Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 10, No. 02, February, 2024

Assessing Air Quality Using Multivariate Statistical Approaches

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Received 08 November 2023; Revised 09 January 2024; Accepted 15 January 2024; Published 01 February 2024

Abstract

The purpose of the current study was to evaluate air quality in Dong Thap province, Vietnam. The air quality data was collected during 2019–2020, representing the time of pre- and mid-COVID-19. Twenty-seven air quality samples (in the areas of urban, residential-administrative, hospital-schools, and industry-craft village areas) were used for the evaluation. Air quality was evaluated using national technical regulations on air quality, including QCVN 26:2010/BTNMT and QCVN 05:2013/BTNMT. The difference of mean air quality between the areas was examined using a one-way ANOVA followed by the Duncan test at a significant level of 5%. The relationship between air quality parameters and microclimate factors was tested using Pearson correlation. Principal component analysis (PCA) was utilized to identify critical variables and potential sources of air variation. Cluster analysis (CA) was applied to group similar air quality sites, thus recommending air monitoring site selection. The results show that the air quality in the study area is not polluted. The concentrations of noise, TSP, SO_2, and NO_2 in the mid-COVID-19 pandemic were significantly lower than those in the pre-COVID-19 pandemic due to the social distancing policy. There was a close correlation among air quality parameters, except for air humidity. PCA identified two to four potential sources of air variation, explaining 84.3%, 100%, 100% and 89.7% of the total air quality variance at urban, residential–administrative, hospital-schools, and industry-craft villages, respectively. CA divided the 27 sampling sites into eight groups by the differences, mainly in humidity, wind speed noise, TSP, and CO. Eight sampling sites could be potentially reduced from the current monitoring program for representativeness and cost-effectiveness purposes. All air parameters in the current study are significant for monitoring, and the potential sources of air quality variation are traffic activities, industrial production, craft village activities, and daily life using fuels in residential areas. The results of the current study provide useful information for air quality monitoring and management. Future monitoring programs should include toxic air pollutants in air quality monitoring programs.

Keywords: Air Quality; Cluster Analysis; Dong Thap Province; Pearson Analysis; Principal Component Analysis.

1. Introduction

Air pollution has gained more attention as a public concern since it has harmful effects on human health, plants, and animals [1–3]. Air pollution can be caused by nature and humans [1, 2, 4]. Natural causes of air pollution include the release of air pollutants from wetlands, strong winds resulting in particulate matter from arid areas, and the eruption of volcanoes. Anthropogenic causes of air pollution include burning fossil fuels (natural gas, coal, and petroleum) for domesticity, transportation, power plant operation, and industrial processes [2, 4–6]. Agricultural biomass combustion and solid waste burning are also human-caused air pollution [5, 6].

Meteorological parameters such as temperature, humidity, and wind speed are important factors spatially and temporally determining air quality patterns. These variables have contributed to the control of releases, fate, transport,

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http://dx.doi.org/10.28991/CEJ-2024-010-02-012

and deposition of air pollutants [4, 7]. The air pollutants of primary concern are suspended particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), peroxyacetyl nitrate (PAN), and ozone (O_3) [4, 8]. As air quality declines, the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma [7, 9]. Fine dust particles and NO_2 have been studied to be associated with an increased risk of arteriosclerosis, myocardial infarction, stroke, and acute heart failure [10]. Meanwhile, SO_2, NO, and particulate matter affect lung function and cause inflammation of the bronchial mucosa [11].

According to WHO statistics (2012), about 7 million deaths have been recorded globally due to air pollution, of which 4.2 million deaths are related to exposure to air pollution [6, 12]. In addition, the environment can be negatively influenced by air pollutants such as ecosystem disruption, water and soil pollution, soil and land degradation, and climate change [4]. Thus, monitoring and evaluation of air quality are essential. Multivariate statistical approaches, including cluster and principal component analysis, have been widely used in air quality assessment. In addition, the Pearson correlation has also been used in this field. For example, Yan et al. (2016) [13] used correlation analysis to examine the relationship between $PM_{2.5}$ and barometric pressure, wind speed, and air humidity in Beijing. Liu et al. (2021) [14] also used correlation to find out the relationship among particulate matter ($PM_{2.5}$, PM_{10}), gaseous (CO, NO_2, SO_2, O_3), and climatic factors (wind speed, humidity, temperature, and pressure). Former studies have used PCA to identify major polluting sources and key air variables determining air quality in a particular study area [8, 15–19]. CA has been used to group sites or seasons with similar air quality characteristics, thus recommending monitoring sites [9, 20].

In Vietnam, air quality monitoring and assessment are required by law. The air quality assessment is performed by comparing the measured air quality values to the limits regulated in national technical regulations on ambient air quality and noise. In addition, the air quality index is sometimes calculated to provide overall air quality information. Studies using multivariate statistical analysis in air quality assessment are limited in the Vietnamese Mekong Delta provinces. This study is implemented to evaluate air quality (influenced by various socioeconomic subjects) in the Mekong Delta province, Vietnam, using Pearson correlation, cluster and principal component analysis. The comparison of air quality before the COVID-19 pandemic (2019) and in the middle of the COVID-19 pandemic (2020) was also compared to emphasize the impact of human activities on air quality in the study areas. The results of the current study could provide useful information for air quality monitoring, assessment, and management.

2. Material and Methods

2.1. Study Areas

Dong Thap is one of 13 provinces in the Mekong Delta region, with a natural area of 338,385 hectares, accounting for 8.17% of the region. It is the gateway to the Long Xuyen quadrangle and is the first important trade relationship of the Greater Mekong sub-region [21]. Currently, the province's industrial production has been increasingly developed. In addition, handicraft production establishments and craft villages are also rising. Trade and service activities have also been extended within and outside the province. Environmental issues have occurred during socioeconomic development [21].

