RESEARCH PAPER

MODELING AIR POLLUTION IN DONG NAI PROVINCE, VIETNAM

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ABSTRACT. Data analysis shows that dust and CO have a very high concentration, causing air pollution. Meanwhile, SO_2 and NO_2 concentrations are lower than the permitted levels. The method inverse distance weighting (IDW) has been proved to be effective in modeling atmospheric pollution space in the study area. The results indicated that the air was contaminated. Pollution levels increase gradually in the following areas: Residential areas <Waste treatment areas <Industrial parks. The integrated pollution map shows that there have been signs of ecological insecurity in the dry season, so there should be measures to control the source of emissions into the environment.

KEY WORDS: AQI, Pollution air, Industrial, Residential, Waste treatment

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INTRODUCTION

Air pollution is considered a global problem. Air pollution is caused by human activities such as burning of fuels (coal, oil, gas), forest burning, mining, metallurgy, etc. and natural activities like volcanic activity (Michelozzi et al. 1998; Ostachuk et al. 2008). The problem of air pollution is becoming increasingly serious. Forest area is decreasing, meanwhile, emissions (CO, CO_2, NO_x ...) are increasing day by day, leading to greenhouse effects, which increase the temperature of the earth. The consequence is to upset the ecological circulation and climate change. In it, the most intuitive is the increase in diseases related to human respiratory tract (Raaschou-Nielsen et al. 2011; Pieters et al. 2015). According to statistics of the World Health Organization, up to 1.3 million people die from air pollution every year in major cities, and cause about 4.2 million premature deaths worldwide (WHO 2016; WHO 2018). China and India are the two countries that are considered to have high air pollution levels in the world (The new york time 2017). As a result, the number of deaths from lung cancer increases significantly (Shuo L. et al. 2018). Dong Nai is the southern province of Vietnam, one of the three satellite towns of Ho Chi Minh City. Many industrial parks with large scale are concentrated here. Accompanied by a huge number of employees and dense road system, often operating with high frequency. As a result, pollutants are released into the environment increasingly, leading to the risks of environmental pollution and human health.

MATERIALS AND METHODS

We used mobile observation stations to measure the parameters of the air environment at 80 monitoring points. Selected monitoring sites are areas with high pollution risk, including industrial zones (48 points), residential areas (23 points) and waste treatment areas (9 points). The monitoring parameters include four basic pollution parameters (dust, SO_2, NO_2 and CO) and meteorological parameters (including temperature, humidity and wind speed). Samples were measured during 4 months of the dry season (December, January, March and April), and three months of the rainy season (August, September and October). Time to measure samples within 24 hours. Method AQI (air quality index) and method NIPI (Nemerow integrated pollution index) used to assess the air quality. AQI and NIPI are calculated according to formula 1 and 2 (Tran Hong Ha 2013; Yang et al. 2010].

$$AQI_i^{24h} = \frac{C_i^{24h}}{S_i^{24h}} \times 100 \quad (1)$$

$$NIPI = \sqrt{\frac{PI_{iave}^2 + PI_{i\max}^2}{2}} \quad (2)$$

C_i^{24h} : The average concentration of substance i.
S_i^{24}h : Permissible environmental standards of substance i
n: Number of pollutants.
$PI=C_i/S_i$ pollution index
IDW and kriging interpolation models have been used to model pollution space. Based on 5 test sample points, we conducted determination of correlation coefficient R^2 to estimate the accuracy of interpolation map results. Comparing the interpolation results of the two methods, we will choose the appropriate method to model air pollution in the study area. The formula for calculating R^2 is given by the following formula (Krause et al. 2005):

$$R^2 = \left(\frac{\sum_i^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_i^n (O_i - \bar{O})^2} \sqrt{\sum_i^n (P_i - \bar{P})^2}} \right)^2 \quad (3)$$

O_i is the ith actual measured value.
$\bar{O}$ is the actual measured average value.
P_i is the predicted value.
$\bar{P}$ is the average predicted value.
n is the number of calculated values.

Table 1. Limits of basic parameters in air (Tran Hong Ha 2013; Yang et al. 2010)

Parameter	Standard (µg/m³)	AQI value	Air quality	NIPI	Rank
Dust (TPS)	140	0-50	Good	NIPI ≤ 0.7	Non-pollution
SO_2	50	51-100	Medium	0.7 <NIPI ≤ 1	Warning line of pollution
NO_x	40	101-200	Bad	1 <NIPI ≤ 2	Low level of pollution
CO	5000	201-300	Very bad	2 <NIPI ≤ 3	Moderate level of pollution
		> 300	Dangerous	NIPI> 3	High level of pollution

RESULTS

Results of monitoring of seasonal parameters are shown in table 2. The study area has a tropical monsoon climate, with characteristics of very high temperature and humidity. This climatic feature greatly affects the dispersion of pollution in the atmosphere. Very high humidity (maximum humidity up to 85% in the rainy season, and 69% in the dry season), low wind speed (average 0.62 m/s in the rainy season and 0.58 m/s in the dry season) will limit the spread of pollutants in the air.

Data in tables 1 and 2 show that the maximum concentrations of SO_2 and NO_2 in the dry and rainy season are both lower than the permissible concentration limits. Their average concentration values are 2 to 3 times lower than the standard. This shows that the air has not been polluted by SO_2 and NO_2. However, the concentration of dust and CO in the air is very high. dust and CO concentration is about 2-3 times higher than standard. A common feature of CO and dust is that the pollution level in the dry season is higher than in the rainy season (the average dust concentration in the dry season is nearly 2 times higher than in the rainy season. The CO content is 1.2 times higher than that in the rainy season). This proves that in the dry season, when the humidity decreases and there is no rain, the level of air pollution with dust and CO increases significantly. According to statistics of Dong Nai Department of Health, the number of people infected with respiratory diseases in the dry season in urban and industrial areas increased by more than 30% compared to the rainy season (Nguyen Trong Hai 2018).

