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APPLICATION OF AIR QUALITY INDEX AND INVERSE DISTANCE WEIGHTING FOR MAPPING THE DISTRIBUTION OF AIR POLLUTION AT SEVERAL URBAN DISTRICTS OF HANOI CITY

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Abstract. The air pollution level can be assessed using air quality index - AQI calculated from the concentration of some gases and particle matters which are measured at ambient air quality monitoring stations. The calculated AQI values are characterized by temporal continuity but spatial discontinuity. However, AQI values of each monitoring station is interpolated by the IDW (Inverse Distance Weighting) method in GIS which helps us to assess the air quality at a detailed and specific level for every location in the study area by establishing distribution maps of air pollution. The interpolation of AQI values for zoning air quality in several urban districts of Hanoi during the Winter (October, November, December 2019) shows that in general, the areas with a very bad level of air quality occupied an important surface in the Northwest of urban districts (on the territory of Bac Tu Liem, Ba Dinh, Tay Ho, Cau Giay) for last 3 months of the year. The areas with a bad level of air quality occupied a large surface in the Southeast in October and December, but its surface became narrow in November. But in November, areas having a bad level of air quality were expanded to the Southeast while they occupied only a small surface at the center of the study area in October and December. Although the distribution of each level vary in terms of coverage, their common pattern has been conserved during three months of Winter. The distribution map of air quality provides the complete picture of the air pollution situation and it helps to adequately evaluate this issue in the urban districts of Hanoi city.

Keywords: AQI, air pollution, IDW, interpolation, GIS.

1. Introduction

With economic development and rapid population growth, human society consumes a large number of resources to preserve its activities. Those growths created many different types of pollution: soil pollution, water pollution, air pollution, noise pollution, etc. But air pollution is rapidly increasing in many major cities around the world and it

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brings deep attention due to its common and contagious nature. Air pollution can cause a potential health risk for people who has pathology such as cancer, heart attack, stroke and respiratory diseases, and asthma due to long-term exposure to pollutants [1]. But it can also result in health problems such as sneezing, coughing, irritation of the eye mucosa, headache, difficulty breathing [2]; Furthermore, dust particles with dimension <10 µm (PM10, PM2.5), when inhaled deeply into the lungs, are likely to enter the bloodstream and cause serious complications [3]. Gases and dust particles are often considered the pollutants associated with the increase of vehicles, industry, thermal power plants, and other human activities when burning fossil fuels, such as gasoline, coal, and natural gas. Therefore, starting in the 1980s, many countries around the world tried to study and propose measures to limit air pollution [4, 5]. Such studies may vary from the concentration measurement of gases and dust [6], assessment of air pollution [7], and impacts of air pollution [8], modeling air quality [9], forecasting air pollution [10], etc.

There are 3 approaches to assess the spatial and temporal variation of outdoor air pollution: spatial interpolation of observed data, statistical/experimental model based on the geographic analysis (Land-use regression - LUR) and Euler grid model (Multiscale air quality model - CMAQ) [11]. The Air Quality Index - AQI (Air Quality Index) is very beneficial for preparing a daily air quality report and providing information to the community on the air quality with its impact on health. The AQI value can be increased or decreased depending on the variations in air emissions [12]. AQI is calculated based on the concentration of 5 main pollutants, including O_3, dust particles, CO, SO_2, and NO_2 gas. Their concentrations are measured at monitoring stations installed at different locations or from the model in a particular period [13, 14]. However, different countries have their AQI that correspond to different national air quality standards, and the received results reflect the air quality around the location of the sampling points [15].

The studies on air quality have also been implemented in Vietnam by the research of Pham Ngoc Dang (1998), in which the author assessed and predicted the air quality evolution of Hanoi city using Gauss-Sutton-Pasquill mathematical model. Based on data on specific environmental impact assessment of existing industrial establishments and new investment in the period 1995 - 1998, the zoning map of air quality has been established [16]. The National Center for Meteorology and Hydrology deployed research on the current state of air pollution in Hanoi city using pollutant concentrations and they identified the sources of air pollution [17]; Le *et al*. (2018) calculated AQI value from 10 automatic air monitoring stations in Hanoi city during the period 7/2017 - 6/2018 [18]. However, the air pollution assessment in the above-mentioned studies has only reflected the air pollution level by AQI values around monitoring stations.

