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Evaluation of Spatial and Temporal Air Quality Variation in Southern Vietnam Using Multivariate Statistical Approaches

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***Abstract*—The study aims to assess the air quality and identify polluting sources in the southern Vietnam using eight air variables of temperature, humidity, wind speed, pressure, noise, total suspended particulates (TSP), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) at 30 stations in eight monitoring periods (April–December) in 2020. Correlation and principal components and cluster analyses were applied in the study. Air quality in traffic and urban areas were identified with the highest pollutant concentrations. Concentrations of air pollutants were dependent on sources of impact but not the seasons. Noise was positively correlated with vehicle density and exceeded the permissible limit of QCVN 26:2010/BTNMT. TSP was found high in urban areas. Air contaminants were positively mutual correlation, while it was negatively correlated with meteorological factors. PCA (Principal Component Analysis) could explain respectively 81.2% and 83.4% of the total variance of spatial and temporal variation of air quality. The main sources of air pollutant could be from transportation, residential areas, industrial production and solid waste treatment plants. Cluster Analysis (CA) has formed five clusters of monitoring stations with similar air quality from 30 original stations. At the same time, the initial 8 observation periods were also grouped into four clusters. Thereby, the monitoring program in this study area could be reduced to four times/year with 25 monitoring locations.**

***Index Terms*—Air quality, southern region, pollution sources, multivariate analysis, Vietnam**

I. INTRODUCTION

Air is a valuable natural resource that helps maintain the existence of humans, animals, plants, as well as regulate ecosystems [1]. However, with the continuous economic development and the increasing population size, some environmental problems, especially air pollution, have become serious [2, 3]. According to Hanh and Manh *et al.* [4], air pollution is one of the global environmental problems, not only an environmental issue but also a human rights issue. According to the World Health Organization, 92% of the world's population lives in a toxic environment, and air pollution is the cause of death for 7 million people every year [5]. In less developed countries, 98% of children under the age of 5 breathe toxic air, which is the cause of death for 600,000 children under the age of 15 each year [5]. Short-term and long-term exposure to airborne toxins have various effects on humans including respiratory and cardiovascular diseases, neurological complications, eye irritation, skin diseases and long-term chronic diseases such as cancer [6, 7].

Air quality is polluted when pollutants exceed recommended limits and adversely affect humans and the environment [7]. Typical air pollutants are ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), total suspended particulates (TSP), particulate matter (PM_{10} and $PM_{2.5}$) [8–10]. Air quality in Vietnam is often assessed through the Air Quality Index (AQI) [11, 12], which evaluates each monitoring indicator [5]. In recent years, multivariate statistical techniques such as correlation analysis, Principal Component Analysis (PCA) and Cluster Analysis (CA) have been widely applied in the assessment of environmental quality from soils and sediments, surface water, ground water and air [9, 13–15]. In the study on air quality in Jahra [16], the sources of air pollution including traffic activities, power plants, saltwater refineries and meteorological factors have been predicted using PCA. PCA also identified SO_2, CH_4, NO, PM_{10}, CO_2 and temperature were significant contributions to air pollution in summer. Meanwhile, air pollution in winter was contributed by SO_2, CH_4, NO, NO_2, CO, O_3 and PM_{10}.According to Jassim and Coskuner [8], applied multivariate statistical analysis to assess air quality in Bahrain, cluster analysis classified 17 monitoring stations into three quality clusters based on similarities in air pollutant characteristics and meteorological parameters. For principal component analysis, dust storms, industrial activities, vehicular emissions, airport activities, and power plants are the major contributors to air pollution [8].

The Southern region, Vietnam consists of two key economic regions, the first is the Southern key economic region, which plays a particularly important role in the country's socio-economic development, is a trading hub, connecting domestically and internationally through a system of seaports, airports, economic locomotives, industrial centers, etc. with the core being the special urban center of Ho Chi Minh City [17]. For the key economic region of the Mekong River Delta, this economic region will be a major center for rice production, farming, fishing and seafood processing, making a great contribution to the export of agricultural and aquatic products of the whole country. In addition, this economic zone also plays an important role in biotechnology transfer, seed supply, technical services, processing and export of agricultural products for the whole Mekong Delta region. In which, the island city of Phu Quoc (Kien Giang), Long Xuyen city (An Giang) and Can Tho city play an important role in the economic development of the region. In the face of the socio-economic development situation of the region, environmental issues, in which the air environment problem are increasingly seriously affected. Typically, Ho Chi Minh City is an urban area with many industrial activities and high traffic volume, the total emission of CO_2, CH_4, NO_x, PM_{10} and $PM_{2.5}$ from traffic

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activities during the day is very large, in turn fluctuated in the range of 383.38–828.19 tons/day; 0.18–1.44 tons/day; 0.01–0.06 tons/day; 0.25–118.55 tons/day and 0.19–1.39 tons/day; for industrial operations, the calculated dust, NO_x, SO_2 and CO loads are 18–125.6 mg/m^3, 3.8–173 mg/m^3, 1–492 mg/m^3 and 3.4–990 mg/m^3, respectively [18]. In the area of Can Tho city, Ninh Kieu is the central district and leads in economic development of the whole city, in terms of traffic, fuel use activities and emissions from electricity consumption, etc. As direct and indirect emission sources, in 2019 the district is estimated to emit a large amount of greenhouse gas with about 1,069,422 tons of CO_2 equivalent [19]. Besides, according to Giao [20], noise and suspended dust content (TSP) in Can Tho city in 2020 were relatively high, ranging from 64.80-82.90 dBA and 93.30–293.20 µg/m^3 respectively. Noise has tended to exceed the allowable limit QCVN 26:2010/BTNMT and at some monitoring locations, the concentration of TSP appears to be approximately the limit of QCVN 05: 2013/BTNMT [20].

This study was conducted with the aims 1) preliminary assessment of air quality in the study area; 2) identify the main factors and sources of pollution affecting the change of air quality in the study area; and 3) recommend the solutions improving the air quality in the study area.