The air quality index of the industrial zone is shown in Fig. 1 and Fig. 2. Most of the monitoring points in the industrial zone have very high dust concentrations in the dry season (2-3 times higher than the permissible concentration limits) and decrease gradually during the rainy season (Fig. 1). Locations that detect very high levels of dust pollution (AQI> 300) are Bien Hoa (BH-01, BH-02), Amata (AM-01), Nhon Trach (NT-01) and especially An Phuoc industrial zone (AP-01) with extremely high dust concentration (AQI> 400). This is a dangerous level, greatly affecting human health. In the rainy season, the concentration of dust drops sharply (about 50% lower than in the dry season). A number of small industrial areas (TP-01, LK-01, BS-01, XL-01) have relatively low dust concentration. Industrial zones with high dust pollution are those producing construction materials, producing animal feed and processing rubber etc. Meanwhile, industrial zones producing clothing, shoes, assembling electronic components have lower dust pollution.

Fig. 2 shows the concentration of CO in the air in industrial areas. All monitoring point have high levels of CO (≥5000µg/m³). In particular, the concentration of CO in the dry months is much higher than the months in the rainy season. Most of the monitoring points have a CO concentration 1-2 times higher than the permissible concentration. Especially, in march, CO concentration is very high (AQI-CO> 400) in Long Thanh industrial zone (LT-02). This shows that the industrial park has a large amount of CO, which is very toxic and has a high risk of affecting human health. CO disperses into the air during incomplete combustion of wood, fuel (petroleum), coal. Especially coal is used a lot in industrial areas, it is the raw material to operate the incinerators.

The analysis results of air pollution data in residential areas are shown in Fig. 3 and 4. Based on Fig. 3, it can be affirmed that the dust concentration in residential areas is much lower than that in industrial areas. Except for Vinh Cuu residential area (VC-22 and VC-23). This area is under construction of roads, so the dust content in this area is very high (AQI> 300 in the dry season). The remaining residential areas have slight dust pollution, 1-2 times higher than the permissible concentration in the dry season, while in the rainy season, most of the sample sites have dust concentrations lower than the permissible concentration. The cause of dust spread in residential areas is mainly due to traffic activities.

Fig. 4 shows that the CO concentration in residential areas is also lower than in industrial areas. Most of the monitoring point have 1-2 times higher than the permitted level in the dry season and the CO concentration decreases gradually during the rainy season. However, in the Bien Hoa city area (BH-01, BH-03) there was an abnormally high CO concentration in march. The CO concentration was dangerously high (AQI> 300).

Table 2. Limits of basic parameters in air (Tran Hong Ha 2013; Yang et al. 2010)

Parameter	Rain season (µg/m³)			Dry season (µg/m³)		
	Mean	Min	Max	Mean	Min	Max
Dust	76.00	7.63	169.52	166.65	14.60	435.59
SO_2	21.19	10.64	30.40	21.62	11.38	27.23
NO_2	16.36	15.00	20.93	17.13	15.00	24.77
CO	5,873.25	5,000.00	8,.474.75	6,552.43	5,000.00	12,574.94
Humidity %	65.23	57.63	85.38	60.45	52.03	69.38
Temperature °C	31.82	29.60	33.15	32.40	30.20	33.78
Wind speed м/с	0.62	0.25	0.85	0.58	0.30	1.0