For effective management of air quality, the an understanding of the spatial and temporal variation of the air quality index is essential. The development of GIS technology provides a powerful capacity for processing, analyzing, and displaying geographic data to scientists and managers. For the research field of air quality, GIS is considered as an efficient tool for monitoring and assessing pollution levels at every location in space by means of AQI index distribution map, which was established using spatial interpolation algorithms [19]. Therefore, the author set out three goals with this research: 1/ Calculate the AQI - air quality index from the concentration of gases and particulate matters measured at the monitoring stations in the urban districts of Hanoi city.

2/ Establish air quality distribution maps by interpolation method and 3/ Analyze the spatial and temporal evolution of air quality during the last 3 months of 2019. The maps established by the interpolation method help us to evaluate more accurately the situation of the air pollution problem in the urban districts of Hanoi city.

2. Content

2.1. Study area

Hanoi is the economic - political - cultural center of the country. Up to now, after several modifications of the administrative boundary, this city composes of 12 urban districts, 18 suburban districts. Urban space has been gradually expanded with the establishment of some new urban districts, such as Tay Ho in 1995, Thanh Xuan and Cau Giay in 1996, Long Bien and Hoang Mai in 2003 and Ha Dong in 2008, Nam Tu Liem, and Bac Tu Liem in 2013. The population of the city increased from 2.431×10^6 to $3{,}184\times10^6$ people from 1995 to 2006, in which the population of the inner urban districts doubled from 1.082×10^6 to 2.05×10^6 in the same period. The population hit 7.661×10^6 in 2017 with a density of 2304 people km^{-2} [20]. The formation of many new districts around the historic inner city led to the explosion of new and dense residential areas. Together with the process of urbanization, industrial development, construction of infrastructure has rapidly taken place; Hanoi's urban inner districts are suffering from a serious impact of environmental pollution, one of which is the deterioration of air quality. Based on data collected from the air quality monitoring stations of the US Embassy in Hanoi, the Green Innovation and Development Center (GreenID) we recognize 91% of the days in the first trimester of 2018, the level of air pollution in the inner city of Hanoi has exceeded the limits allowed by the World Health Organization (WHO). In September 2019, for many consecutive days, the air quality in the urban inner city was very bad. These factors have negative impacts, directly affecting the health of the community.

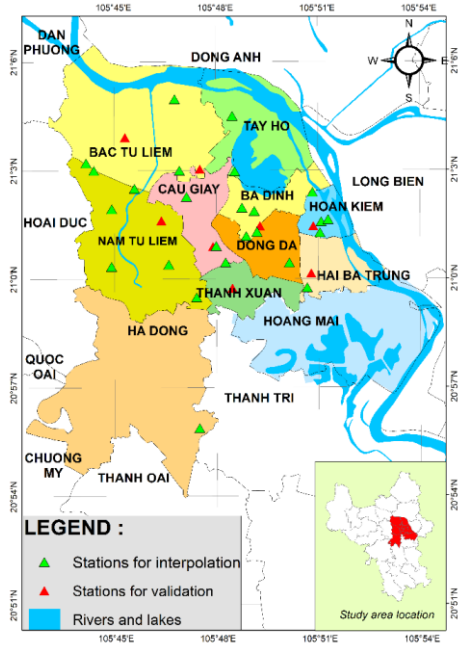


Figure 1. Study area and the location of monitoring stations

2.2. Methodology

2.2.1. Air quality index

The Vietnam Air Quality Index (abbreviated as VN_AQI) is an indicator calculated from the observed parameters of air pollutants in Vietnam (including SO_2, CO, NO_2, O_3, PM10, PM2.5) [21]. To announce the state of air quality and the extent to which it affects human health. The AQI air quality index is usually expressed on a scale of values (Table 1).