In this study, air quality is of interest. The air quality in the areas of urban, residential, administrative offices, hospitals, schools, and industry-craft villages was selected for study. Air quality data at 27 locations was collected from the Department of Natural Resources, Dong Thap province. In urban areas, 14 air samples were collected, including KK1-KK14. Four samples were collected at the residential-administrative areas (KK15–KK18). Three samples were collected at the hospital (KK19–20) and school area (KK21). In the industrial-craft village areas, six air quality samples were collected (KK22–KK27). The distribution of air quality samples is presented in Figure 1. Eight air quality parameters (i.e., temperature, humidity, wind speed, noise, suspended dust (TSP), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2), were evaluated in this study. The microclimate factors comprising temperature, humidity, and wind speed were measured directly in the field according to QCVN 46:2012/BTNMT. The noise level is measured on-site according to TCVN 7878-2:2010. Air quality samples for analysis of total suspended particulates (TSP), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) were collected, stored, and transported to the laboratory and analyzed using standard methods (TCVN 5067-1995; TCVN 5971-1995 and TCVN 6137:2009).

2.2. Data Analysis

The air quality in the areas of urban, residential-administrative, hospitals-schools, and industry-craft villages was evaluated using national technical regulations on air quality, including QCVN 26:2010/BTNMT [22] and QCVN 05:2013/BTNMT [23]. The difference in mean air quality between the areas was examined using a one-way ANOVA followed by the Duncan test at a significant level of 5%. The relationship between air quality parameters and microclimate factors was tested using Pearson correlation. Principal component analysis (PCA) was utilized to identify critical variables and potential sources of air pollution in the study area. Cluster analysis (CA) was applied to group similar air quality sites, thus recommending air monitoring site selection. Correlation and one-way ANOVA were performed using SPSS, while PCA and CA were implemented using Primer 5.2.