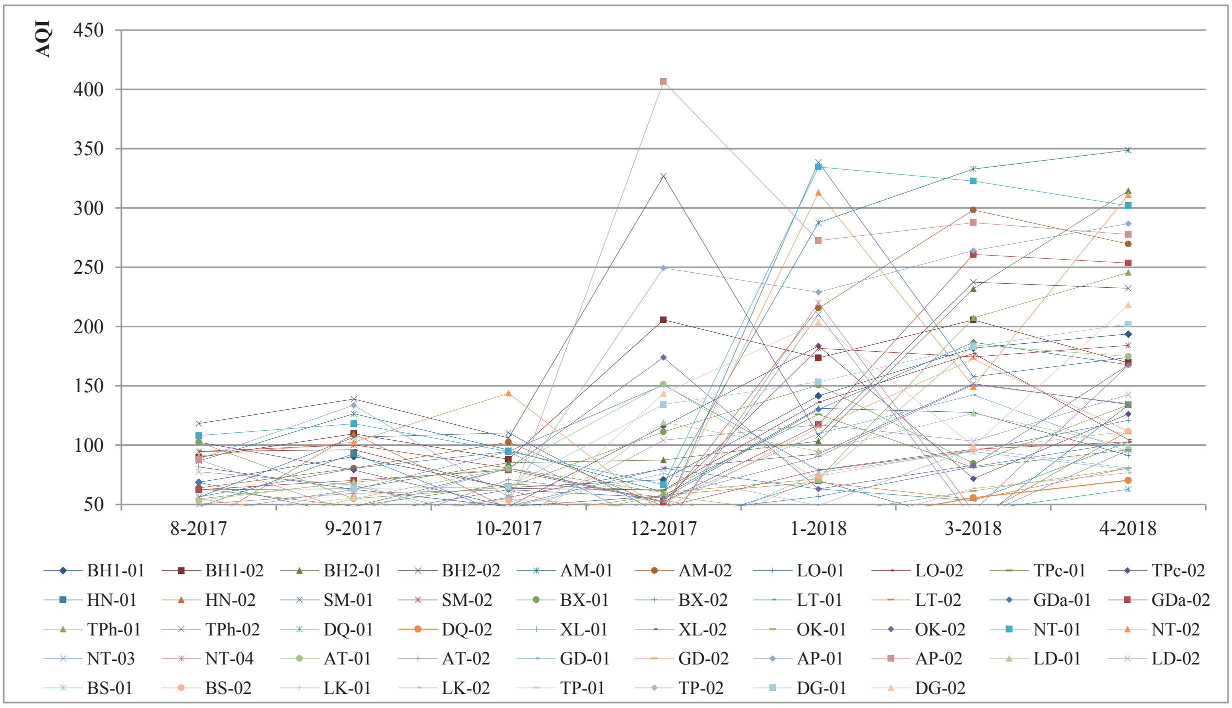

Fig. 1. AQI-dust Index in industrial areas

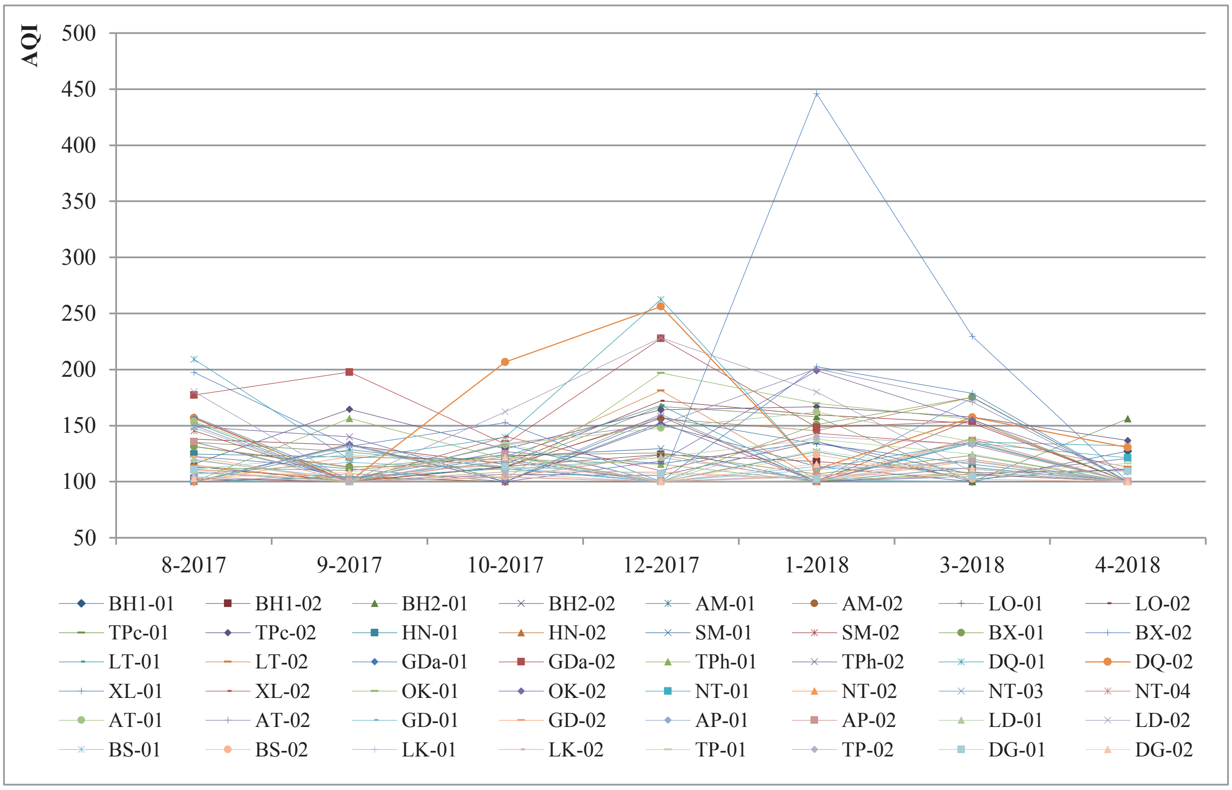

Fig. 2. AQI- CO index in industrial areas

In the waste treatment area, the dust concentration is quite high, most of the monitoring points in the dry season have AQI-dust value from 100-200. Dust concentration decreased significantly in the rainy season (Fig. 5). At that time, CO concentration was about 1-2 times higher than the permitted level (Fig. 6). Especially in Xuyen Moc waste treatment area (XM-06), there is a dangerous concentration of CO (AQI> 300). It can be seen that the level of pollution in the waste treatment area is lower than in the industrial zone but higher than the pollution level in the residential areas.

Based on the above analysis, it can be concluded that air pollution in the study area is mainly caused by dust and CO. Pollution levels decrease in the following order: industrial park – waste treatment area – residential area.

According to Li et al. (2008), the choice of interpolation method depends on many factors (Sample density, sampling methods and data types affect the estimation of spatial interpolation). These factors will affect the ability to interpolate in different ways, resulting in differences in interpolation results. Therefore, it is difficult to select the appropriate spatial interpolation method for a given input data set. Several interpolation techniques were used to estimate pollution concentrations, including inverse distance weighting, splines, theissen triangulation, and kriging.