The daily AQI value is calculated using the following formula [21].

$$AQIx = \frac{Ii+1-Ii}{BPi+1-BPi} (Cx - BPi) + Ii$$

where

- AQIx: AQI value of pollutant x;
- BPi: minimum concentration of observed value for pollutant as regulated at level i;
- BPi (Cx + 1): maximum concentration of observed value for pollutant as regulated at level i + 1;
- Ii: AQI value at level i provided in the table which corresponds to BPi value;
- Ii+1: AQI value at level i+1 provided in the table which corresponds to BPi+1 value;
- *Cx:* for PM2.5 and PM10, the average value of 24 hours.

For O_3: Cx is the maximum value of the maximum 1-hour average value of the day and the maximum 8-hours average value of the day. Do not calculate AQI for O_3 when the maximum 8-hours average value is higher than 400 µg/m^3.

For SO_2, NO_2 and CO: Cx is the maximum 1-hour average value of the day.

Table 1. BPi values for each pollutant [21]

I	I_i	BPi values assigned for each pollutant (unit: $\mu g/m^3$)						
		O_3 (1h)	O_3 (8h)	CO	SO_2	NO_2	PM_{10}	$PM_{2.5}$
1	0	0	0	0	0	0	0	0
2	50	160	100	10000	125	100	50	25
3	10	200	120	30000	350	200	150	50
4	150	300	170	45000	550	700	250	80
5	200	400	210	60000	800	1200	350	150
6	300	800	400	90000	1600	1350	420	250
7	400	1000	-	120000	2100	3100	500	350
8	500	≥ 1200	-	≥ 150000	≥ 2630	≥ 3850	≥ 600	≥ 500

After having the daily AQIx value of each pollutant, the maximum AQI value of the pollutants has been selected as the representative AQI value of the day [21]

$$AQId = \max (AQIx).$$

2.2.2. IDW interpolation

Inverse Distance Weighting (IDW) is the simplest interpolation method, most commonly used in GIS analysis functions. This method is based on the theory that the closer the sample points are to the point to be determined, the more impact on the Z value to be calculated, and per contra, the farther the sample points are the less impact there is [22]. The value of each point is calculated using the following formula:

$$Zo = \frac{\sum_{i=1}^{N} Z1 \times d_1^{-n}}{\sum_{i=1}^{N} d_1^{-n}}$$

where

- Zo: estimated value of variable z at the point i;
- Zi: the value of sample point i;
- d1: the distance between the sample point and estimated point;
- N: weight based on a distance.

Advantages and disadvantages of IDW: IDW method is easy to implement, it does not take much time. When there is a set of dense and widely distributed points on the calculation surface, the IDW method will get optimal results. This study area is located on the plain, the terrain is relatively flat, the IDW interpolation method will be very suitable because this interpolation method does not generate estimated values outside of the interpolated area and it is inaccurate for mountainous areas [22].

Table 2. Range of AQI value stipulated by Ministry of Ressources and Environment [21]

Air quality	AQI value	Impact level for health
Good	0 - 50	Air quality is good, it does not affect health
Medium	51 - 100	Air quality is acceptable. Sensitive people suffer certain health effects
Slightly bad	101 - 150	The sensitive people have health problems, the normal people have a little health effect
Bad	151 - 200	The normal person begins to have health effects, and the sensitive group has more serious health problems
Very bad	201 - 300	Health warning: people suffer more serious health effects
Extreme	301 - 500	Health emergency warning: the health of the entire population is severely affected

2.2.3. Processing and data used

The steps of processing are presented in Figure 2.

