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IDW MAP BUILDER AND STATISTICS OF AIR POLLUTION IN BRAŞOV

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Abstract

An inverse distance weight (IDW) interpolation algorithm is used to create pollution maps over the urban area of Brașov. The time period chosen for this study was the first half of 2020, in order to analyze the lockdown period due to Covid-19 pandemic. The study involves the average hourly, daily and monthly concentration of several pollutants before, during and after lockdown period and, in the end, the conclusions were drawn based on these analysis.

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Key words: IDW interpolation, pollution, statistics grids

1 Introduction

Many studies established the close relationship between air pollution and certain respiratory diseases or an increased mortality [1, 2]. Even though, during the last years huge efforts have been made to improve air quality in urban areas (industrial restructuring, technological changes and pollution control), the problem of air pollution remains and it needs to be very carefully monitored and studied in order to be able to warn and protect the citizens. It was observed that people's lives are shortened by an average of nearly three years by different sources of air pollution [3]. Thus, long-term exposure to air pollution contributes to the cause of many diseases such as cardiovascular and respiratory disease, lung cancer, or lower respiratory tract infections. Also, the presence of aggressive substances such as sulfur, or carbon can lead over time to the degradation of man-made habitat [4, 5, 6]. Taking all that into account, it is obvious that mapping urban

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air pollution can be very helpful for the institutes that take care of air quality for establishing the zones with high illness risks. Below we detail the main molecules that contribute most to the air pollution:

- The greatest sources of CO to outdoor air are the vehicles or machinery that burn fossil fuels. Even though it is not likely for high levels of CO to occur outdoor. When this does happen it can affect the health condition especially of people with some types of heart diseases.

- Aside the emissions from the burning of fossil fuels, other sources of SO_2 gas are power plants, metal processing industry or smelting facilities.The vulnerable people at high concentrations of SO_2 are especially children and elderly, and, obviously, those with pre-existing conditions. SO_2 is also responsible for smog or haze formation.

- As the other pollutants, NO_2 is also released in the air from the burning of fuel. The main effect for humans health is irritation of the airways in the respiratory system. Function of the exposure time and the concentration of NO_2 can cause or aggravate respiratory diseases such as asthma. Also, when interacting with atmospheric water, NO_2 forms acid rains that are harmful for the ecosystems.

- Particulate matter (PM) is a general term for small particles or liquid droplets in the atmosphere. For example, PM10 are the particles with a diameter smaller then 10 μm. The primary sources for PM are incomplete combustion, vehicles emissions, dust. Exposure to particle pollution can cause or aggravate heart or lung diseases. Therefore, these is also a public health hazard.

Even though Brașov city is located between mountains and surrounded by large forest regions, according to The European Public Health Alliance 2020 report [7], this city is in top 5 the most polluted cities in Europe with very high concentration of NO_2. Thus, a careful monitoring and study of the pollution evolution in this area is needed in order to be able to take the right legal actions for increasing the air quality and so to improve population's health and reduce the financial and social costs.

In this paper, we focused on an inverse distance algorithm that was used to create pollution maps (grids) for urban area of Brașov and draw conclusions regarding pollution for the current year (2020). We also made a comparison of air quality during the lockdown (most of all economic and social activities were stopped) period due to the Covid-19 pandemic and the period when the economy was restarted. For this study, the concentrations of carbon monoxide(CO), sulfur dioxide(SO_2), nitrogen dioxide(NO_2) and particulate matter (PM10) were taken into consideration .

The paper is organized as follows: Section 2 describes IDW interpolation and the proposed algorithm used to create pollution grids. In Section 3, statistics graphs and grids are presented. Finally, in the last section the conclusions are drawn and new perspectives related to the usage of IDW algorithm are presented.

2 Inverse distance weighting

Inverse distance weighting (IDW) is a type of deterministic method for multivariate interpolation with a known scattered set of points [8, 10]. The assigned values to unknown points are calculated with a weighted average of the values available at the known points. The name IDW is motivated by the weighted average applied, since it resorts to the inverse of the distance to each known point ("amount of proximity") when assigning weights. For a given set of $k \in \mathbf{N}^*$ values v_i measured at the points $P_i(x_i, y_i), i = 1, 2, ..., k$, the interpolated value $v(x, y)$ calculated at the point $P(x, y)$ is:

$$v(x,y) = \begin{cases} \dfrac{\sum_{i=1}^{k} w_i(x,y) * v_i}{\sum_{i=1}^{k} w_i(x,y)} & d(P,P_i) \neq 0, \forall \in \{1,2,...,k\} \\ v_i & \text{if } \exists i \in \{1,2,...,k\} : d(P,P_i) = 0, \end{cases} \tag{1}$$

where

$$w_i(x,y) = \frac{1}{dist(P,P_i)^p}. \tag{2}$$

In (2), $dist$ is a formula used to measure the distance between the points P and P_i.