II. MATERIALS AND METHODS

A. Description of the Study Area

The southern region of Vietnam includes 21 provinces/cities, divided into two main regions including the Southeast region with the provinces of Ninh Thuan, Binh Thuan, Binh Phuoc, Tay Ninh, Binh Duong, Dong Nai, Ba Ria-Vung Tau and Ho Chi Minh City; and the Mekong Delta with the provinces of Long An, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Dong Thap, An Giang, Kien Giang, Hau Giang, Soc Trang, Bac Lieu, Ca Mau and Can Tho city. The region includes two major key economic regions of the country, namely the Southern key economic region and the Mekong Delta key economic region. This place is considered as a dynamically developing economic region with high economic growth rate, with the largest industrial, business and service development activities in the country, where many industrial parks are concentrated industrial clusters and many industrial and handicraft production establishments of different sizes and industries are widely dispersed in many localities. The important industries of the southern key economic region are mainly petroleum, leather, textiles, chemicals, fertilizers and steel rolling, while the key economic region of the Mekong River Delta is the center of rice production, farming, fishing and aquatic product processing. With the increasing speed of industrialization and modernization, environmental problems have been brought along, in which the region's air environment has been strongly affected by industrial, urban and industrial and transportation.

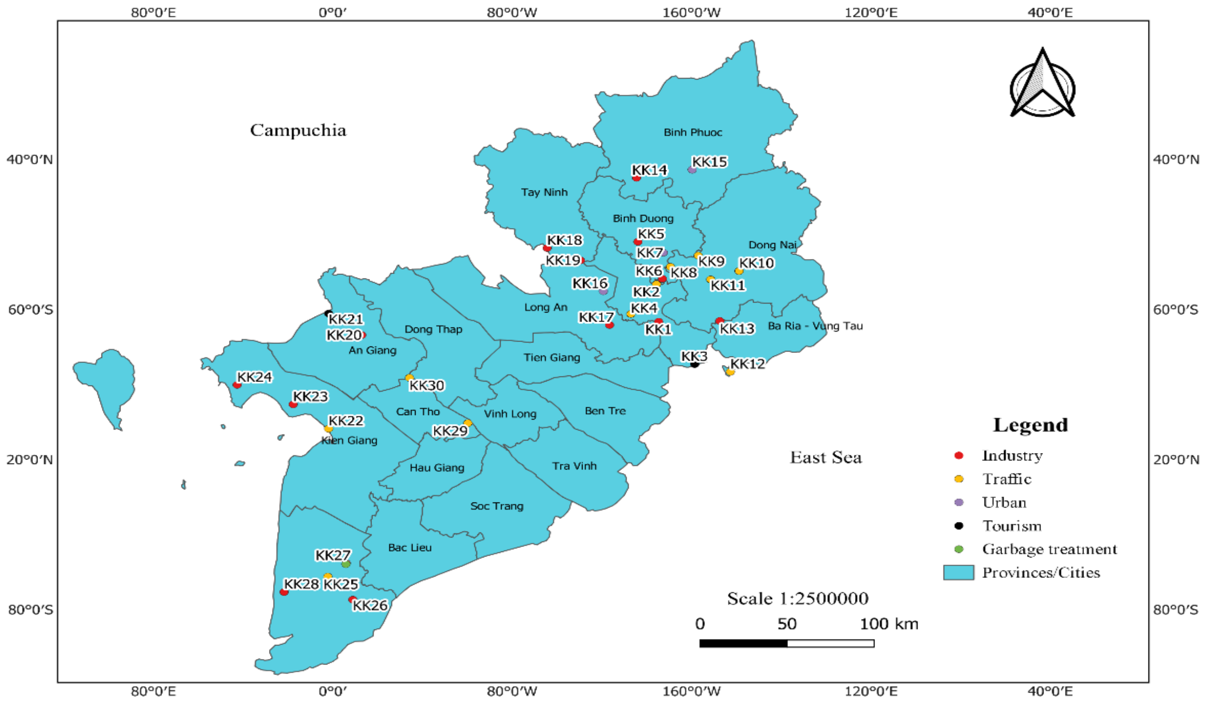

Fig. 1. Map of air sampling locations in southern Vietnam.

B. Description of Sampling Stations and Sampling Times

To assess the air quality in the South, 30 monitoring stations (KK1–KK30) have been established in 11 provinces/cities including Ho Chi Minh, Binh Duong, Dong Nai, Ba Ria-Vung Tau, Binh Phuoc, Long An, Tay Ninh, An Giang, Kien Giang, Ca Mau and Can Tho, affected by industrial activities, traffic, urban areas, garbage treatment plant and tourist areas. Specifically, locations KK1, KK5, KK6, KK13, KK14, KK17, KK18, KK19, KK20, KK23, KK24, KK26 and KK28 are influenced by industrial activity. Air quality affected by traffic activities including KK2, KK4, KK8, KK9, KK10, KK11, KK12, KK22, KK25, KK29 and KK30. Air quality is influenced by urban areas, including locations KK7, KK15 and KK16. At location KK27, representing air quality affected by garbage treatment activities. Two positions KK3 and KK21, the area affected by tourism activities. Details of locations of air monitoring stations in the southern region of Vietnam are shown in detail in Fig. 1 and Table I.

TABLE I: LOCATIONS OF AIR SAMPLING STATIONS

No.	Sample symbol	Location
1	KK1	Hiep Phuoc Industrial Park
2	KK2	Binh Phuoc intersection
3	KK3	Management Board of Can Gio Biosphere Reserve
4	KK4	Nguyen Van Linh-National Highway 1A intersection
5	KK5	My Phuoc Industrial Park - Vanh Dai
6	KK6	Song Than II Industrial Park
7	KK7	Tan Phuoc Khanh Town
8	KK8	Chau Thoi intersection
9	KK9	Provincial square
10	KK10	Dau Tay crossroads
11	KK11	Vung Tau crossroads
12	KK12	Round of martyrs
13	KK13	My Xuan A Industrial Park
14	KK14	Minh Hung Industrial Park
15	KK15	Dong Xoai Town
16	KK16	Duc Hoa Town
17	KK17	Thuan Dao Industrial Park
18	KK18	Moc Bai Border Gate Economic Zone
19	KK19	Trang Bang Industrial Park
20	KK20	Binh Long - Binh Chanh Industrial Park
21	KK21	Nui Sam tourist area
22	KK22	Junctions to Ha Tien-Tran Phu-Mac Cuu
23	KK23	Hon Soc Quarry
24	KK24	Xi VICEM Ha Tien
25	KK25	Nguyen Trai-Ngo Quyen crossroads
26	KK26	Hoa Trung Industrial Park
27	KK27	Ca Mau Garbage Treatment Plant
28	KK28	Song Doc Industrial Park
29	KK29	Revolution crossroads August – Hung Vuong
30	KK30	Lo Te junction

Air quality in the southern region is assessed based on four microclimate parameters (temperature, humidity, wind speed and pressure) and four air pollution components (noise, TSP, SO_2 and NO_2). Sampling time is carried out eight times/year, corresponding to the dry season (April, November, December) and the rainy season (May, June, July, August, September) 2020. At each monitoring period, every air quality parameter was collected three times/location. Thus, a total of 720 samples were used to evaluate for a parameter in this monitoring program. The microclimate parameters including temperature, humidity, wind speed and air pressure were measured in the field by Kestrel 5500 meter according to QCVN 46:2012/BTNMT. Noise is also measured in the field by ACO 6226 equipment according to TCVN 7878-1:2008 and TCVN 7878-2:2010. For air pollutants TSP, SO_2 and NO_2 were collected by SIBATA MP-∑500NII instrument with collection time of 60 min/sample and analyzed in the laboratory according to TCVN 5971:1995, TCVN 6137:2009 and TCVN 5067:1995, respectively. In addition, the study also conducted counting of vehicle traffic in the study area. Details of instruments used can be found in Table II.