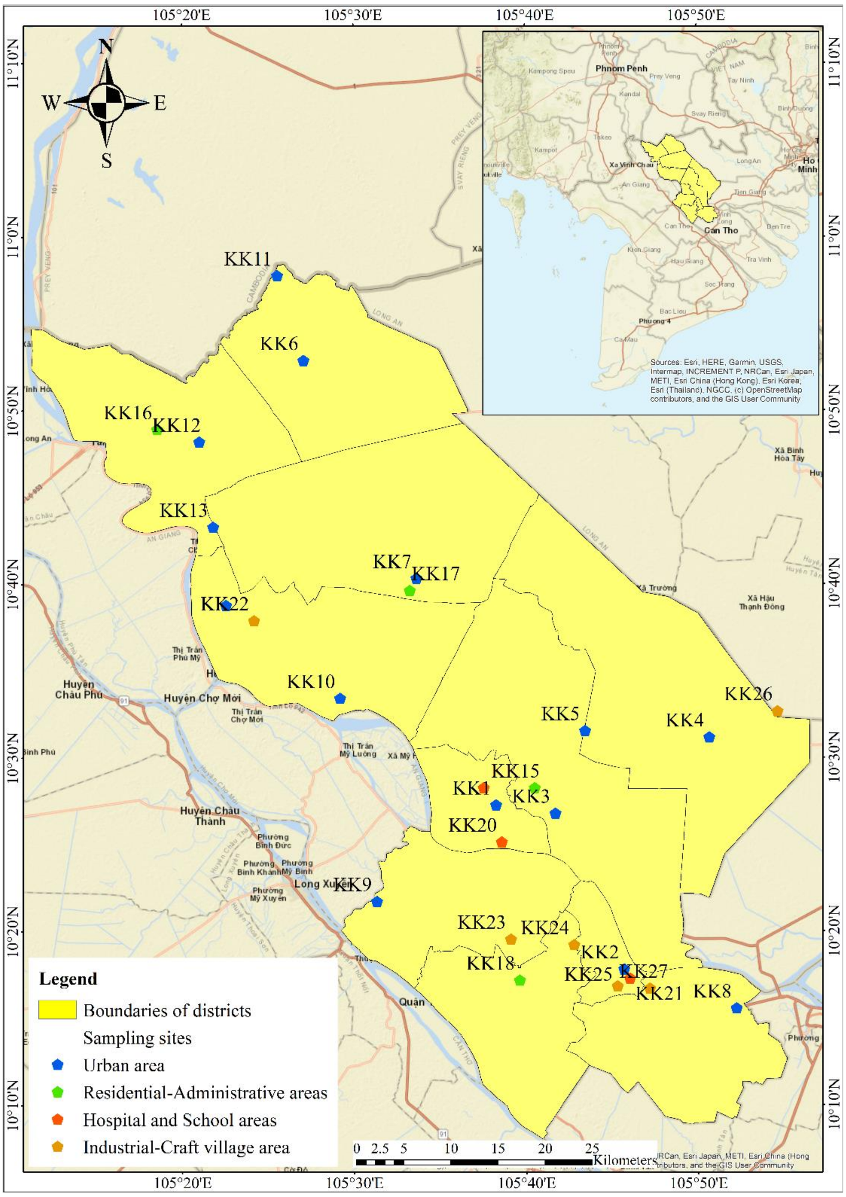

Figure 1. Location map of air quality measurement in the study areas

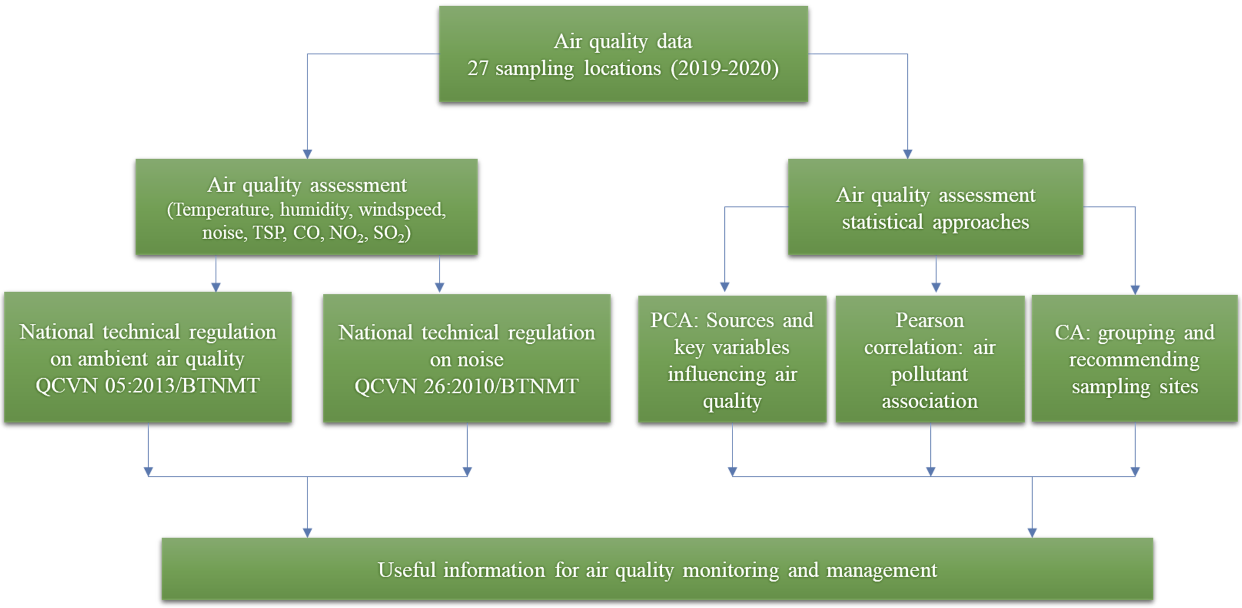

Figure 2. Flowchart of the study

3. Results and Discussion

3.1. Air Quality in the Study Area

The air temperature in the study area during the period of 2019–2020 was relatively stable at 32.34±1.12ºC. There was no statistically significant difference in air temperature between the impact areas of urban, residential-administrative, hospital-school, and industry-craft village areas (Table 1). Similarly, the air temperature in each impact area before and in the middle of the COVID-19 pandemic was not significantly different ($p > 0.05$) (Table 2). Several former studies reported air temperatures in the Mekong Delta of Vietnam. Giao et al. (2023) [24] found that air temperature over the ten-year period in An Giang province ranged from 30.15±1.28 to 32.71±2.20ºC (averaged at 31.67±2.57ºC). This study also found a significant difference in air temperature over a long period. In southern Vietnam, the air temperature in 2020 ranged from 31.49±2.51–32.34±2.32 ºC and had no significant difference between the seasons [25]. Other studies found temperatures in HCM city and Dong Nai province were in the ranges of 29.6-36.2ºC and 31.82-32.40ºC, respectively [26, 27]. As can be seen that temperature air temperature between this study and those reported in the literature is in similar ranges. However, air temperature in urban areas of Long Xuyen city, An Giang province, during the period of 2016–2019 highly fluctuated between 29-35.6ºC [28]. On a local scale, the air temperature is not much different. However, the mean annual temperature in the globe has increased [29, 30]. Air temperature is the critical factor controlling air quality, especially particulate matters, CO, O_3, and SO_2 [26, 31]. High temperatures could have serious consequences for human health and the ecosystem [32–34].

Surface humidity is important for weather and climate monitoring [35]. The average humidity in the air in the period of 2019–2020 was 75.07±2.26%. Between the impact areas, the air humidity was relatively stable, ranging from 74.75±1.55 to 75.18±2.36% (Table 1). The recorded air humidity in all areas did not differ significantly ($p>0.05$) (Table 1). The humidity in the air in the pre-COVID-19 pandemic and the middle of COVID-19 in all areas was not significantly different ($p>0.05$) (Table 2). In Can Tho city, air humidity was in the range of 64.16±0.13%-78.95±3.88% [36]. Hung et al. (2020) [26] reported that humidity in Dong Nai province was 60.45-65.23%. Humidity in southern Vietnam was 66.02±9.24–72.22±11.69% [25]. Another study reported that humidity in the Hanoi area was 80–95% [37]. All previous studies revealed that humidity is geographically and seasonally dependent [35]. Humidity is reported to affect temperature, ozone formation, and the variation of particulate matter concentrations [35, 38]. Humidity could play a significant role in transmitting air-borne diseases and severe heat discomfort [3, 35, 39].

Table 1. Mean values of air quality parameters in the study area

Parameters	Unit	Urban	Residential-administrative	Hospital-school	Industrial-craft	Mean ± SD
Temperature	ºC	32.33±1.08^a	32.14±1.15^a	32.67±1.11^a	32.34±1.23^a	32.34±1.12
Humidity	%	75.18±2.36^a	74.78±1.70^a	74.75±1.55^a	75.16±2.66^a	75.07±2.26
Wind Speed	m/s	1.10±0.41^a	1.03±0.32^a	1.07±0.41^a	1.20±0.35^a	1.11±0.38
Noise	dBA	63.14±3.78^a	60.06±3.75^b	62.79±3.48^a	59.74±4.61^b	61.89±4.19
TSP	mg/m^3	0.21±0.06^{ab}	0.18±0.03^b	0.20±0.05^{ab}	0.22±0.07^a	0.21±0.06
CO	mg/m^3	3.43±0.62^a	3.35±0.54^a	3.39±0.47^a	3.62±0.66^a	3.45±0.60
SO_2	mg/m^3	0.044±0.02^a	0.042±0.02^a	0.043±0.02^a	0.045±0.02^a	0.044±0.02
NO_2	mg/m^3	0.0426±0.02^a	0.0452±0.02^a	0.0422±0.02^a	0.0395±0.02^a	0.042±0.02

Notes: Letters ^{a,b} in the same row are not statistically significant and vice versa ($p<0.05$).

Table 2. Comparing air quality parameters in 2019 and 2020

Parameter	Urban area		Residential - administrative area		Hospital and School areas		Industry-Craft area	
	2019	2020	2019	2020	2019	2020	2019	2020
Temperature	32.45±0.79^a	32.21±1.31^a	32.16±0.66^a	32.13±1.55^a	33.12±0.29^a	33.22±1.46^a	32.71±0.68^a	31.98±1.55^a
Humidity	74.98±0.54^a	75.39±3.31^a	74.64±0.49^a	74.91±2.43^a	74.93±0.54^a	74.57±2.22^a	74.92±0.52^a	75.40±3.8^a
Wind Speed	1.096±0.45^a	1.107±0.37^a	0.88±0.31^a	1.18±0.26^a	1.28±0.48^a	0.85±0.16^a	1.34±0.36^a	1.06±0.29^b
Noise	63.37±4.00^a	62.91±3.60^a	60.70±4.92^a	59.43±2.22^a	65.10±2.16^a	60.48±3.03^b	58.09±5.4^a	61.39±3.06^a
TSP	0.205±0.06^a	0.217±0.07^a	0.19±0.03^a	0.16±0.02^b	0.24±0.03^a	0.16±0.04^b	0.23±0.05^a	0.21±0.08^a
CO	3.42±0.63^a	3.44±0.62^a	3.35±0.60^a	3.345±0.51^a	3.36±0.39^a	3.43±0.57^a	3.68±0.61^a	3.56±0.74^a
SO_2	0.05±0.01^a	0.04±0.02^b	0.0415±0.008^a	0.0413±0.03^a	0.05±0.01^a	0.03±0.02^b	0.0531±0.01^a	0.0369±0.02^b
NO_2	0.05±0.009^a	0.03±0.019^b	0.054±0.01^a	0.036±0.02^b	0.0498±0.01^a	0.0345±0.02^a	0.0432±0.01^a	0.0359±0.02^a

Notes: Letters $^{a, b}$ in the same row are not statistically significant and vice versa ($p<0.05$).