Usually, $dist$ is:

$$dist(P,P_i) = l_h(P,P_i) = (|x - x_i|^h + |y - y_i|^h)^{1/h}, \tag{3}$$

where $h > 0$. For practical applications, commonly, $h = 2$ ($dist$ is the Euclidean distance):

$$dist(P,P_i) = l_2(P,P_i) = \sqrt{|x - x_i|^2 + |y - y_i|^2}, \tag{4}$$

The parameter $p > 0$ is the power of the distance. In real applications, the best results are obtained for $p = 2$.

A grid $G = (g_{ij})_{i=\{1,2,...,m\},j=\{1,2,...,n\}}$ of $m \times n$ interpolated values ($m, n \in \mathbf{N}^*$) for a 2D rectangular region given by $x_{min}, x_{max}, y_{min}, y_{max} \in \mathbf{R}$ ($x_{min} < x_{max}$ and $y_{min} < y_{max}$) can be calculated as follows:

Algorithm for IDW interpolation grid (AIDWIG)

$dy = (y_{max} - y_{min})/n;$
$dx = (x_{max} - x_{min})/m;$
$y = y_{min};$
for $i = 1$ to n do

$x = x_{min}$;
for $j = 1$ to m do
$g_{ij} = v(x, y)$;
$x = x + dx$;
end for;
$y = y + dy$;
end for;

3 Inverse distance weighting on GPU

High Performance Computing (HPC) framework on Graphics Processing Unit (GPU) can be used for general purpose computing tasks. One advantage of GPUs is that they provide the possibility to accelerate certain types of computations on virtually each personal computer. Due to the growing popularity of GPU programming, there are many approaches that involves it for accelerating various processes, many of them in geospatial analysis. In [12], the prospect of GPU computing in geographic information science from a more empirical standpoint is introduced and their study presents the behavior of spatial interpolation algorithms using massively parallel environments. In [13], the authors present an efficient parallel Adaptive Inverse Distance Weighting (AIDW) interpolation algorithm on modern GPU. The algorithm is an improvement of GPU-accelerated AIDW algorithm by adopting fast k-nearest neighbors search. Xia et al. propose also a generic methodological framework for geospatial analysis based on GPU and its programming model Compute Unified Device Architecture [14].

The Clarke algorithm is a parallel implementation of the IDW interpolation. It consists mainly of three steps: spatial domain decomposition, interpolation and output data gathering. Since its basic elements include a K-nearest neighbor searching for each point, the Clarke algorithm is computation-intensive. Therefore, spatial domain decomposition is introduced to parallelize the interpolation to minimize the execution time.

To resume, IDW interpolation is highly computation-intensive, especially for a large-scale space, thus we also studied the parallel approach of the algorithm. The tests were performed on an Asus ROG Strix G17 G712LV, Intel Core i7-10750H up to 5.10 GHz processor, 16GB RAM, NVIDIA GeForce RTX 2060 6GB GDDR6 with 1920 CUDA cores.

Experimental results presented in Table 1 showed that the CUDA-based implementations running on GPU led to image resolution dependent speedups. IDW interpolation was executed to obtain images having the size ranging from 150x100 to 4800x3200. The experiments showed that for small images (150x100, and 300x200) the CPU time was better. For large images the GPU speed-up was consistent (up to 19 times faster).

Table 1: GPU speed-up

Image size	CPU time	GPU time	GPU speed-up
150 x 100	0.017	0.031	0.55
300 x 200	0.065	0.071	0.92
600 x 400	0.268	0.101	2.65
1200 x 800	1.090	0.167	6.52
2400 x 1600	4.415	0.322	13.71
4800 x 3200	17.913	0.942	19.02

4 Statistics graphics and pollution grids for Brașov

Data for four stations reporting hourly pollution in Brașov were downloaded from [11] for the first half of current year (2020) for carbon monoxide (CO), fraction of particles with an aerodynamic diameter smaller than 10 µm ($PM10$), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). The coordinates of the four stations are:

latitude = 45.637722, longitude = 25.630704 (named BV-1)
latitude = 45.652490, longitude = 25.583146 (named BV-2)
latitude = 45.659380, longitude = 25.616236 (named BV-3)
latitude = 45.651580, longitude = 25.625683 (named BV-5)

We applied AIDWIG to generate pollution grids for Brașov. The resolution of each grid was considered as follows:

$m = 600$ (for latitude),
and
$n = 900$ (for longitude).