TABLE II: LIST OF EQUIPMENT USED TO MEASURE AIR QUALITY

Component	Parameter	Measurement method	Measuring range
Kestrel 5500	Temperature, Humidity, Wind speed and Air pressure	QCVN 46:2012/BTNMT	-
ACO 6226	Noise	TCVN 7878-1:2008 TCVN 7878-2:2010	30–140 dBA
Sibata MP-∑500NII	TSP, SO_2 and NO_2	TCVN 5971:1995 TCVN 6137:2009 TCVN 5067:1995	5 μg/m^3 (TSP) 10 μg/m^3 (SO_2) 7 μg/m^3 (NO_2)

C. Data Analysis

Southern air quality data including temperature, humidity, wind speed, pressure, noise, TSP, SO_2 and NO_2 are aggregated and analyzed for fluctuations according to each type of impact such as industry, traffic, urban areas, tourist areas and garbage treatment plant, while the analyzed monitoring time fluctuates according to the dry season and the rainy season. At the same time, the statistical difference between the types of impacts, the monitoring time (dry season and rainy season) was tested by Independent Samples Tests. Descriptive statistics were performed using SPSS software version 20.0. Air quality in the South is compared with QCVN 26:2010/BTNMT National Technical Regulation on Noise [21] and QCVN 05:2013/BTNMT National Technical Regulation on Ambient Air Quality [22] as showed in Table III.

TABLE III: ALLOWABLE LIMITS FOR AIR QUALITY PARAMETERS

No.	Parameters	Unit	Limit values
1	Noise	dBA	70
2	TSP	μg/m^3	300
3	SO_2	μg/m^3	350
4	NO_2	μg/m^3	200

Pearson correlation analysis is a very useful statistical tool to determine the relationship between environmental parameters and the source of pollutant formation [23, 24], which has been applied in a number of studies on air pollution in Beijing [25] and Madrid area [9] and evaluated the relationship between PM_{10} dust with air pollutants and meteorological factors in two cities of Athens (Greece) and Birmingham (UK) in Europe [26]. In this study, Pearson correlation was performed based on data of four microclimate factors namely temperature, humidity, wind speed and pressure with four air pollution parameters namely noise, TSP, SO_2 and NO_2 at 30 monitoring stations, in order to determine the linear correlations formed between the observed parameters and the correlation coefficient (r) was used to measure those correlations. Pearson correlation analysis was performed using SPSS software version 20.0. In addition, the correlation between noise and traffic volume is also examined in the study through the coefficient of determination R^2. According to Thư and Qui [27], R^2 value fluctuates in the range of 0-1, the closer the value to 1, the stronger the correlation, and the value close to or greater than 0.5 is acceptable.

Principal Component Analysis (PCA) is a multivariate statistical analysis technique that has been widely applied in many studies, with the ultimate aim of helping to reduce the original data, extract the important data, the source of the data. The source has the most influence on the change in the quality of the observed environment [9, 28]. According to some studies by Jassim and Coskuner *et al.* [8] and Ramson and Nwachukwu *et al.* [29], PCA analysis is widely used to identify the main factors affecting the air quality and the components (PCs) with eigenvalues greater than 1 are the set of environmental parameters contribute significantly, indicating typical pollution sources. In this study, PCA analysis was carried out to determine the environmental parameters, the main source of pollution affecting the air quality in the South, both in terms of space and time of observation. At the same time, it can be utilized for the evaluation of the parameters selected in the current monitoring program are appropriate or need to be adjusted in the future. PCA analysis was performed using Primer 5.2 software.

The air quality monitoring network in the southern region of Vietnam is established with 30 stations and eight monitoring periods. For the purpose of identifying monitoring objects with similar air quality based on 8 air quality parameters, at the same time narrowing the scope and frequency of monitoring but still ensuring representativeness, Cluster Analysis (CA) was applied in this study. CA analysis is a classification method used to divide a large data set into a number of distinct groups [2]. The results of cluster analysis are usually presented in the form of a dendrogram plot, which shows an overview of the clustering of monitoring stations and the monitoring time of the air [2, 9, 20]. Similar to principal component analysis, cluster analysis was also performed using Primer 5.2 software.

III. RESULTS AND DISCUSSION

A. Spatial and Temporal Variation of Air Quality

1) Temperature, humidity, wind speed and pressure

The southern air temperature in 2020 fluctuates relatively stable among different types of impacts, ranging from 31.49±2.51–32.34±2.32 °C. The results of the statistical analysis showed that the spatial variation in temperature among the five different types of impacts was not statistically significant ($p > 0.05$) (Table IV). For the seasonal variation in air temperature, the dry season and the rainy season were recorded at 31.84±2.75 °C and 32.22±2.66 °C, respectively, the difference was not statistically significant between the two seasons ($p > 0.05$) (Table V). Compared with some previous studies in the provinces/cities in the southern region of Vietnam, the air temperature recorded in the current study (2020) is still within the defined range. As in Long Xuyen city, An Giang province, the air temperature fluctuates between industrial, urban and traffic areas in the period 2016–2019 from 29–35.6 °C [30]. The air temperature in Can Tho city is reported to fluctuate in the range of 30.13±2.12-31.70±2.48°C when it fluctuates by spatial and from 30.17±2.03-31.60±2.45 °C when it fluctuates by temporal [20]. In Ho Chi Minh City in the period 2015-2016, the recorded air temperature in the rainy season is 31.2±1.18°C and in the dry season is 33.4±2.05 °C [31]. According to Czarnecka and Nidzgorska-Lencewicz [32], air quality is mainly dependent on temperature, which is most often explained by the variation of summer ozone and airborne particulate matters as SO_2 in winter [32]. In addition, according to Basu [33], high temperature is associated with increased risk for cardiovascular, respiratory, cerebrovascular and certain cardiovascular diseases such as ischemic heart disease, heart failure and myocardial infarction [33].