The mean value of the wind speed in the study during the period of 2019–2020 was 1.11±0.38 m/s. The wind speeds in the areas were 1.03±0.32-1.20±0.35 m/s, and there was no statistically significant ($p>0.05$) (Table 1). Table 2 shows that the wind speeds in 2019 and 2020 at various impact areas were also not statistically significant ($p>0.05$). Compared with the study of Hung et al. (2020) [26], the wind speed measured in Dong Nai province was relatively lower, ranging from 0.58 to 0.62 m/s. The wind speed measured in Can Tho city was 0.28±0.26-0.83±0.59 m/s [35, 36]. The wind speeds over space and time in the southern part of Vietnam were in the ranges of 0.57±0.13-0.78±0.44 m/s and 0.70±0.37-0.76±0.48 m/s, respectively [25]. Wind speeds were also measured and reported in other parts of the world. For example, wind speed in Nigeria was measured at 0.4–0.7 m/s [40], and wind speed in Turkey was 1.96 m/s [41]. The wind speed in the study area is relatively higher than in former studies, which could mean that wind speed is space-dependent. Wind speed has an influence on air quality in a way that it blows and disperses pollutants. When wind speed is less than 1.5 m/s, it could reduce the dispersion of air pollutants [31]. Wind speed has been shown to be negatively correlated with particulate concentrations due to the main effects related to dust dispersion and dilution [37, 42].

The mean noise values in the study areas in 2019–2020 were 61.89±4.19 dBA, ranging from 59.74±4.61 to 63.14±3.78 dBA (Table 1). The noise values in urban and hospital-school areas were significantly higher than in residential and industrial areas. The high noise values are mainly caused by motorized vehicles and human activities [28]. Former studies also found that urban and traffic areas had the highest noise levels [24, 25]. Comparing noise between pre-COVID-19 and mid-COVID-19, it was found that the noise values at urban, residential-administrative, and industrial-craft areas were almost the same, while a significant difference in noise value was found at the hospital-schools area. This could be the result of the social distancing policy of the Vietnamese government during COVID-19 combat. In An Giang province, the noise values over ten years were 63.09–68.27 dBA (66.61±6.33 dBA) [24]. In southern Vietnam, the noise values were from 61.83±7.37–74.64±2.48 dBA [25]. In Can Tho and HCM cities, the noise levels were in the ranges of 68.73±2.48-79.54±1.95 dBA and 62.6±8.61-72.1±7.99 dBA, respectively [27, 28]. The study in Nigeria found that the noise level was 77.70–87.50 dBA [43]. Noise levels depend on the area since the noise is associated with human activities [25, 27, 28, 43]. Noise is also dependent on the season since human activity is seasonally dependent. Noise on the weekend is less than on weekdays, and noise in the day is less than at night [44]. Noise can significantly impact health, for example, headaches, stress, and increased blood pressure [45, 46]. The study results indicated that the noise level in the study area is within the limit of QCVN 26:2010/BTNMT (70 dBA). However, noise levels in the day and at night should be lower than 55 dBA and 45 dBA [46].

The total suspended particulates (TSP) in the air in Dong Thap province in the period of 2019–2020 reached an average of 0.21±0.06 mg/m^3, ranging from 0.18±0.03 to 0.22±0.07 mg/m^3 (Table 1). The lowest TSP was found in the residential-administrative areas and the highest in the industrial-craft village areas (Table 1). This difference was statistically significant ($p < 0.05$). TSP concentrations in residential-administrative and hospital-school areas were significantly different ($p < 0.05$) between pre-COVID-19 and mid-COVID-19. This could indicate that the social distancing policy during the combat period decreased TSP concentrations. In urban and industrial-craft areas, the TSP in 2019 and 2020 were not different ($p > 0.05$) (Table 2). Former studies reported that TSP in Can Tho city and in Long Xuyen city, An Giang, were in the ranges of 171.99±44.86-265.81±18.75 µg/m^3 [28] and 0.161±0.01-0.24±0.13 mg/m^3 [36], respectively. TSP ranging from 59.25±37.84 325.21±164.39 µg/m^3 was reported in South Vietnam [25]. In large cities such as HCM and Hanoi, TSP concentrations were found at 128–680 µg/m^3 [47] and 241.6–551.0 µg/m^3 [48], respectively. As can be seen, TSP concentrations in Dong Thap province are within the limit of QCVN 05:2013/BTNMT (0.3 mg/m^3). However, the TSP concentrations in south Vietnam, in HCM City and Hanoi, exceeded the limit. TSP is reported to be related to health issues such as respiratory disease, cardiovascular disease, and premature death [49].