The latitude-longitude grid limits for Brașov urban area were established as follows:

$y_{min} = 45.62$,
$y_{max} = 45.68$,
$x_{min} = 25.56$,
$x_{max} = 25.65$.

It is easy to see that $dx = dy$ in AIDWIG (both are equal to 10^{-4}) so that the aspect ratio in the standard coordinate system of WGS 84 (World Geodetic System 1984) was preserved.

When implementing AIDWIG, we considered Euclidean distance (4) in (1) and $p = 2$ in (2).

Using AIDWIG we generated hourly pollution grids, 24 hours averaged grids, daily, weakly and monthly averaged grids, and mean grids for each day in the

Table 2: Limit values for pollutants [11]

Pollutant	Short period limit (mg/m^3)	long period limit (mg/m^3)
CO	10	-
NO_2	0.20	0.04
SO_2	0.35	0.125
PM10	0.05	0.04

week to see how pollution differs in the working days compared to week-end days. We also graphically compared the statistics on days in the week and watched the evolution of pollution per month. This was separately done for each of the four stations and in average for all stations.

First, for each pollutant we created two maps for comparing the mean concentration in January (before the lockdown) and May (the last month of lockdown) (see Figure 1). It is obvious that the air quality was significantly improved for each of the pollutants factors due to reduced industrial activity and vehicle circulation.

In Figure 2, the maps when the highest hourly values of each pollutants concentrations were recorded are presented. All maximum values were recorded in January, and the worst value was for NO_2. Thus, the maximum recorded value for NO_2 was 178 mg/m^3 and this value is very close to the upper accepted limit value for short period (see Table 2).

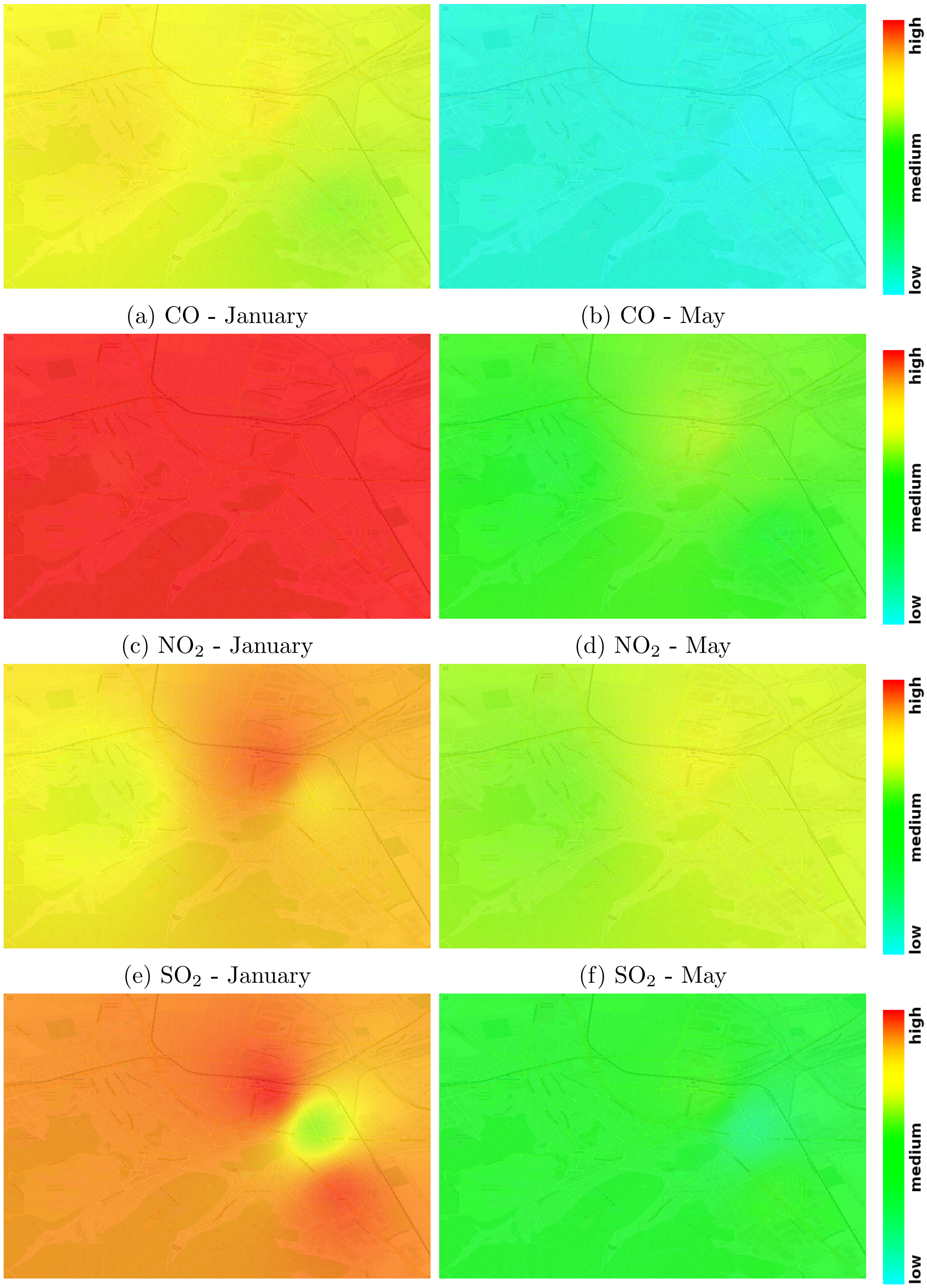
As mentioned before, Brașov is one of top 5 cities in Europe regarding NO_2 concentration. In Figure 3 a comparison between two days of the week mean values of NO_2 is presented and, in Figure 4, the chart of evolution of mean value of NO_2 for all days of the week is shown. As expected, Sunday's value is significantly lower than the values of the working days.