The air humidity in the south of Vietnam in 2020 among industrial, traffic, urban, garbage treatment plant and tourism areas range from 66.02±9.24–72.22±11.69% and the air humidity between different types of effects is not statistically significant ($p > 0.05$) (Table IV). However, when fluctuated by monitoring time, the difference in humidity was statistically significant between the dry season and the rainy season ($p < 0.05$) (Table V). Specifically, the relative humidity of the air in the dry season (64.02±10.40%) is lower than that of the rainy season (69.01±9.28%). It was also noted that humidity has a higher value in the rainy season (71.18±8.01%) [20]. Compared with the study in Nigeria, the air humidity fluctuates according to the observed space between markets, bus stations, schools, hospitals, residential areas, commercial centers tend to be higher, ranging of 65.6±4.8-84.6±7.0% [29]. According to Belan and Savkin [34], air humidity has a negative effect on ozone formation in the near-surface air layer. In addition, when the relative humidity of the air is moderate (70–80%), high humidity (80–90%) and extremely humid conditions (90–100%) play a significant role in reducing the concentration of particulate matter in air pollution [35]. In addition, according to Gao and Sun *et al.* [36], air humidity has an indirect effect on the incidence of allergic, respiratory and digestive diseases in children and humidity also plays a large role in the transmission of viral diseases such as flu.

The recorded wind speed in the southern part of Vietnam is not statistically significant when it fluctuates in both space and time of observation (Tables IV & V). Variations in observation space between impact areas, wind speed fluctuates in the range of 0.57±0.13-0.78±0.44 m/s, while wind speed fluctuates over time (dry season and rainy season) from 0.70±0.37-0.76±0.48 m/s. Research results are quite consistent with the study of Ramson and Nwachukwu *et al.* [29], wind speed recorded in the Nigerian ranging from 0.4 to 0.7 m/s [29]. However, the wind speed in southern Vietnam is relatively lower than in Balikesir (in Turkey), where wind speed is from 1.96 m/s [37]. According to Radzka [38], an increase in wind speed would contribute significantly to the reduction of air pollutant concentrations, which is significantly correlated with PM_{10} and $PM_{2.5}$ dust [38]. In addition, according to Czarnecka and Nidzgorska-Lencewicz [32], when the wind speed is less than 1.5 m/s, it is estimated to significantly reduce the dispersion of air pollutants [32]. For air pressure, the study results recorded that the air pressure ranged from 1006.42±4.23–1010.23±1.84 mbar and the difference was statistically significant between the impact areas ($p < 0.05$). Specifically, in the tourist area was recorded the highest air pressure which was statistically different from the urban, garbage treatment areas and the industry and traffic areas (Table IV). Similarly, between the observation time of the dry season and the rainy season, the air pressure is also significantly different ($p < 0.05$), the air pressure ranges from 1007.78±4.21 mbar (rainy season) to 1009.81± 4.09 mbar (dry season) (Table V). According to Ilten and Selici [37], elevated concentrations of air pollutants such as TSP and SO_2 are strongly associated with high atmospheric pressure.

TABLE IV: SUMMARY OF AIR QUALITY IN THE STUDY AREA

Parameters	Unit	Industry	Traffic	Urban	Garbage Treatment	Tourism
Temp.	°C	32.34±2.32a	31.93±2.43a	31.96±2.93a	31.49±3.57a	31.49±2.51a
Humidity	%	66.36±9.35a	67.57±9.43a	66.02±9.24a	72.22±11.69a	69.96±8.53a
Wind Speed	m/s	0.78±0.44a	0.76±0.37a	0.62±0.25a	0.66±0.50a	0.57±0.31a
Pressure	mbar	1008.61±3.45c	1008.68±5.34c	1006.42±4.23b	1009.06±1.99b	1010.23±1.84 a
Noise	dBA	70.70±4.53b	73.42±3.61a	74.64±2.48a	69.10±2.24c	61.83±7.37d
TSP	µg/m^3	231.19±212.74b	268.70±212.33b	325.21±164.39a	130.50±93.40bc	59.25±37.84d
SO_2	µg/m^3	28.92±14.50b	35.68±19.26a	38.58±17.54a	26.13±13.90a	15.88±5.98c
NO_2	µg/m^3	30.22±16.61b	41.27±23.35a	42.38±16.33a	22.00±11.51c	14.00±2.53d

Notes: Letters a, b, c, d indicated significant differences at a significance level of 5%; in contrast, the same letters have no statistically significant difference.

TABLE V: SEASONAL VARIATION IN AIR QUALITY IN SOUTHERN VIETNAM

Parameters	Unit	Dry season	Rainy season
Temp.	°C	31.84±2.75a	32.22±2.66a
Humidity	%	64.02±10.40b	69.01±9.28a
Wind Speed	m/s	0.70±0.37a	0.76±0.48a
Pressure	mbar	1009.81±4.09a	1007.78±4.21b
Noise	dBA	71.34±4.78a	71.51±5.41a
TSP	µg/m^3	234.93±198.79 a	242.28±218.40 a
SO_2	µg/m^3	35.36±20.87a	29.06±14.56b
NO_2	µg/m^3	35.29±20.57a	34.01±21.83a

Notes: Letters a, b indicated significant differences at a significance level of 5%; in contrast, the same letters have no statistically significant difference.

2) *Noise, TSP, SO_2 and NO_2*

The noise in industrial, traffic, residential areas, garbage treatment plant and tourist areas ranged from 61.83±7.37–74.64±2.48 dBA, the difference is statistically significant between monitoring areas ($p < 0.05$) (Table IV). The noise recorded in the tourist area is the lowest, while in the urban and traffic areas are highly concentrated. From the results of analysis of fluctuations by observation space, it is found that the noise in three areas of industry, traffic and urban areas has exceeded the allowable limit of QCVN 26:2010/BTNMT (noise 70 dBA) from 1.01–1.07 times. In addition, the results also recorded in the above areas, the number of motorized vehicles in circulation fluctuated from 1,975 to 5,176 vehicles on average, especially motorbikes had the largest number of vehicles. Noise fluctuates over time, ranging from 71.34±4.78 dBA (dry season) to 71.51±5.41 dBA (rainy season), with this value the noise in the study area has exceeded the permissible limit of QCVN 26:2010/BTNMT and in general the temporal variability of noise is not statistically significant difference between periods ($p > 0.05$) (Table V). Noise pollution in densely populated, urban and traffic-heavy areas has been reported in a few studies such as in district 14 - one of the busiest areas of Tehran ranging from 70.05±7.3 dBA (weekend) to 72.62±6.3 dBA (weekday) [39]; in the urban residential area of Desa Tun Razak in the Klang valley, the highest recorded noise was 75.5 dBA during the day and 73.4 dBA at night [40] and in the city of Nagpur — one of the developing cities of India, the noise was recorded from 81.2±4.8–92.2±7.9 dBA [41]. According to the World Health Organization (WHO), noise levels during the day and night should be below 55 dBA and 45 dBA respectively [40]. In addition, according to an investigation by Farooqi and Sabir *et al.* [42], noise causes symptoms such as headache, insomnia, increased blood pressure, physiological stress and dizziness, significantly affecting human health.