The carbon monoxide (CO) concentration was to be averaged at 3.45±0.60 mg/m^3 (ranging from 3.35±0.54 to 3.62±0.66 mg/m^3) between 2019 and 2020. The CO concentrations did not significantly differ among the areas ($p>0.05$) (Table 1). Similarly, CO concentrations in each impact area were not statistically significant ($p>0.05$) between the pre-COVID-19 and the mid-COVID-19 periods. Overall, the concentration of CO in the study area was much lower than that of QCVN 05:2013/BTNMT (30 mg/m^3). Several former studies have reported similar results. CO concentrations in traffic, industrial production, and densely populated areas were measured at 5–14 mg/m^3 [47]. Giao (2021) [28] reported CO concentrations in industrial, urban, and traffic areas were in the ranges of 4.22±1.77-5.59±-0.05 mg/m^3, 4.93±1.61-9.63±4.68 mg/m^3 and 6.03±2.15-8.30±2.95 mg/m^3, respectively. At monitoring stations near parks, main roads, and markets in Cau Giay, Hanoi, CO concentrations were reported to be 4.4–13.3 mg/m^3 [49]. Giao et al. (2023) [24] reported that CO concentrations in An Giang province over 10-year period were in the range of 4.40–7.26 mg/m^3 (5.87±2.36 mg/m^3). The results of the current studies and former studies in Vietnam revealed that CO concentrations vary differently; however, they are low and are within the regulation limit. However, in the areas where it is heavily affected by traffic activities, the CO concentrations could be measured up to 390-3560 mg/m^3 (mean value at 1240 mg/m^3) due to incomplete fuel combustion [19]. The main sources of CO emissions could be vehicles and industrial and solid waste processes [19, 50, 51].

Sulfur dioxide (SO_2) in the air ranged from 0.042±0.02 to 0.045±0.02 mg/m^3, averaging at 0.044±0.02 mg/m^3 during the period of 2019–2020. SO_2 concentrations were not statistically significant between the four monitoring areas ($p>0.05$) (Table 1). The concentrations of SO_2 in the urban areas, hospitals, schools, and industry-craft villages in the mid-COVID-19 pandemic were significantly lower than those of the pre-COVID pandemic. This could be the influence of social distancing policy during the COVID-19 confrontation in the study area. In An Giang province, the concentration of SO_2 over the 10-year period was in the range of 0.063–0.1139 mg/m^3 (averaged at 0.078±0.05 mg/m^3) [24]. SO_2 concentration was measured at 15.88±5.98–38.58±17.54 µg/m^3 in the south of Vietnam in 2020. The highest concentration was found in urban areas, while the lowest concentration was measured in tourism areas [25]. The concentration of SO_2 in the air reported in the current and former studies was still far lower compared to that of QCVN 05:2013/BTNMT (0.35 mg/m^3). In some parts of the world, SO_2 could be measured at up to 2000 mg/m^3 [49]. Several studies have reported that the main sources of SO_2 are from the combustion of coal and petroleum and the byproducts of metal smelting [52, 53]. SO_2 could result in respiratory diseases and acid rain, which could damage ecosystems.

The nitrogen dioxide (NO_2) concentration in the study area was measured in the range of 0.0395±0.03-0.0452±0.02 mg/m^3 (Table 1). NO_2 concentration in urban and residential-administrative areas in the mid-COVID-19 period was significantly lower ($p < 0.05$) than in the pre-COVID-19 pandemic. However, there was no significant difference ($p > 0.05$) in NO_2 at the hospital-school and industrial-craft areas between 2019 and 2020 (Table 2). The NO_2 concentrations over 10-year period in An Giang province were from 0.049-0.097 mg/m^3 [24], and NO_2 in southern Vietnam was 14±2.53–42.38±16.33 µg/m^3 [25]. Similar to SO_2, NO_2 is also related to the use of coal and petroleum [52, 53]. In this current study, the concentration of NO_2 in the air is still within the limit of QCVN 05:2013/BTNMT. The previous study reported that NO_2 is a precursor of anthropogenic ozone and urban smog [54].

3.2. Correlation among Air Quality Parameters

Table 3 shows the correlation between microclimate factors and air pollutants in each monitoring area in Dong Thap province in the period 2019–2020. For urban areas, the results of Pearson correlation analysis showed that temperature has an average negative correlation with humidity (r = -0.375, p<0.01) and noise (r = -0.285, p<0.05), is positively correlated with CO (r = 0.406, p<0.01) and SO_2 (r = 0.465, p<0.01), and is strongly positively correlated with NO_2 (r = 0.525, p<0.01). Wind speed formed an inverse correlation with noise at an average level (p<0.01), and the correlation coefficient r reached -0.463. At the same time, noise level has a moderate negative correlation with NO_2 (r = -0.284, p<0.05). Notably, TSP and gaseous pollutants are positively correlated, ranging from moderate to strong. Specifically, TSP appeared to have a strong positive correlation with CO (r = 0.533, p<0.01) and a moderate correlation with SO_2 and NO_2 with the coefficients r of 0.317 (p<0.05) and 0.482 (p<0.01), respectively. CO has an average positive correlation with SO_2 and NO_2, with r coefficients of 0.380 and 0.392, respectively. The Pearson correlation analysis found a positive correlation between SO_2 and NO_2 with an r coefficient of 0.736 at p<0.01. This analysis found no correlation between the humidity and the air pollutants.

Table 3. Pearson correlation matrix of air quality parameters

Areas	Parameters	Temp.	Humidity	Wind speed	Noise	TSP	CO	SO_2	NO_2
Urban	Temperature	1							
	Humidity	**-0.375****	1						
	Wind speed	0.063	-0.009	1					
	Noise	**-0.285***	0.035	**-0.463****	1				
	TSP	0.192	0.098	-0.006	-0.170	1			
	CO	**0.406****	-0.043	-0.230	-0.024	**0.533****	1		
	SO_2	**0.465****	-0.212	0.202	-0.260	**0.317***	**0.380****	1	
	NO_2	**0.525****	-0.195	0.158	**-0.284***	**0.482****	**0.392****	**0.736****	1
Residential-administrative	Temperature	1							
	Humidity	-0.207	1						
	Wind speed	0.068	0.001	1					
	Noise	0.008	0.096	-0.101	1				
	TSP	0.088	0.236	-0.059	0.258	1			
	CO	**0.743****	0.016	-0.128	0.298	0.225	1		
	SO_2	**0.838****	-0.133	0.178	-0.159	-0.019	0.478	1	
	NO_2	**0.697****	-0.258	-0.114	0.103	0.221	0.346	**0.717****	1
Hospitals-School	Temperature	1							
	Humidity	-0.195	1						
	Wind speed	0.174	-0.111	1					
	Noise	**0.670***	0.188	0.508	1				
	TSP	**0.707***	0.106	0.195	**0.767****	1			
	CO	**0.639***	-0.351	-0.466	0.102	0.413	1		
	SO_2	**0.792****	-0.162	0.415	**0.715****	**0.799****	0.419	1	
	NO_2	**0.888****	-0.303	0.258	**0.695***	**0.720****	**0.582***	**0.910****	1

Industrial-craft areas	Temperature	1							
	Humidity	-0.319	1						
	Wind speed	0.286	0.221	1					
	Noise	-0.058	0.135	-0.306	1				
	TSP	0.258	0.190	**0.437***	**-0.413***	1			
	CO	**0.413***	-0.046	-0.038	-0.363	**0.437***	1		
	SO_2	**0.808****	-0.104	0.361	-0.269	**0.411***	**0.643****	1	
	NO_2	**0.686****	-0.007	0.403	-0.396	**0.759****	**0.701****	**0.816****	1

Notes: **: correlation significant at 0.01; *: correlation significant at 0.05.