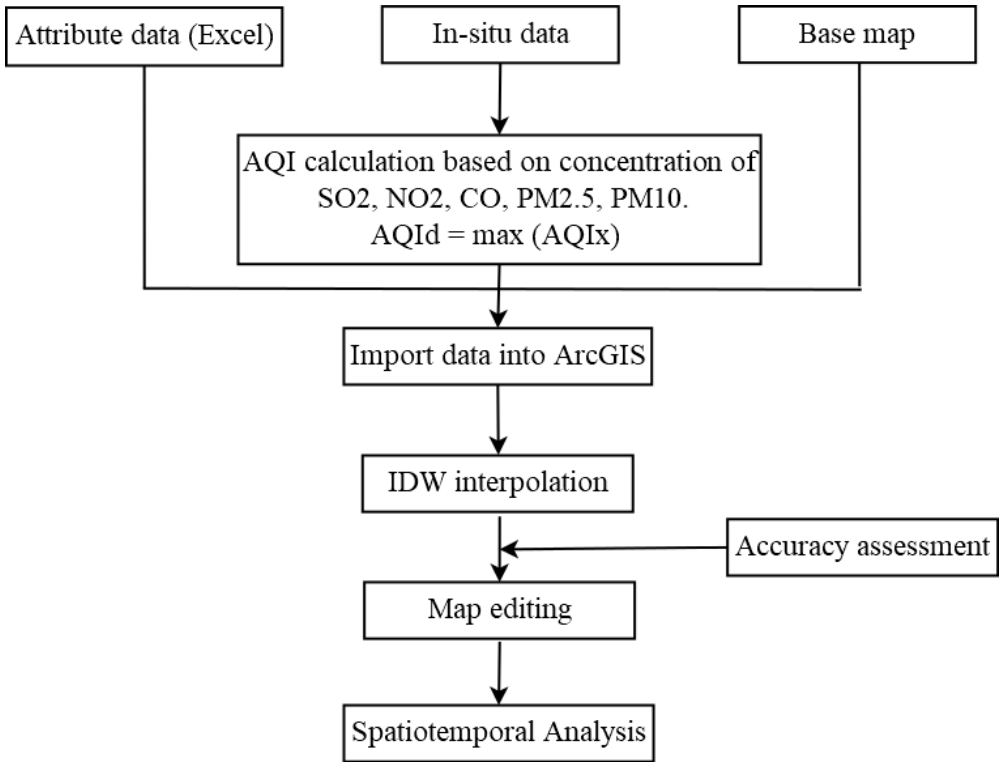


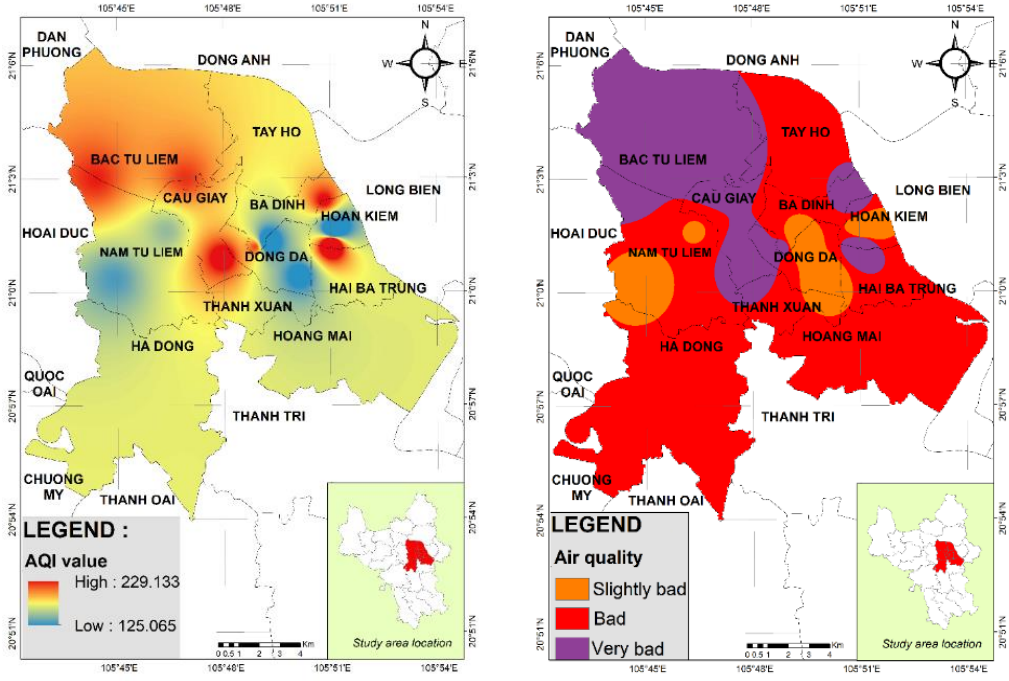
Figure 2. Processing steps

Used data in the research are concentrations of SO_2, NO_2, CO and particulate matters PM2.5, PM10 in the last 3 months of 2019 (October, November and December) which are hourly collected from 12 monitoring stations of the Northern Center for Environmental Monitoring, and 19 monitoring stations of University of Technology (Hanoi National University), and 2 monitoring stations of The World Air Quality Project located in the urban inner city. Besides, the study also used some background data layers in shapefile format to present geographical reference for preparing maps.

2.4. Results and discussion on spatiotemporal variability of air pollution

The zoning map of air quality was established based on the calculated AQI value corresponding to the concentration of gases and particulate matter. The maximum AQI value is taken as the daily