Characterization of particulate pollutants suspended in ambient air is usually limited to estimating total suspended particulate matter (TSP) content. According to Table IV, the concentration of TSP in the air fluctuates according to the observation space in industrial, traffic, urban areas, garbage treatment areas and tourist areas ranged from 59.25±37.84 325.21±164.39 µg/m^3, highest concentration in urban areas and statistically significant difference with the remaining monitoring areas ($p<0.05$). This is also the only area where the concentration of TSP in the air exceeds the allowable limit of QCVN 05:2013/BTNMT (TSP 300 µg/m^3). However, when fluctuating over time of monitoring, the concentration of TSP fluctuated in the range of 234.93±198.79–242.28±218.40 µg/m^3 and the difference was not statistically significant between the dry season and the rainy season (Table V). With this result, the concentration of TSP that fluctuates over time is still within the limit of QCVN 05:2013/BTNMT (TSP 300 µg/m^3). When compared with the study of Essiett and Bede [43], the TSP concentration recorded in the Ikot Abasi area (Nigeria) was higher, ranging from 115.74–254.63 µg/m^3, and tended to be highest in traffic area and commercial center [43]. However, in another area of Nigeria, the TSP concentration tends to be lower, ranging from 15.8±6.8-108.5±46.8 µg/m^3 and the TSP concentration is also highest in the commercial center [29]. According to research by Trang and Tuan [5], the TSP concentration was highest at the intersection with total suspended dust of 521 µg/m^3 in 2016, but in 2018 TSP concentration tends to be high in residential areas reached 398.25 µg/m^3 [5]. In addition, the concentration of TSP in the air is reported to be moderately correlated with the dust content of PM_{10} and $PM_{2.5}$ [44]. According to Gobo and Ideriah [45], most of the effects of TSP on human health are the result of inhalation, exacerbation of respiratory (bronchial) disease, cardiovascular disease, and premature death [45].

Sulfur dioxide (SO_2) is a colorless, highly reactive gas that is considered an important air pollutant, mainly emitted from fossil fuel consumption, volcanic activities and other pollutants in industrial processes [6]. Research results show that the concentration of SO_2 in the air fluctuates spatially among industrial, transport, urban, garbage treatment and tourism areas, ranging from 15.88±5.98–38.58±17.54 µg/m^3, highest concentration in urban areas and lowest in tourist areas. At the same time, the statistical analysis showed that the SO_2 concentration in three traffic areas, urban areas and garbage treatment areas were significantly different from the industrial and tourist areas (Table IV). Besides, SO_2 concentration fluctuates over time, ranging from 29.06±14.56 µg/m^3 (rainy season) to 35.36±20.87 µg/m^3 (dry season), the difference is statistically significant (Table V). In the rainy season, the SO_2 content is relatively low, possibly due to the heavy rainfall that contributes to the dilution of the pollutant content, this result is similar to the study of Hoque and Ashraf *et al.* [46], in the rainy season, the SO_2 concentration was only recorded at 10.26 ppb, while in the dry season the SO_2 concentration was up to 23.45 ppb, however, the SO_2 concentration recorded in the air of Dhaka city was higher than that of the current study area [46]. Compared with some studies conducted in the northern region of Vietnam such as Ha Long city, Quang Ninh province, affected by similar activities from tourism, population, and traffic areas, the SO_2 concentration recorded only ranging from 16-30 µg/m^3 [5], lower than the current study area. In Lao Cai city, the SO_2 content ranges from 0.009–0.097 mg/m^3 [12], with this result the SO_2 content fluctuates considerably compared to the Southern region. According to Ghorani-Azam and Riahi-Zanjani *et al.* [6] and Zhang and Chen *et al.* [47], SO_2 not only causes harms to human health such as irritation, respiratory dysfunction, exacerbation of cardiovascular disease, eye damage, bronchospasm, but also causes into acid rain, acidifying the soil, affecting soil, forest and freshwater ecosystems. In general, the SO_2 content in the air in the Southern Vietnam study area is still within the allowable limit of QCVN 05:2013/BTNMT (SO_2, 350 µg/m^3).

Nitrogen dioxide (NO_2) is an important ambient air pollutant that can increase the risk of respiratory infections, mainly emitted by motorcycle engines, is a traffic-related air pollutant [6]. According to Zhang and Chen *et al.* [47], NO_2 is an important precursor of anthropogenic ozone and urban smog, and an important factor in the formation of nitric acid, fine particulate matter, and polycyclic aromatic nitro-hydrocarbons. The concentration of NO_2 determined in the study area ranged from 14±2.53–42.38±16.33 µg/m^3 among the types of impacts (Table IV), continuing to be the lowest in the tourist area and the highest in the urban area. Through statistical analysis, the NO_2 concentration in two areas (traffic and urban) was significantly different from the remaining areas of industry, tourism and garbage treatment plant. According to Table V, the NO_2 concentration was not statistically significant between the dry season and the rainy season, ranging from 34.01±21.83–35.29±20.57 µg/m^3. According to Ghorani-Azam and Riahi-Zanjani *et al.* [6], NO_2 is a pollutant related to traffic activities where the number of motor vehicles is very high. In the traffic area, an average of 5,176 vehicle turns was recorded, of which motorbikes accounted for 66.83%, cars accounted for 14.51%, trucks accounted for 12.19% and heavy vehicles accounted for 6.47% of the total. The urban area recorded an average of 3,933 vehicle turns (motorcycles, cars, trucks and heavy vehicles accounted for 70.81%, 13.27%, 12.15% and 3.76% of the total, respectively). Compared with the provinces in the North such as Quang Ninh, Lao Cai, the concentration of NO_2 identified in the Southern study area tends to be higher [5], [12]. However, in the study area Oyigbo and Etche (Nigeria), where there is heavy traffic, industry and population activities, the concentration of NO_2 in the air was recorded 0.026±0.01–0.162±0.049 ppm which was higher that of the the southern region of Vietnam [29]. Similarly, in Dhaka City, NO_2 concentrations were recorded higher than in the present study area, ranging from 12.6–81.5 ppb [46]. In the study of Núñez-Alonso and Pérez-Arribas *et al.* [9], in the Madrid region, the NO_2 concentration ranged relatively widely, from 5.2–62.9 µg/m^3. In general, the concentration of NO_2 in the air in the southern region of Vietnam is still within the allowable limit of QCVN 05:2013/BTNMT (NO_2 200 µg/m^3).