In Figure 5, the chart of evolution of mean value of NO_2 for the first half of year 2020 is presented. It is observed that the monthly mean values of each pollutant's concentration decreased during lockdown period.

5 Conclusions and perspectives

An IDW interpolation method was described and used to build pollution maps of Brașov urban region. Hourly, daily and monthly mean concentration maps of several pollutants before, during and after lockdown period were presented. As expected, the reduced industrial activity and vehicles circulation improved the air quality.

As a future work, other interpolation methods such as kriging could be applied to generate similar maps and then compare with IDW. Also, the study could be extended for other highly polluted cities from Romania and abroad.



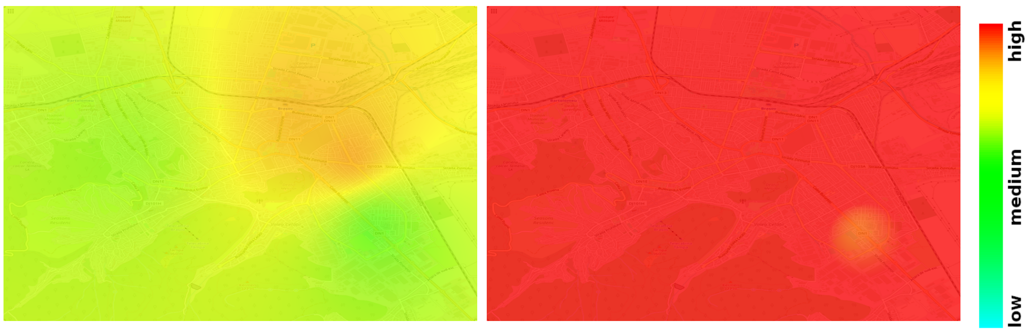
(a) CO - January (b) CO - May

(c) NO_2 - January (d) NO_2 - May

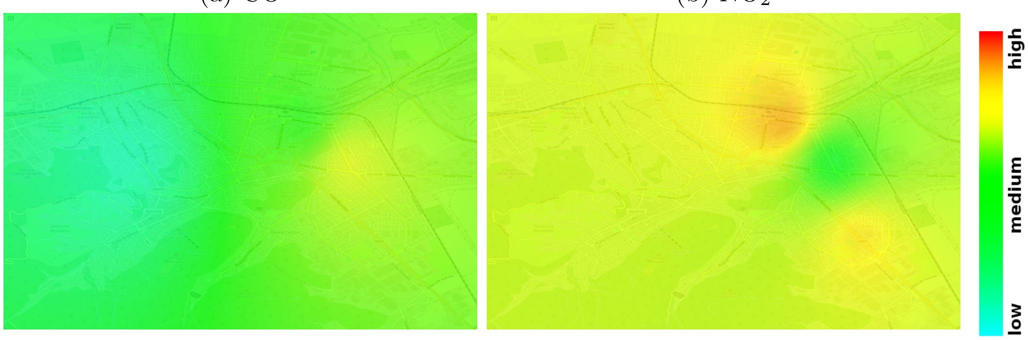