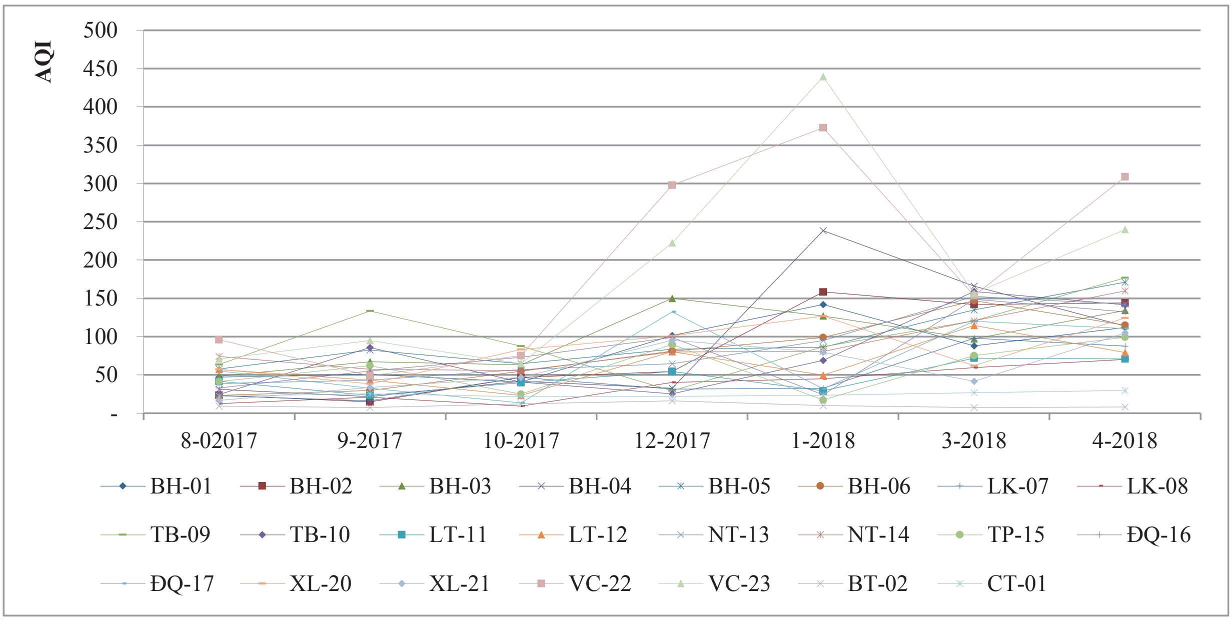

Fig. 3. AQI-dust index in urban residential areas

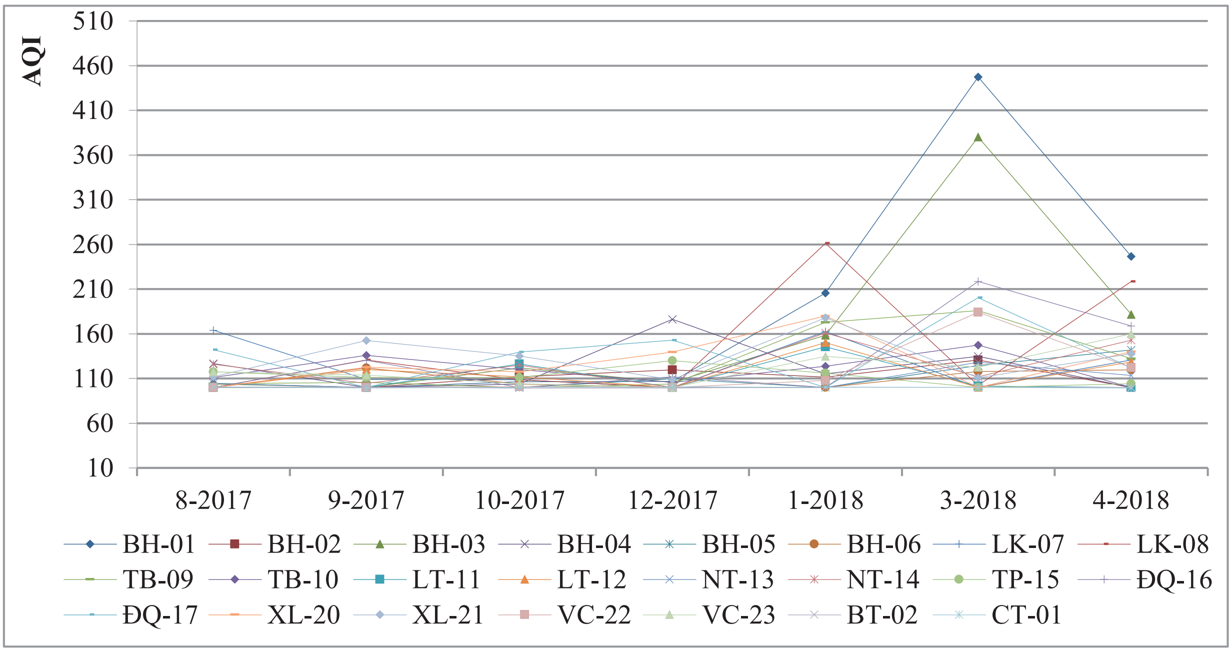

Fig. 4. AQI-CO index in urban residential area

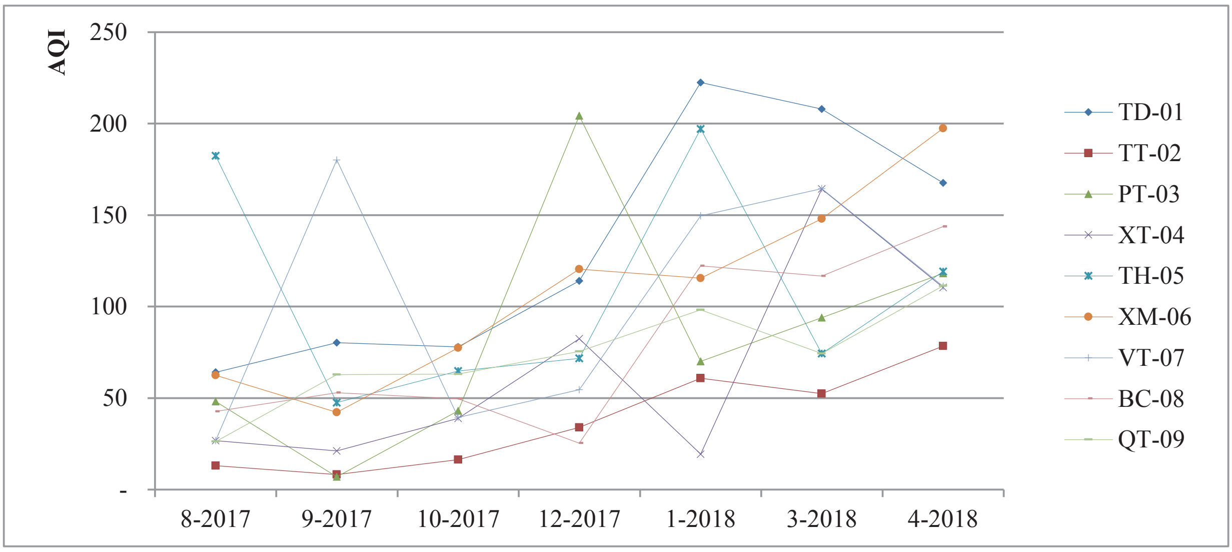

Fig. 5. AQI-dust index in solid waste disposal areas

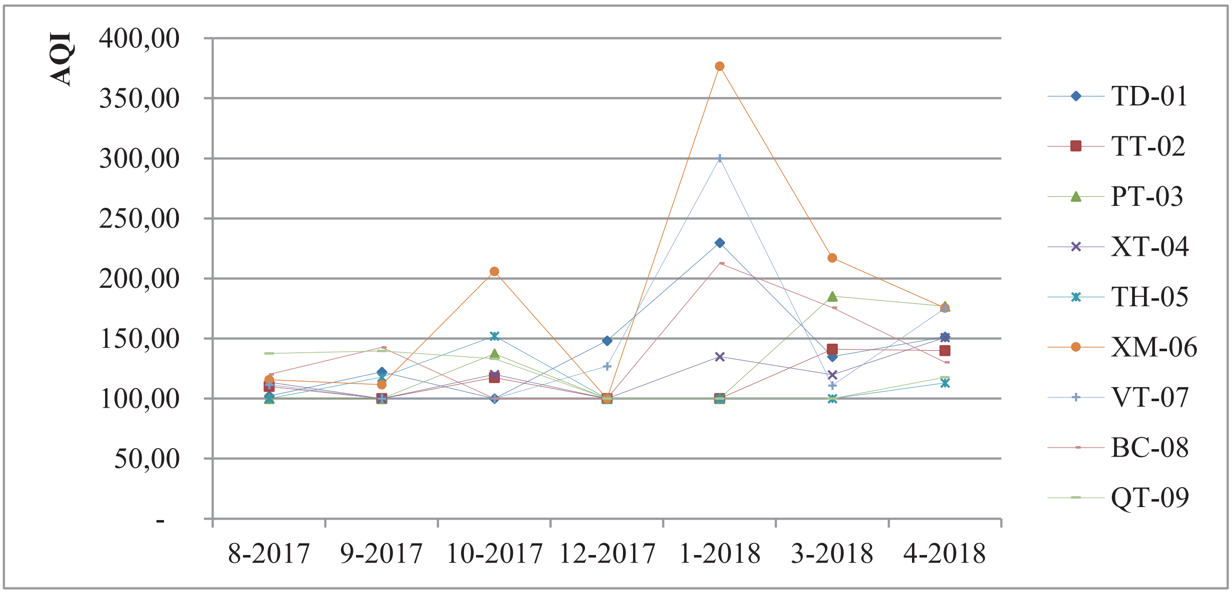

Fig. 6. AQI-CO index in solid waste disposal areas

IDW interpolation is also thought to be quite effective for modeling air pollution (Wong et al. 2004; Kumar et al. 2016). According Dilip Kumar (2011), IDW interpolation results in better results than kriging interpolation in assessing air pollution in Port Blair India (Dilip K. et al. 2011). Meanwhile, Jerrett suppose that kriging is the most commonly used method interpolation in air pollution studies (Jerrett et al. 2001). Therefore, to select the interpolation method for each specific case, it is common to use the method of comparing the interpolation value with the analytical value (Li et al. 2008; Oke et al. 2013). The results in table 3 show that the standard deviation difference of IDW is lower than that of Kriging. This shows that the IDW method gives an optimal result than the kriging method in interpolation of pollution values in the study area.

Interpolation results of air pollution distribution by IDW interpolation method were shown in Fig. 7 and Fig. 8. According to figure 7, in the northern and eastern Areas, air quality is good and medium (AQI-dust<100). Meanwhile, in the southwest region, where most of the industrial and residential areas (about 80%) are concentrated, there is a very high level of dust pollution, air quality is at a bad level (100<AQI-dust ≤200). Vinh Cuu residential