B. The Relationship between Meteorological Factors and Air Pollutants

The results of Pearson correlation analysis between meteorological factors (temperature, humidity, wind speed, pressure) and air pollution components (noise, TSP, SO_2, NO_2) are given in Table VI. According to Guo and Wang *et al.* [25], the Pearson correlation coefficient was calculated to show the relationship between pollutants, $r \geq 0.5$, $0.25 \leq r < 0.5$ and $0 < R \leq 0.25$ presented a correlation of strong, medium and weak, respectively [25]. The analysis results show that the linear correlations are formed between the air pollution components, all at the $p < 0.01$ significance level. Noise moderately affects the formation of TSP, SO_2 and NO_2 content in the air with correlation coefficients of 0.432, 0.417 and 0.540, respectively. While TSP is thought to have a direct effect, strongly correlated with SO_2 (0.608) and NO_2 (0.731). Besides, a close linear relationship between SO_2 and NO_2 was also found with the correlation coefficient r of 0.781. Meanwhile, air pressure is found to have a negative influence, weakly negatively correlated with noise (–0.227) and NO_2 pollutant (–0.133), at 90% and 95% significance level, respectively. Another negative correlation between air humidity and SO_2 was also found with the coefficient *r* of –0.145. Finally, air temperature and humidity negatively affect each other (*r*= –0.812), which is consistent with low humidity value in dry season when ambient temperature is high and vice versa. Positive correlations between air pollutants such as PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO have also been reported in several studies by former studies [9, 25, 46]. However, not all air pollutants are linearly correlated, as according to Alfoldy and Kotb *et al.* [24], nitrous oxide gases such as NO, NO_2 have a strong negative effect on the formation of ozone (O_3) in the air. In addition, according to Çelik and Kadi [48], SO_2 concentration decreases with low temperature and high humidity ratio, corresponding to the positive correlation formed between temperature and SO_2, while the negative correlation is formed between moisture and SO_2, similar to the present study results. Wind speed has been shown to be inversely correlated with air pollutants, the higher the wind speed, the stronger the air mobility, which is beneficial for the diffusion and dilution of pollutants in the air [49].

TABLE VI: PEARSON CORRELATION MATRIX OF METEOROLOGICAL FACTORS AND AIR POLLUTANTS IN SOUTHERN VIETNAM

Parameters	**Temp.**	**Humidity**	**Wind Speed**	**Pressure**	**Noise**	**TSP**	**SO_2**	**NO_2**
Temp.	**1**							
Humidity	**-0.812****	**1**						
Wind Speed	0.083	−0.123	**1**					
Pressure	−0.089	0.095	−0.122	**1**				
Noise	0.037	−0.044	0.006	**−0.227****	**1**			
TSP	0.034	−0.050	0.051	−0.117	**0.432****	**1**		
SO_2	0.003	**−0.145***	0.061	−0.110	**0.417****	**0.608****	**1**	
NO_2	0.054	−0.095	0.016	**−0.133***	**0.540****	**0.731****	**0.781****	**1**

Note: **: correlation at the level of significance $p < 0.01$; *: correlation at the level of significance $p < 0.05$.

