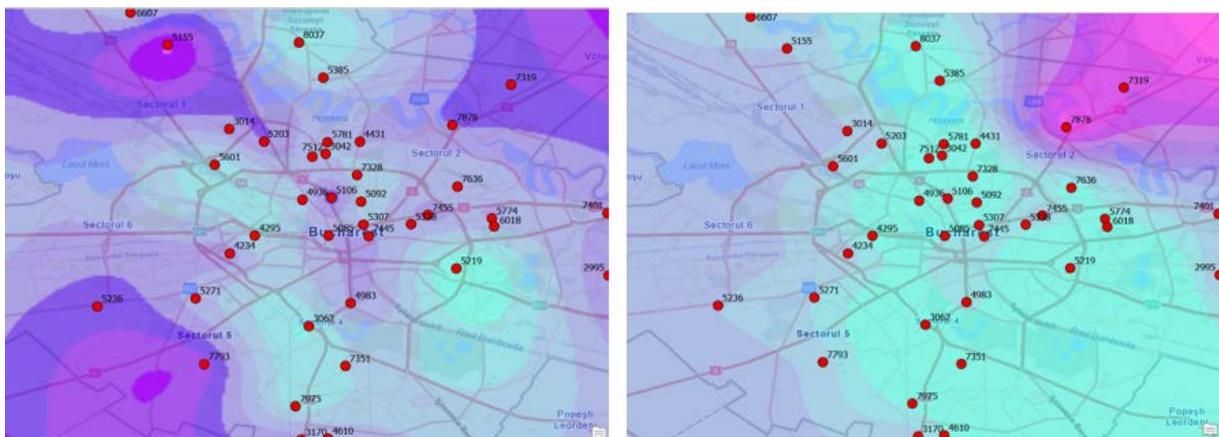Figure 11 - Change in PM 2.5, PM 10, NO_2 over DateTime

Figure 12 – Interpolation of PM 2.5 Values for 6-7 a.m. of March 21, 2022 (left side) and 9-10 p.m. of March 20, 2022 (right side)

The Create Space Time Cube by Aggregating Points tool correlates sensor attributes (PM 2.5, PM 10, and NO_2) in space-time intervals. Several combinations of statistics can be specified, but in this case, we have chosen the "maximum" statistic that finds the highest value for all records of the specified field in each bin. The Emerging Hot Spot Analysis tool identifies trends in grouping point densities in a space-time cube. It can detect eight trends specific to hot or cold points: new, consecutive, intensifying, persistent, decreasing, sporadic, oscillating and historical (figure 13).

Each "bin" (container) is analyzed in the context of the neighboring ones to measure how intense the grouping is for both high and low values. The result of this analysis is a z-score, p-value and binning category for each bin in the space-time cube. [5]

The z-scores and the returned p-values provide information on whether to reject the null hypothesis.

For the PM 2.5 and PM 10 indices, Oscillating Hot Spot points were obtained, but a model was not detected for the NO_2 index. For a better analysis of the data, three local scenes were created (figure 14).
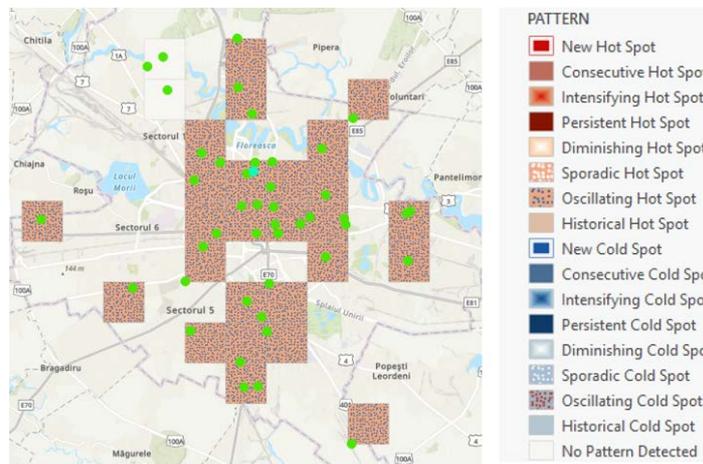