In residential-administrative areas, the correlation between air pollutants was found only between temperature and CO, SO_2 and NO_2 at a strong level, with correlation coefficients of 0.743, 0.838, and 0.697, respectively. In particular, there was also a positive correlation between SO_2 and NO_2 ($r = 0.717$, $p<0.01$). For the hospitals-schools area, a positive correlation was found between temperature and noise ($r = 0.670$, $p<0.05$), TSP ($r = 0.707$, $p<0.05$), CO ($r = 0.639$, $p<0.05$), SO_2 ($r = 0.792$, $p<0.01$), and NO_2 ($r = 0.888$, $p<0.01$). Noise strongly correlates with most air pollutants, including TSP, SO_2 and NO_2, with correlation coefficients of 0.767, 0.715, and 0.695, respectively. In particular, a positive correlation between TSP and gaseous pollutants was also found in this analysis (Table 3). Similarly, in the industrial-craft village areas, TSP and gaseous pollutants (i.e., CO, SO_2, and NO_2) were positively correlated (Table 3). For example, SO_2 and NO_2 have a close relationship, with the correlation coefficient reaching 0.816 ($p<0.01$). A positive correlation between gaseous and TSP was reported in the study by Kuerban et al. (2019) [55], which is similar to the current research results. No correlation was found between humidity and air pollutants in all monitoring areas. However, air humidity has been shown to have an inverse correlation with the concentration of air pollutants in several previous studies, as the higher the humidity, the concentration of air pollutants tends to decrease [6, 56]. For the concentration of fine dust particles, CO, SO_2, and NO_2 were negatively correlated with wind speed, dispersion, and dilution, reducing the concentration of pollutants in the specific monitoring area [15]. In addition, a positive correlation was found between temperature and air pollutants during winter observations, while in spring and autumn, a negative correlation was mainly observed [15].

3.3. Key Parameters Influencing Air Quality in The Study Area

The results of principal component analysis (PCA) are presented in Table 4. In the study, only PCs with eigenvalues greater than 1 remained to explain the air quality variation in each monitoring area. In the urban area, principal component analysis based on the average value of eight air quality parameters at 14 monitoring locations formed 4 PCs, explaining 84.30% of the total variance of the quality variation. The PC1, PC2, PC3, and PC4 explained 29.90%, 23.60%, 18.10%, and 12.70% of the total variance in air quality, respectively. PC1 explains most of the change in air quality through the correlation with most air variables, including temperature (0.366), humidity (-0.341), wind speed (0.472), noise (-0.377), TSP (-0.326), and CO (-0.490). PC2 showed weak correlations with microclimate variables, including temperature (0.481), humidity (-0.315), and wind speed (-0.373). PC3 exhibited positive correlations with air pollutants such as TSP (0.584), CO (0.303), and NO_2 (0.662). PC4 showed a weak correlation with humidity (0.483), SO_2 (0.305), NO_2 (-0.311) and a moderate correlation with noise (-0.595), respectively, indicating sources of air quality impacts from both natural and artificial factors. The analysis results showed that, in urban areas, all air quality parameters monitored significantly affect air quality. The source of pollution formation mainly comes from traffic activities. Motor vehicles circulate at intersections, market areas, and border gates, along with natural factors such as temperature, wind, and humidity, which contribute to changes in air quality in this area. Motorized vehicles have been found to emit a variety of pollutants, mainly nitrous oxide, which have a serious daily impact on urban air [57]. In the metropolitan area, the main sources of sulfur oxides and nitrogen are generated from road traffic and emissions from fuel-burning equipment [15]. Several pollutants (CO, NO_x, and particulate matter) emitted by petrol-derivative motor vehicles have important impacts on air quality in urban areas [9, 58, 59].

Table 4. Key parameters influencing air quality in the study area

Variable	Urban				Residential-administrative			Hospital-School		Industrial-craft		
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC1	PC2	PC1	PC2	PC3
Temp.	0.366	0.481	0.202	0.224	0.425	-0.297	0.243	-0.131	0.541	-0.093	**0.555**	-0.113
Humidity	-0.341	-0.315	-0.265	0.483	-0.485	0.156	0.196	0.423	0.203	**-0.329**	**-0.427**	-0.241
Wind speed	0.472	-0.373	0.079	0.221	-0.403	-0.386	-0.056	-0.437	-0.151	**-0.344**	**0.302**	-0.016
Noise	-0.377	0.181	-0.017	-0.595	-0.425	0.04	0.445	0.437	-0.15	-0.255	**0.514**	-0.244
TSP	-0.326	-0.22	0.584	0.274	-0.426	-0.351	0.022	0.408	0.247	**0.443**	0.23	**-0.364**
CO	-0.49	0.192	0.303	0.223	-0.231	0.371	-0.516	0.353	-0.355	**0.416**	0.045	**0.549**
SO_2	0.041	0.604	0.111	0.305	-0.039	0.613	-0.011	0.238	-0.481	-0.215	0.274	**0.64**
NO_2	0.191	-0.219	0.662	-0.311	0.073	0.316	0.659	-0.275	-0.45	**0.533**	0.159	-0.163
Eigenvalues	2.39	1.89	1.45	1.02	3.71	2.64	1.65	4.87	3.13	2.96	2.66	1.56
%Variation	29.9	23.6	18.1	12.7	46.3	33	20.6	60.9	39.1	37	33.3	19.5
Cum.% Variation	29.9	53.5	71.6	84.3	46.3	79.4	100	60.9	100	37	70.3	89.7