representative value for each monitoring station. Then, the station's maximum daily AQI value in the month is used for interpolating and mapping air quality distribution to show extreme pollution in the corresponding month. The obtained results with the air quality map for 3 months of Winter show that the highest AQI value attained in December, then October and November alternately. To validate the results of the interpolated AQI value, we analyze the correlation between the calculated AQI value at 8 monitoring stations (Figure 1) with the interpolated AQI values at the corresponding pixel. The results of regression analysis show that they have a very large correlation because the R^2 values reach 0.911; 0.907; 0.927 correspondings to October, November, and December respectively.

October

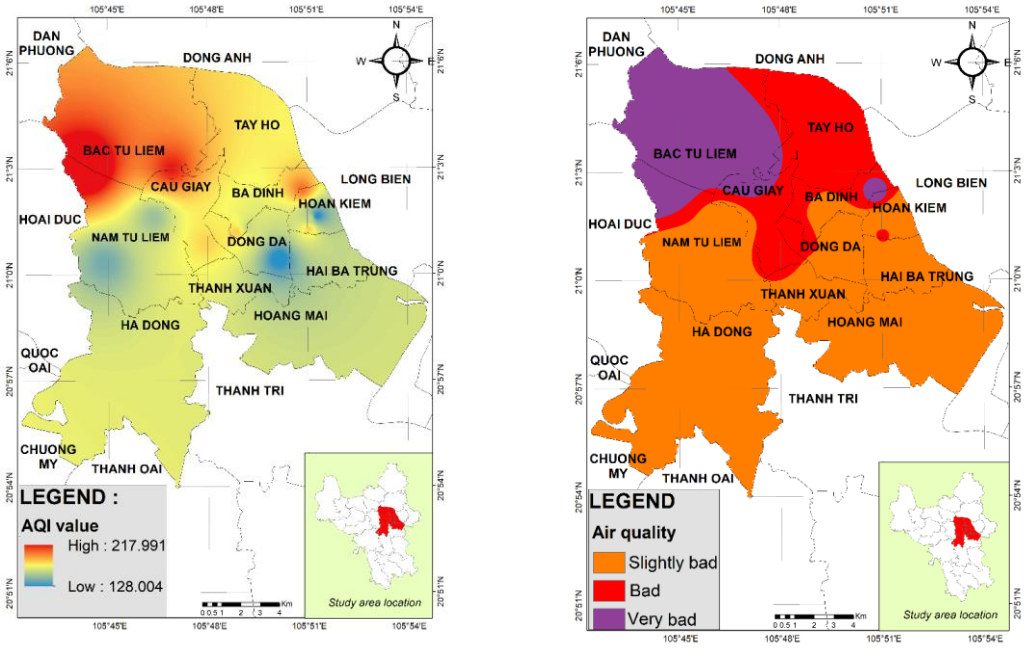


(a) *(b)*

Figure 3. Distribution of AQI on October 1st, 2019: (a) continuous values, (b) classified levels