(e) SO_2 - January (f) SO_2 - May

(g) PM10 - January (h) PM10 - May

Figure 1: Mean concentration of pollutants comparative maps for January (a), c) e), g)) and May(b), d), f), h)) 2020.



(a) CO (b) NO_2



(c) SO_2 (d) PM10

Figure 2: Maps of maximum concentration of pollutants for 2020

(a) Thursday (b) Sunday

Figure 3: Maps of mean concentration of NO_2 per days of the week

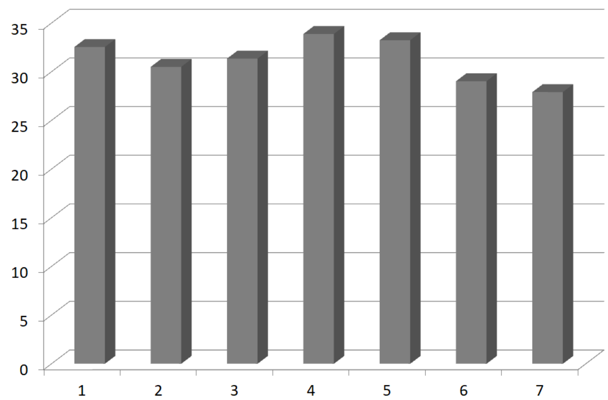
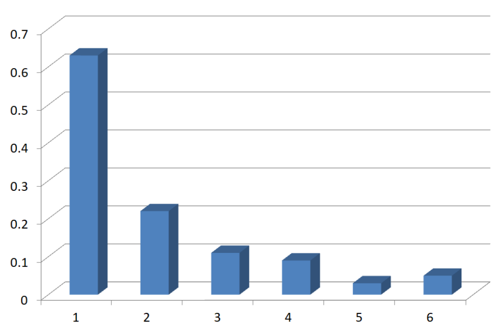
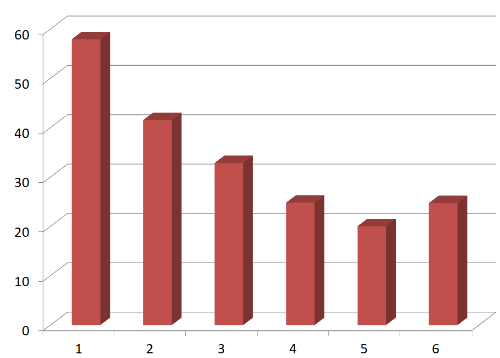


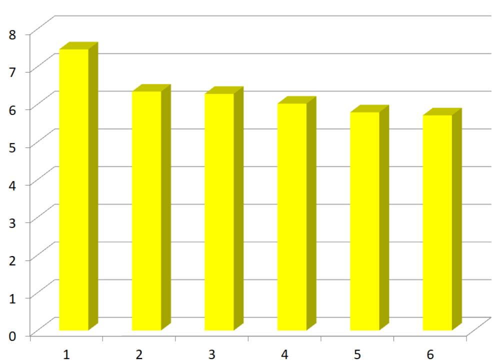
Figure 4: Mean concentration of NO_2 ($\mu g/m^3$) per days of the week.



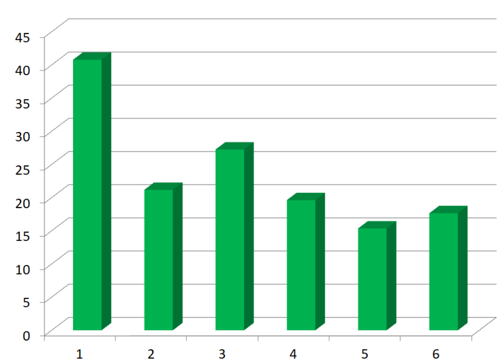
(a) CO



(b) NO_2



(c) SO_2



(d) PM10

Figure 5: Evolution of pollutant concentration for the first half of 2020. The unit of measurement for CO is mg/m^3 and μm for NO_2, SO_2 and PM10.

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