In the residential-administrative areas, principal component analysis was performed from the average value of eight air parameters at 4 monitoring stations formed by 3 PCs, explaining 100% of the total variance. The first principal component (PC1) explains more than 46% of the variability of the original air quality dataset, which is correlated with the variables of temperature (0.425), humidity (-0.485), wind speed (-0.403), noise (-0.425), and TSP (-0.426). PC1 was considered the main component of a set of air quality impact factors of natural and anthropogenic origin. Similarly, the second principal component (PC2) correlated with air pollutants, including TSP (-0.351), CO (0.371), SO_2 (0.613), and NO_2 (0.316), and wind speed (-0.386). Meanwhile, the third major component (PC3) has a weak positive correlation with noise (0.445), a moderate level with NO_2 (0.659), and a negative correlation with CO (-0.516). The results of PCA analysis showed that eight observed air quality parameters contribute to changes in air quality in residential-administrative areas. Pollution sources come from emissions from vehicles; the main daily activities of households are cooking using coal and gas. According to Nguyễn et al. (2022) [60], a significant amount of NO_x would be released from households during the use of gasoline, gas, and firewood. In addition, according to the study by Singh et al. (2021) [8], using fossil fuels (diesel and gasoline) and wood burning is also the main cause of polycyclic aromatic hydrocarbons (PAHs), which are carcinogens and mutagenic substances. According to Shihab (2022) [19], using kerosene for heating contributes to changes in SO_2 concentrations in the air in residential areas.

In the hospitals-schools area, PCA results formed 2 main components based on air quality data sets at three monitoring stations from 2019–2020. PC1 and PC2 explained 60.90% and 39.10% of the total variance of air quality variability, respectively. PC1 exhibited a weak positive correlation with humidity (0.423), noise (0.437), TSP (0.408), and CO (0.353), whereas PC1 showed a weak negative correlation with wind speed (-0.437). PC2 explained the change in air quality in the study area through correlation with the remaining air variables as temperature (0.541), CO (-0.355), SO_2 (-0.481), and NO_2 (-0.450). This monitoring area was mainly affected by motor vehicles going in and out of hospitals and schools. The processes of fuel combustion and exhaust gas from motor vehicle engines have contributed to air pollution in the study area. In the industrial-craft village area, three main components formed from the PCA results explain 89.7% of the total variance in air quality. The first principal component (PC1), which explained 37% of the total variance, has a weak negative correlation with humidity (-0.329) and wind speed (-0.344), while a weak positive correlation with TSP (0.443), CO (0.416), and a moderately positive correlation with NO_2 (0.533).

The second principal component (PC2) was mainly correlated with microclimate variables, including temperature (0.555), humidity (-0.427), and wind speed (0.302). In addition, the PCA analysis also found a moderate correlation between PC2 and noise (0.514). The third principal component (PC3) correlated with air pollutants such as TSP (-0.364), CO (0.549), and SO_2 (0.640). Eight monitoring air environment variables contribute to changes in air quality in this area, originating from natural factors (temperature, wind, humidity) and artificial (emissions from traffic activities, industrial production, brick production, animal feed production, and packaging) in the study area. According to previous research by Bhat et al. (2014) [61], the production of bricks could emit significant amount of particulate matters, sulfur dioxide, carbon monoxide, black carbon, and carbon dioxide. For traffic activities, NO_2 concentration would change according to the volume and number of vehicles in traffic. CO results from incomplete fuel combustion in the vehicle engine, and SO_2 is generated by heavy-duty diesel engines, buses, and trucks [19, 62, 63]. NO_2 can be formed through the chemical reactions of nitric oxide and other air pollutants, and NO_2 is an important precursor of ozone [54].

The monitoring variables (i.e., temperature, humidity, wind speed, TSP, CO, SO_2 and NO_2) significantly impacted. The sources of artificial pollution were traffic, industrial production, craft village activities, and daily fuel use in residential areas. Natural factors, including temperature, humidity, and wind speed, were found to contribute to the impact of air quality in the study area.

3.4. Clustering Air Quality in the Study Area

Cluster analysis (CA) was used to group monitoring sites with similar characteristics, thereby suggesting a reduction in the number of monitoring stations [64]. Based on the average value of microclimate environmental parameters (temperature, humidity, wind speed) and air pollutants (noise, TSP, CO, SO_2, and NO_2) at 27 locations in the period of 2019–2020, cluster analysis (CA) has formed eight air quality groups (Figure 3). The characteristics of each identified group are presented in Table 5. Groups I, II, and VII had only one site, namely KK14, KK12, and KK27, respectively. Group I was characterized by high wind speeds and humidity. The noise in this group was the lowest. Group II was at the KK12 National Highway 30 in the Hong Ngu market area, with the highest values of noise (64.85 dBA) and NO_2 (0.048 mg/m^3). The high concentrations of CO and SO_2 characterized Group VII. These groups include the separate sites that should be retained for future air quality sampling.