The calculated results of AQI values at monitoring stations showed that AQI values of 10/31 days in October were at a low level; for the rest of the month, the AQI values were at a moderate level (AQI> 50). October 1th had the highest AQI value in this month at all stations. Figure 3a below shows the map of interpolated AQI values on October 1st, 2019. After the interpolation step, the obtained AQI values were classified into air quality groups based on thresholds issued by the Ministry of Natural Resources and Environment (Figure 3b). The zoning map of air quality for October 1st, 2019 shows that: most urban districts have "bad" and "very bad" air quality. A part of the Nam Tu Liem, Dong Da, Thanh Xuan, Ba Dinh, Hoan Kiem districts has AQI values ranging from 101 to 150. This is the "bad" level of air quality. Sensitive people with health care problems are susceptible to impact, ordinary people have less impact on health. Most of the Ha Dong, Hoang Mai districts and a part in the Dong Da, Ba Dinh, Nam Tu Liem, Hai Ba Trung, Thanh Xuan, Tay Ho districts had the AQI values ranging from 151 to 200. This is the "bad" level of air quality, people should reduce vigorous activities outdoors, avoid prolonged exercise, and get more rest indoors. The remaining of Bac Tu Liem district, most of Cau Giay district, and a few areas in Tay Ho, Ba Dinh, Hai Ba Trung districts had AQI values ranging from 201 to 300. This is the "very bad" level of air quality, people minimize outdoor activities and move all activities indoors. If it is necessary to go outside, wear a qualified mask.

November

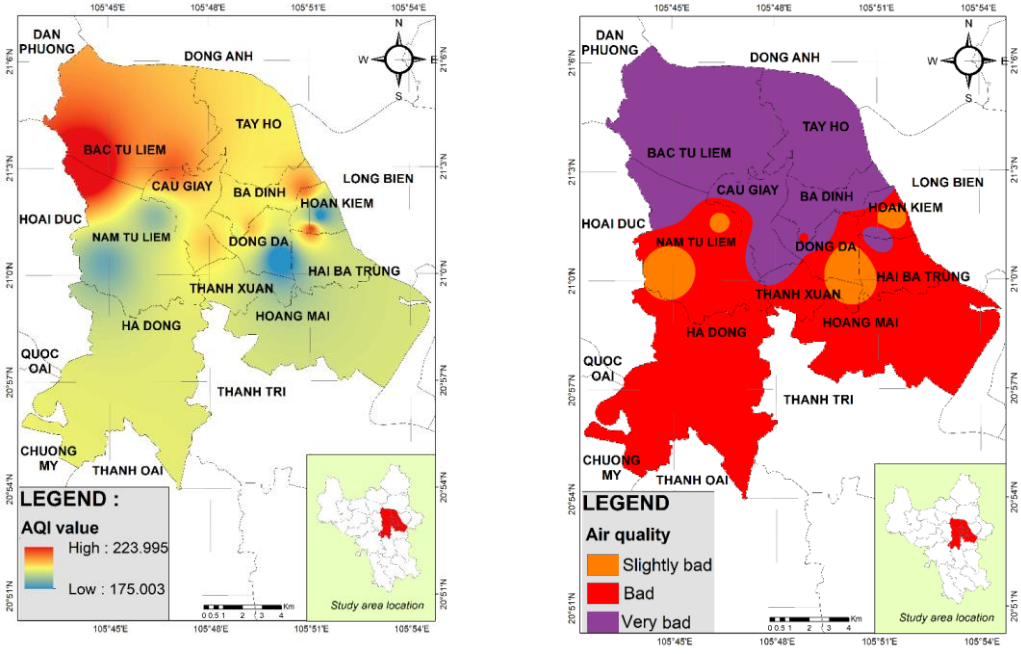


(a) *(b)*

Figure 4. Distribution of AQI on November 6th, 2019: (a) continuous values, (b) classified levels