area (point 20) and waste treatment area (points 21, 24) have very bad air quality (200<AQI-dust ≤300). In particular, An Phuoc industrial park (point 68) is at dangerous air quality (AQI-dust >300). However, in the rainy season, due to heavy and continuous rainfall (the average annual rainfall is from 1900ml-2400ml, about 80% of the rainfall is distributed during the rainy season), leading to significantly improved air quality. Most of the area has good and moderate air quality. Only a small area has bad air quality in Nhon Trach Industrial Zone (point 61). Although the air quality is improved, the rain that carries the pollutants will pollute the soil and water. Figure 8 shows that the entire study area has relatively high levels of CO, air quality is at a bad level (100<AQI-CO≤200). Concentration of CO does not decrease seasonally, in the dry season there is a waste treatment area (point 27) with very bad air quality (200<AQI-CO≤300).

Based on the data of the test points, proceed to determine the R2 coefficient, to evaluate the interpolation results. The R^2 value of the interpolation maps of Dust and CO pollution is shown in table 2.

Table 4 shows that the R^2 coefficient of dust is quite high (0.75) while the correlation coefficient R^2 of CO is very high (> 0.9). This can be explained by the fact that the CO concentration in the atmosphere of the study area is not too different (Figure 2). In contrast, dust content with significant differences between different areas, when interpolated, will have a lower correlation. However, with correlation R^2 > 0.7 can be seen, using IDW interpolation method is suitable to model air pollution in the study area.