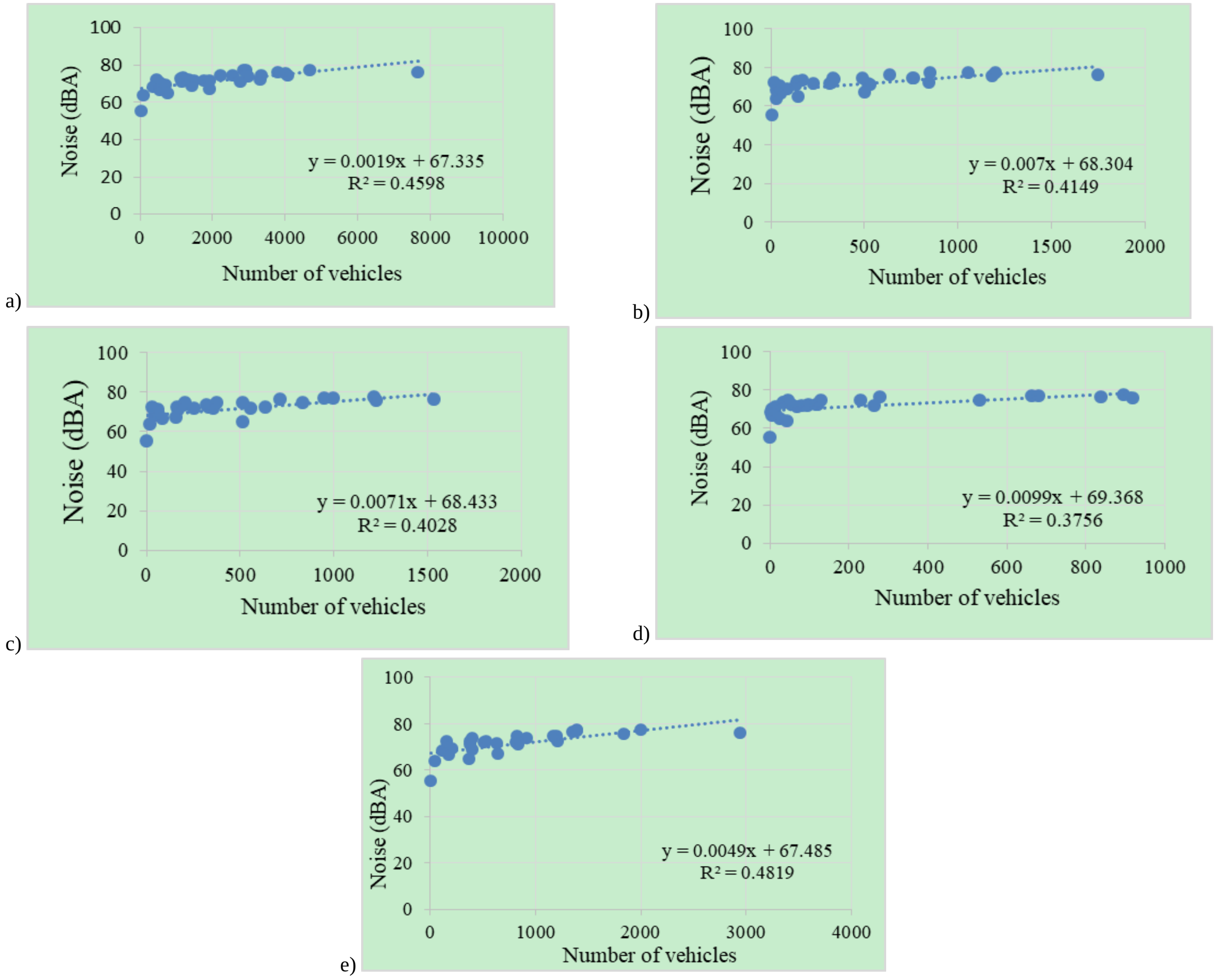

Fig. 2. Correlations between noise and traffic a) motorbikes, b) cars, c) trucks, d) heavy vehicles, and e) total number of vehicles.

C. Correlation between Noise and Traffic of Each Type of Vehicle and Total Traffic of Motor Vehicles

Inventory of vehicles circulating in the southern region of Vietnam in eight surveys, the study recorded a total of 96,830 vehicles in operation. In which, motorbike is the main means of transport in the study area with a total of 64,250 motorbikes, accounting for 66.35% of the total. There were about 13,565 cars, 12,686 trucks and 6,329 heavy trucks, accounting for 14.01%, 13.10% and 6.54% of the total vehicles recorded, respectively. Fig. 2 shows in detail the correlation between noise and traffic of each type of vehicle, the total number of motor vehicle traffic in the study area. From Fig. 2, it can be seen that the correlation between noise and traffic volume recorded in the area is mainly at the average level. Among the four types of vehicles listed, motorcycle traffic and noise show the highest correlation, with the R^2 coefficient reaching 0.4598 (Fig. 2a). While, heavy truck traffic has the lowest correlation to noise formation in the study area, the R^2 coefficient is only 0.3756 (Fig. 2d). In general, the total number of motor vehicle traffic with noise has a linear relationship (R^2=0.4819) (Fig. 2e), the greater the number of traffic vehicles, the higher the recorded noise and vice versa. According to Chi and Ha [50], the measured noise level is mainly due to the noise of the engine and the vehicle owners using inappropriate horns, or using the horn for the wrong purpose, and the study was carried out in the city. Hue also demonstrated that the higher the number of vehicles, the higher the noise level in the area. Besides, the frequency of honking is especially high when the traffic on the roads is congested and the noise of motorbikes is considered a noticeable source, contributing to the high L_{max} value [40]. In the study of Fiedler and Zannin [51], it is reported that when the total vehicle traffic is reduced by 50% or the heavy vehicle traffic is reduced by 50%, the noise level at some major transport hubs in urban Latin America will be reduced by about 3 dBA compared to the present. According to Lee and Jerrett *et al.* [52], a linear correlation between vehicle traffic and noise measured in three American cities of Atlanta, Los Angeles and New York was also determined, the total number of vehicles observed explained significant change in noise level in the area with the coefficient R^2 of 0.78, 0.58 and 0.62, respectively [52]. Similarly, in the study of Ky and Lap *et al.* [31] also proved that there is a strong positive correlation between traffic volume and noise, traffic volume is a significant contributor to noise pollution in the study area.

D. Main Variables Affecting Air Quality in the Southern Vietnam

Principal component analysis (PCA) of observed spatial variation is based on data of eight environmental variables and 30 air monitoring stations. In this study, the data's KMO test is 0.606 and the significance level of Bartlett's test of sphericity is 0.000 < 0.001, which means the feasibility for PCA and the data meet the basic requirements of PCA.

The results of PCA analysis have identified three components (PCs) with eigenvalues greater than 1, making an important contribution to the air quality variation in the study area, explaining 81.2% of the total variance of the original data (Fig. 3a). Table VII, detailing the results of PCA analysis. Three main components PC1, PC2, and PC3 explain 48.2%, 20% and 13.1% of the total variance of air quality variation according to the observed space, respectively. PC1 shows a weak positive correlation with humidity (0.317), negative correlation with all observed air pollution components such as noise (−0.396), TSP (−0.432), SO_2 (−0.467) and NO_2 (−0.475) were weak. PC1 is considered a source of effects from natural and man-made activities. PC2 is a collection of microclimate factors, influenced by natural conditions, with moderate positive correlation with temperature (0.573), moderate and weak negative correlation with humidity (0.573) and pressure (−0.332). While, PC3 appeared to have a positive correlation with wind speed (0.903), influenced by natural conditions. Thereby, it can be seen that all the observed environmental variables contribute to the influence of the air quality in the study area when it fluctuates according to the observation space. Similarly, in the principal component analysis of the observed time variation, three components (PCs) with eigenvalues greater than 1 were also identified, explaining 83.4% of the total variance of the original data set (Fig. 3b). The first principal component explained 47.8% of the total variance, has a weak positive correlation with air temperature (0.456), a weak negative correlation with humidity (−0.425) and three air pollutants TSP (−0.442), SO_2 (−0.341) and NO_2 (−0.437). The second principal component, which explains 19% of the total variance, exhibits a weak negative correlation with humidity (-0.305) and a mean with noise (−0.619), while PC2 is positively correlated at a weak level with wind speed (0.396) and air pressure (0.365). Both main components PC1 and PC2 may represent both natural and man-made sources affecting air quality in the study area. The third major component has an average positive and negative correlation with wind speed (0.653) and air pressure (−0.553), influenced by natural conditions. Detailed results of analysis of PCA changes over time are presented in Table VII. From that, eight observed environmental variables all contribute significantly to the change of air quality in the South of Vietnam when it fluctuates with the observation time. The research results are also consistent with the studies of Wang and Wang *et al.* [53], Abdullah and Ismail *et al.* [54].