According to obtained results, the air quality in November has generally improved in comparison to October. But the AQI value remains at a high level and the highest value at all monitoring stations fell on November, 6th with the AQI values ranging from 108 to 228. This is the dangerous and "bad" level of air quality. Figure 4a below shows the map of interpolated AQI values for November 6th, 2019. Then interpolated AQI values were classified into air quality groups based on threshold issued by the Ministry of Natural Resources and Environment (Figure 4b). The zoning map of air quality for November 6th, 2019 shows that: most of the Ha Dong, Hoang Mai, Thanh Xuan, Hai Ba Trung, Hoan Kiem districts had AQI values ranging from 101 - 150. This is the "bad" level of air quality. Most of the Tay Ho, Cau Giay districts, and a part of Ba Dinh and Dong Da districts had a "bad" level of air quality with AQI values ranging from 150 to 200. The entire Bac Tu Liem district and a part of Cau Giay, Ba Dinh, and Nam Tu Liem districts had AQI values ranging from 201 to 300. With this "very bad" level of air quality, people need to minimize outdoor activities and move all activities indoors. If it is necessary to go outside, wear a qualified mask.

December



(a) *(b)*

Figure 5. Distribution of AQI on December 31st, 2019: (a) continuous values, (b) classified levels

Results of calculation for daily AQI value at monitoring stations in December showed that most AQI values were at a low level (AQI > 100). During the extreme pollution period (December 8th-14th), most AQI values were at a bad level (AQI > 150). In comparison to November, air pollution tends to increase in both the number of days and severity. The highest AQI values at all monitoring stations fell on December 13th. Figure 5a below shows the map of interpolated AQI values for December 13th, 2019. Then interpolated AQI value values were classified into air quality groups based on threshold issued by the Ministry of Natural Resources and Environment (Figure 5b). The zoning map of air quality for December 13th, 2019 shows that: the air quality with the highest AQI value in December is worse than those of October and November. The area with a "very bad" level of air quality is widespread. Moreover, Bac Tu Liem district still retains the AQI values ranging from 201 to 300. Besides, this pollution class also occupied the large territory of Tay Ho, Ba Dinh and Cau Giay districts, and a small part of Hoan Kiem and Dong Da districts. The AQI values range from 151 to 200 accounting for the most of Ha Dong, Hoang Mai, Hai Ba Trung districts and a part of Nam Tu Liem, Dong Da, Hoan Kiem districts. The remaining with AQI ranging from 100-150, occupies a small part of the area.

3. Conclusion

The results of interpolated AQI values and the zoning map of air quality showed that most inner districts had a bad and very bad level of air quality. Bac Tu Liem district had the "very bad" level of air quality in the three highest days of Winter, in which heavily polluted areas include: small and medium industrial cluster - Minh Khai ward; bio-high-tech industrial park in the communes of Tay Tuu, Lien Mac, Co Nhue; Nam Thang Long Industrial Park in Thuy Phuong ward has large-scale industrial factories. Industrial zones emit a large number of gases, making the AQI value in this area always high. The area of Pham Van Dong and Cau Giay streets also had a "very bad" level of air quality because there are road digging works, sidewalks for installation of underground structures along the route, and traffic jams often happened. Along with Chua Lang, Tran Duy Hung, Vu Pham Ham streets, the AQI values were very high due to the concentration of schools and hospitals. During peak hours, there is always serious congestion due to the large volume of people participating in traffic, the cars and motorcycles emitting a large number of pollutants like SO_2, NO_2, O_3, etc. causing the deterioration of air quality in this area. In Hoan Kiem and Ba Dinh districts, several streets such as Quan Thanh, Phung Hung, Hang Giay, Hang Ma, Tran Nhan Tong are also areas with high traffic density.

The calculation of AQI value and IDW interpolation method has allowed mapping the distribution of air quality from the concentrations of pollutants at monitoring stations which are scattered around the urban districts of Hanoi city. It has simultaneously established a statistical database of in situ measurement data including names, coordinates, concentrations of gases, and particulate matters at 33 air monitoring stations and daily calculated AQI values. The distribution map of air quality helps to assess the air pollution situation in the inner urban districts of Hanoi city and to find out the causes and to propose solutions for reducing air pollution level. However, due to the unreasonable disposition of monitoring stations, the study area did not entirely cover by collected data. This fact makes a considerable difficulty for the interpolation process which is based on the location of these monitoring stations. Therefore, on the one hand, it is crucial to maximizing the coverage of data collection from in situ measurement; on the other hand, it is necessary to improve the algorithm in GIS technology with higher accuracy and efficiency for interpolation functions.

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