Figure 9 shows the integrated pollution distribution of dust, SO_2, NO_2 and CO. During the dry season, most of the study area has low pollution levels, only a small part of

Table 3. Compares the results between IDW and Kriging interpolation methods

Pollutant	Standard deviation of data	Standard deviation of IDW	Standard deviation of Kriging	Standard deviation difference	
				IDW	Kriging
Dust-rain	25.94	15.54	14.33	10.4	11.61
Dust-dry	62.09	35.16	28.89	26.93	33.2
SO_2-rain	11.81	4.88	2.70	6.93	9.11
SO_2- dry	11.37	4.80	2.76	6.57	8.61
NO_2-rain	3.26	1.33	0.72	1.93	2.54
NO_2-dry	4.96	2.18	1.92	2.78	3.04
CO-rain	14.52	7.49	3.83	7.03	10.69
CO-dry	28.94	13.12	6.49	15.82	22.45

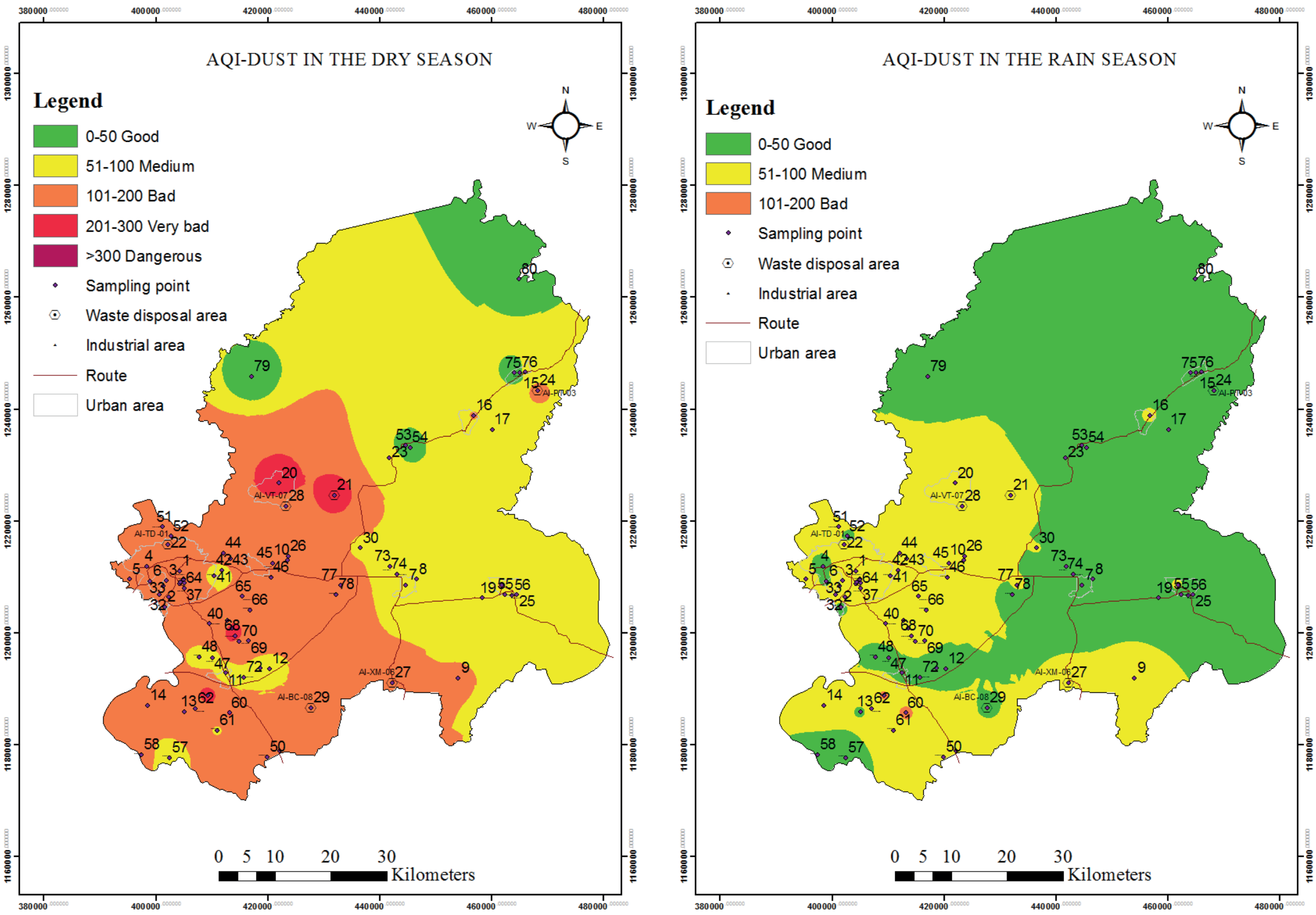

Fig. 7. Distribution of air pollution by dust

Table 4. Correlation analysis results

	Correlation Coefficients (Rainy Season)		Correlation Coefficients (Dry Season)	
	Dust	CO	Dust	CO
Coefficient R^2	0.75	0.97	0.73	0.91

the northern region has pollution pollution warning levels. The two locations were found to have moderate levels of combined pollution at the waste treatment area (point 21) and the Vinh Cuu residential area (point 20). In the rainy season, the complex pollution level decreases significantly. Most areas have pollution warning levels, a small area of low pollution levels. This proves the ability to self-clean the air in the rainy season is very high. However, this is also a sign that ecological non safety, when in the dry season, most areas, the air is slightly polluted, and some areas have moderate pollution levels, in the long run, it will affect human health. This is a result of the rapid increase in the number of industrial zones, the significant increase in the number of vehicles, especially the process of treating waste mainly by burning without effective measures to control the amount of gas discharged into the environment. Emissions not only include these basic substances, they can also include many other hazardous components such as heavy metals, benzene, etc Therefore, to ensure ecological safety as well as to protect human health, it is necessary to take measures to thoroughly treat the source of air pollution, especially in industrial areas (points 62, 68, 70) and waste disposal sites (points 21, 24 and 27).