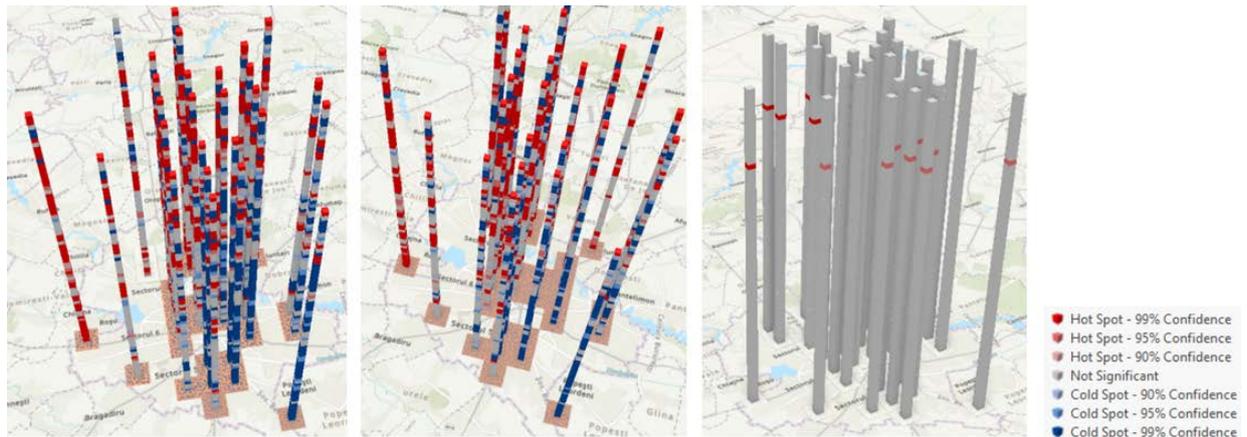Figure 13 – Example - Emerging Hot Spot Analysis for PM 2.5

Figure 14 – Space Time Cube for PM 2.5 (left side), PM 10 (middle), NO_2 (right side)

4. Model Builder as Workflow Automatization

In ArcGIS Pro it is possible to automate the workflow [6],[7] so that the models obtained are quickly integrated and used (figure 15).

Thus, in order to automate the performed stages, a Model was created based on the used geoprocessing tools. Geoprocessing history is essential when the purpose is to share the analysis, either as a geoprocessing package or as a web tool. Any analysis must first have been successfully executed and connected to geoprocessing history to be further shared.

Figure 15 - Model Extract

5. Conclusions

As interpretation, the Gi* statistic returned for each feature in the dataset is the z-score as standard deviation. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot), and for statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot).

The p-value is a probability - spatial pattern probability created by some random process. If the p-value is very small, it means it is a small probability that the observed spatial pattern is the result of random processes, so it can be rejected the null hypothesis (figure 16, 17).

Figure 16 – Example - Time Graph for PM 2.5 - z-score Indicator

ArcGIS Pro offers tools for using temporal data from start to finish, giving 2D and 3D possibilities to manage, analyze, and visualize information about space and time in an insightful way.

The critical period in terms of indicator values, observed from the graphs, is between 6 a.m. and 7 p.m., on March 21.
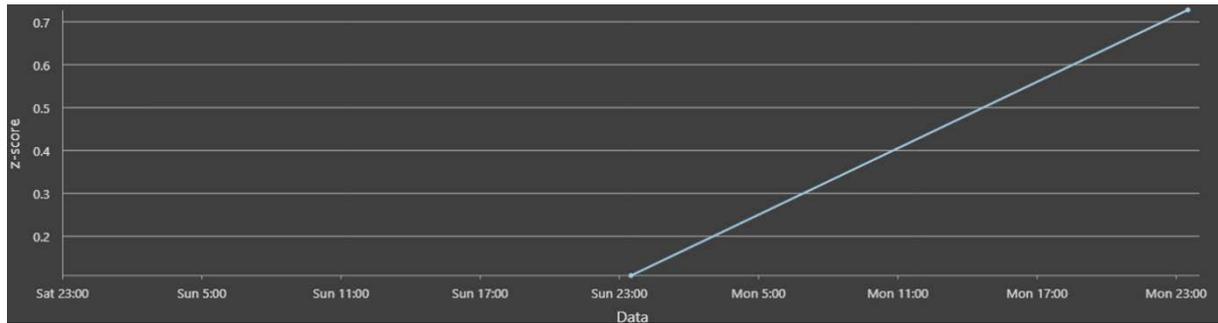
Figure 17 – Example - Time Graph for PM 10 - z-score Indicator

The recorded value for the PM 2.5 indicator is approximately three times higher than the admissible average value per day. The PM10 indicator is also increased, being 9 μg/m3 higher than the permitted average. Also, the level of the recorded NO_2 indicator has double values compared to the optimal daily reference. The extreme values were recorded for the sensors located in the city suburb.

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7. Acknowledgements