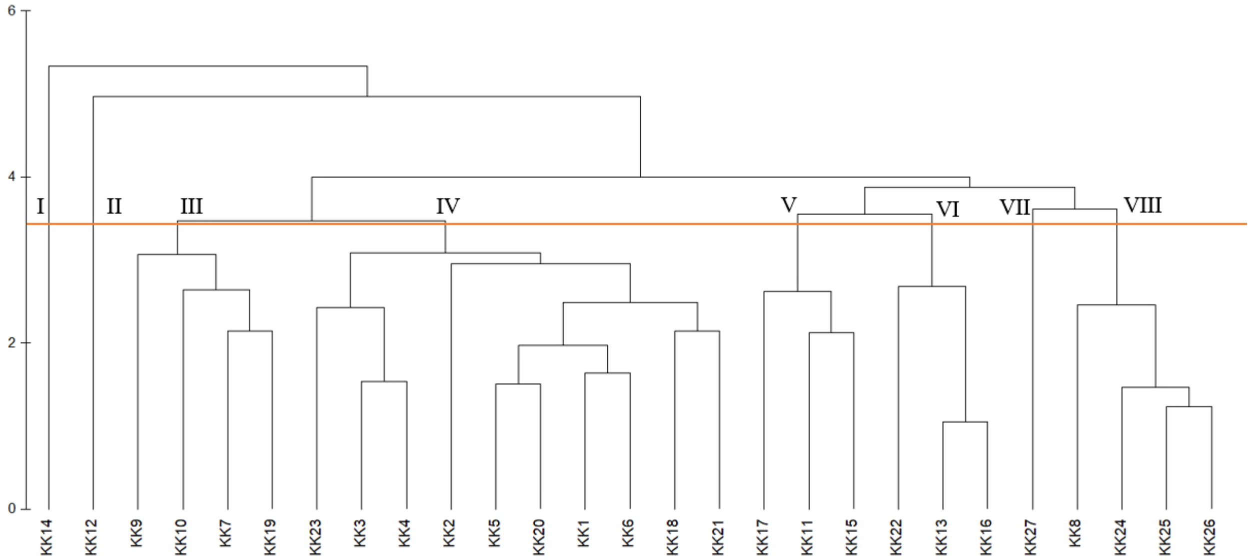

Figure 3. Clustering air quality in Dong Thap province

Table 5. Mean values of air quality parameters in the identified clusters

Parameters	Unit	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
Temperature	ºC	32.78	31.75	32.21	32.53	32.26	32.08	32.08	32.38
Humidity	%	76.20	75.90	76.32	74.53	73.99	76.01	74.75	74.86
Wind speed	m/s	1.60	1.50	0.85	1.12	1.02	1.13	1.18	1.14
Noise	mg/m^3	56.58	64.85	64.66	63.76	58.22	59.93	57.13	60.44
TSP	mg/m^3	0.208	0.223	0.224	0.198	0.178	0.183	0.195	0.256
CO	mg/m^3	3.020	2.990	3.568	3.352	3.349	3.354	4.173	3.797
SO_2	mg/m^3	0.047	0.036	0.043	0.045	0.040	0.042	0.049	0.044
NO_2	mg/m^3	0.042	0.048	0.040	0.043	0.047	0.036	0.038	0.043

The groups III, IV, V, VI, and VIII were gathered from 3 to 10 locations (Figure 3). Group III comprised four locations, including KK7-Tram Chim town, KK9-Lap Vo market area, KK10-Thanh Binh market area, and KK19-Dong Thap General Hospital area. This group comprised two impact areas: urban (KK7, KK9, and KK10) and hospital (KK19). Group III had a higher CO concentration compared to groups I and II, but the other air parameters in Group III were generally lower than those in Groups I and II. As can be seen, the air quality in the market areas is similar; thus, two sites from the market (KK7 and KK9) could be considered to be removed from the current monitoring program. Group IV comprised 10 locations, including KK1-in front of Cao Lanh market, KK2-Sa Dec market area, KK3-Nguyen Trai - Nguyen Minh Tri intersection, My Tho town, KK4-Thap Muoi market area, KK5-The junction of Thet street, My An town, KK6-in front of Tan Hong market, KK18-in front of Lai Vung District People's Committee, KK20-gateway of Dong Thap University, KK21-Sick area Sa Dec General Hospital, and KK23-Vam Cong industrial cluster. Group IV included the locations affected by various socioeconomic activities (urban, residential-administrative areas, hospitals-schools and industry-craft villages). KK2, KK4, KK6, and KK21 could be considered for reduction from the current monitoring program.

This could be explained by the fact that the air quality in the study area is still within the limits of the regulation, and the sites being recommended for reduction are in the same groups and close together. Group V comprised three locations at KK11 (urban), KK15, and KK17 (residential-administrative). KK15 or KK17 could be considered for reduction since they are in the same group and the air quality at these sites is still good. Group VI included three sites: K13 (urban), KK16 (residential-administrative), and KK22 (industrial-craft). Group VIII comprised K8 (urban), K24, K25, and K26 (industrial-craft). There is no recommendation for reducing sampling sites in Group VI; however, one of the three sites could be reduced for Group VIII. CA results suggested the potential for reducing eight air sampling locations for cost-effectiveness.

4. Conclusion

The air quality in Dong Thap province was evaluated in this study. It was found that all air quality parameters were within the limits of QCVN 26:2010/BTNMT and QCVN 05:2013/BTNMT. The variation of temperature, humidity, wind speed, CO, SO_2, and NO_2 between the subject areas was not significantly different, but the noise and TSP were different. Noise (hospital-school), TSP (residential-administrative; hospital-school), SO_2 (urban), and NO_2 (urban; residential-administrative) in mid-Covid-19 were significantly lower than those in the pre-COVID-19 pandemic. This could be due to the social distancing policy in COVID-19 combat. The Pearson correlation showed a close correlation among air quality parameters except air humidity. PCA results indicated that there were two to four potential sources of air pollution in urban, residential-administrative, hospital-school, and industry-craft village areas. The PCs could explain 84.3%, 100%, 100% and 89.7% of the total variance in air quality in the respective areas. All the air parameters in the current study have a significant influence on air quality. Sources of air quality variation could be from traffic activities, industrial production, craft village activities, and daily life using fuels in residential areas. Natural factors, including temperature, humidity, and wind speed, contributed to the impact of air quality in the study area. CA separated the air quality in the study area into eight groups, each containing three to 10 locations. Humidity, wind speed noise, TSP, and CO are the parameters that classify the clusters. Eight sampling sites (KK2, KK4, KK6, KK7, KK9, KK17, KK21, and KK25) were recommended for removal from the current monitoring program for representativeness and cost-effectiveness purposes. The results of the current study provide useful information for air quality monitoring and management.

5. Declarations

5.1. Author Contributions

Conceptualization, N.T.G. and P.Q.N.; methodology, N.T.G. and P.Q.N.; software, N.T.G.; validation, P.Q.N.; formal analysis, N.T.G. and P.Q.N.; investigation, N.T.G.; resources, N.T.G. and P.Q.N.; data curation, N.T.G. and P.Q.N.; writing—original draft preparation, N.T.G. and P.Q.N.; writing—review and editing, N.T.G. and P.Q.N.; visualization, N.T.G. and P.Q.N.; supervision, N.T.G. and P.Q.N.; project administration, N.T.G. and P.Q.N.; funding acquisition, N.T.G. and P.Q.N. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

The authors would like to thank the Department of Environment and Natural Resources (Dong Thap province) for providing data. All the discussion in the article is only the view of the authors not the views of the data provider. The authors also would like to thank the colleagues for their encouragement and assistance during preparation of this manuscript.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

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