DISCUSSION

We know that, to model spatial variations of air pollution concentration, dispersion models are often used. These models conceptualize pollution dispersion in terms of deterministic processes, which are implemented through Gaussian plume equations (Gualtieri et al. 1998; Clench-Aas et al. 1999; Bellander et al. 2001; Pamela F.H. et al. 2011). However, to run these models requires a large data set, measuring many parameters at the same time, and data must be collected continuously over time (by hour or by day). This requires a complete monitoring system and the outcome depends on the size of the monitoring system. The common characteristic of developing areas is that environmental pollution has not been given enough attention and the system of equipment and technologies for environmental monitoring have not been fully established. Most air pollution data measurements are based on mobile stations and measurement of discontinuous air data. Mostly measure the concentration of substances in the air at a given time. Some authors argue that the interpolation model can be used effectively to model air pollution spaces without data on emissions and meteorology (Van L.M. 1993; Janssen et al. 2008; Candiani et al. 2013). In particular, IDW interpolation method is considered as an appropriate tool to analyze the change of air pollution space. The only input data is the pollutant concentration. This suggests that it is easy and economical to collect data, while meteorological and emissions data collection is more time-consuming and costly (Awkash Kumar et al. 2016). However, the disadvantage of the interpolation method is the need to use a dense network of monitoring points. Jerrett et al. (2005), estimated that a dense network of sampling sites ranging from 10 to

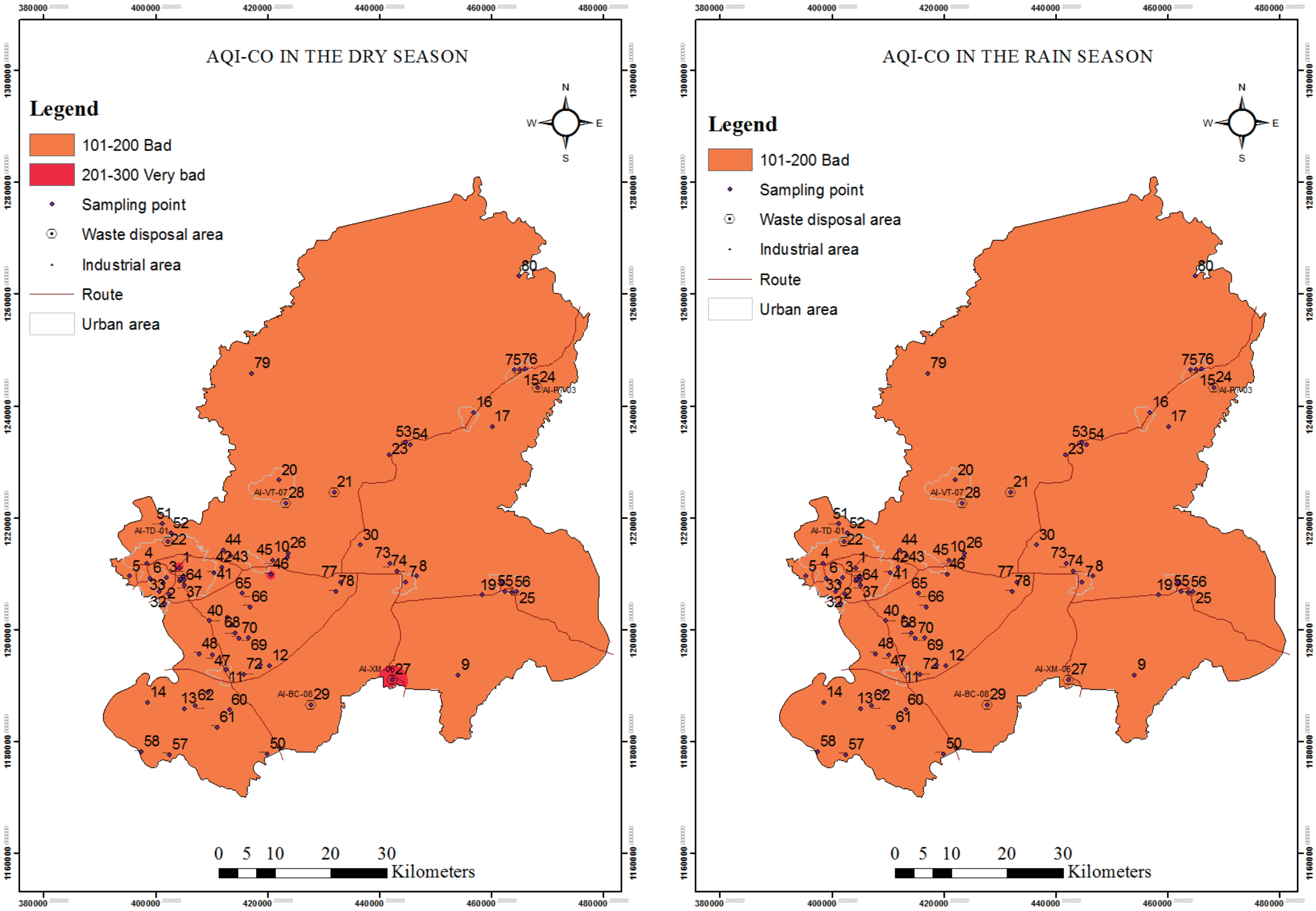

Fig. 8. Distribution of air pollution by CO

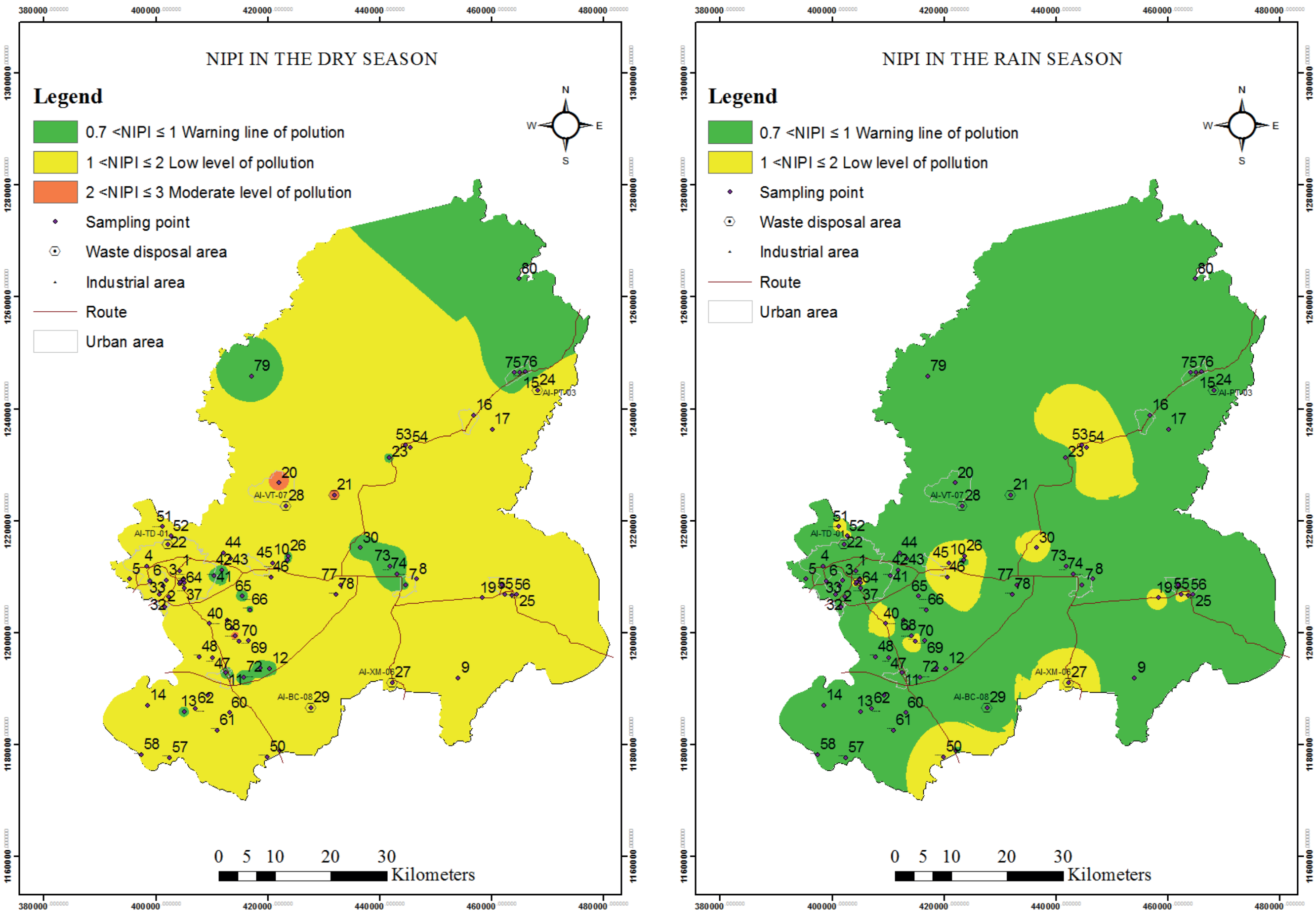

Fig. 9. Integrated air pollution map

100 stations is required for meaningful interpolation results depending on the size of the study area. Therefore, the use of interpolation method to model air pollution is considered as an appropriate option for study area.

For air environment, natural conditions such as wind speed, air humidity and topography are the major factors that influence the dispersion of pollution in the air. Characteristics of the natural conditions of the study area are relatively low wind speed (0.2 m/s – 1.0 m/s), flat terrain and an average humidity > 60%. With high humidity, pollutants, when released into the environment, will quickly absorb water and become heavier as a result they will be distributed closer to the ground. Combined with low wind speeds (almost static), flat terrain, pollutants tend to disperse around discharge sources. Pollution levels are highest at the source of discharge and the level of pollution decreases as the distance to the source of discharge is increased. The IDW inverse weighting method estimates the interpolation values based on the inverse distance from the interpolation point to the sample point. Therefore, the farther the distance, the lower the value of the interpolation point. This shows a similarity between the IDW interpolation model and the actual pollution dispersion in the study area.

In figures 7 and 8, areas with the highest pollution levels are shown polluted in concentric shapes, with a focus on monitoring points in industrial areas (points 62, 68, 70), residential area (points 20) and waste disposal sites (points 21, 24 and 27). These are areas with large discharge sources and continuous discharge into the environment. Meanwhile, in other areas such as in residential areas, and smokeless industrial areas such as garments, assembly of electronic components, etc. pollution sources come mainly from traffic activities (scattered discharge sources), the pollution diffusion is more uniform. The correlation coefficient R2> 0.7 indicates that, the results of pollution modeling by the IDW interpolation method, although it is not possible to guarantee the high accuracy as when using complex air pollution dispersion models, but it is also somewhat reflect the extent and distribution of polluted areas.

CONCLUSION

The analysis results indicate that the study area has been polluted by CO and dust. Air quality varies from good to moderate, bad and dangerous in different areas. The most polluted air is in industrial zones, then in waste treatment areas and finally in residential areas. Air quality is subject to significant seasonal changes. In the dry season, pollution levels are almost double that in the rainy season.

Air pollution map created by IDW method has relatively high accuracy (R2> 0.7). Therefore, this method can be considered as effective in interpolation of air pollution values in the study area. The integrated pollution map shows a higher risk of ecological insecurity due to air pollution in the dry season. Therefore, measures are needed to reduce emissions, especially in the dry season.

The interpolation method is considered to be effective in modeling air pollution with developing areas, areas with limited monitoring and cost systems. With the input of a simple and low-cost data collection system, it can help visually depict polluted areas to warn of the dangerous increase of air pollution to human health.

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