From the above analysis, it can be seen that eight environmental parameters including temperature, wind speed, humidity, air pressure, noise, TSP, SO_2 and NO_2 all affect the air quality in Southern Vietnam in space and time observation. Emissions from motor vehicle engines related to traffic activities at intersections, roads in urban residential areas and emissions from industrial production activities in the study area are the sources contributing to air pollutants such as NO_2, CO_2 and TSP. In the study area, there are many large industrial parks such as Hiep Phuoc, My Xuan A, Minh Hung, Thuan Dao, Trang Bang, Binh Long-Binh Chanh, Hoa Trung and Song Doc. In addition, the study area also has a garbage treatment plant, waste incineration, and emissions are formed and released into the environment. Noise emitted mainly from traffic vehicles such as motorcycles, cars, trucks, and in the study area recorded a total of more than 96,800 vehicle traffic during the survey. At the same time, microclimate factors (natural conditions) also make an important contribution to the air quality here. According to Isiyaka and Azid [1], heavy industrial activities and automobile exhaust contribute greatly to NO_2 emissions, and it is estimated that about 60% of NO_2 is emitted from power plants and industrial activities, 28% comes from motor vehicles. Besides, in the study of Hieu and Quynh *et al.* [55], indicated that motorcycles contribute the most to total traffic emissions, accounting for more than 70% of total TSP emissions. According to Zhang and Chen *et al.* [47], a PCA analysis based on six air pollutants identified $PM_{2.5}$, PM_{10} and CO as the main pollutants affecting air quality, followed by SO_2, NO_2 and O_3, the main sources of air quality. The generation of pollutants also comes from traffic activities and heavy industries, along with natural conditions such as wind speed, rainfall impact [47]. In the study of [56], it was also shown that NO_2 originates from traffic activities and in urban areas, air pollution mainly comes from motor vehicle traffic in the area), and climatic factors such as temperature, wind speed, precipitation, and humidity are also reported to affect air quality [56].

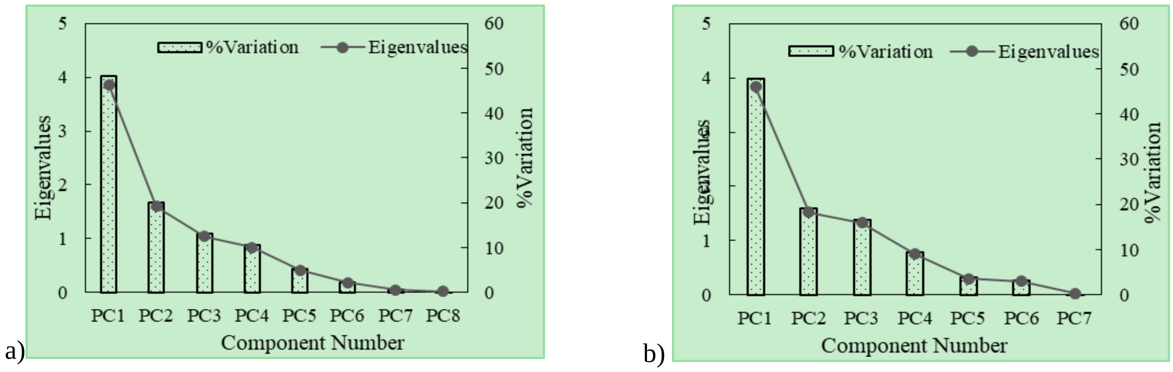

Fig. 3. Scree chart from PCA analysis results a) by space and b) by observation time.

TABLE VII: PCA RESULTS BY SPACE AND TIME OF AIR QUALITY OBSERVATION

Variable	Spatial Variation			Temporal Variation		
	PC1	**PC2**	**PC3**	**PC1**	**PC2**	**PC3**
Temp.	-0.284	0.573	-0.149	0.456	-0.094	0.243
Humidity	0.317	-0.589	0.056	-0.425	-0.305	0.258
Wind Speed	-0.031	-0.019	0.903	0.038	0.396	0.653
Pressure	0.177	-0.332	-0.366	0.295	0.365	-0.553
Noise	-0.396	-0.194	-0.083	-0.146	-0.619	-0.228
TSP	-0.432	-0.263	-0.043	-0.442	0.251	0.08
SO_2	-0.467	-0.238	-0.094	-0.341	0.378	-0.267
NO_2	-0.475	-0.224	-0.086	-0.437	0.137	-0.111
Eigenvalues	3.86	1.6	1.04	3.83	1.52	1.33
%Variation	48.2	20	13.1	47.8	19	16.6
Cum.%Variation	48.2	68.2	81.2	47.8	66.8	83.4

E. Clustering Air Quality in Southern Vietnam

Cluster analysis (CA) of spatial variation observed at 30 stations from eight environmental variable data formed five air quality groups (Fig. 4a). Group IV represents only a separate position, which is KK3. From Table VIII, it is found that this is the group with the best air quality, all pollution components such as noise, TSP, SO_2 and NO_2 are within the allowable limits of current Vietnamese regulations, respectively, 55.15 dBA, 39.38 $\mu g/m^3$, 16.46 $\mu g/m^3$, 13.17 $\mu g/m^3$ and the lowest of all classified groups. Groups II and III both gather two monitoring locations with similar air quality. Group II includes locations in industrial areas, namely KK18 and KK23. The concentration of TSP determined in group II was very high (358.06 $\mu g/m^3$), exceeding the allowable limit of QCVN 05:2013/BTNMT by 1.19 times. Group III includes a location influenced by the industrial area KK24 and one location affected by the traffic area KK 29. At these locations, the determined wind speed and humidity were the highest among the groups, leading to the formation of relatively low air pollutants and no signs of pollution still within the allowable limits of Vietnamese standards). Group I gather nine locations, influenced by three impact areas of industry, traffic and urban areas, including KK2, KK4, KK6, KK7, KK8, KK10, KK11, KK13 and KK16. Group I was evaluated as the group with the most polluted air quality, the concentrations of TSP, SO_2 and NO_2 were all higher than the other groups, respectively, recorded at 392.88 $\mu g/m^3$, 41.58 $\mu g/m^3$ and 50.56 $\mu g/m^3$ and the TSP content exceeded the allowable threshold of QCVN 05:2013/BTNMT by 1.31 times. Group V gathers a variety of monitoring stations with similar air quality characteristics, with 16 locations KK1, KK5, KK9, KK12, KK14, KK15, KK17, KK19, KK20, KK21, KK22, KK25, KK26, KK27, KK28 and KK30 belong to industrial, traffic, urban, tourist areas and garbage treatment areas. Group V is considered to have poor noise quality and tends to exceed the permissible limit of QCVN 26:2010/BTNMT. From the analysis results, in order to ensure a comprehensive air quality assessment across all types of industrial, traffic, urban, tourism, and garbage treatment plant impacts as well as monitoring provinces/cities, 30 initially selected monitoring locations can be reduced to 25 locations, saving about 17% of the total related costs. Moreover, greenhouse gas intensity increased significantly with meteorological parameters such as temperature, humidity, and CO_2 elevation [57]. Therefore, the current findings could significantly support giving the adaptation measures to cope up with the climate change and global warming. The process of grouping air quality with spatial variation has been reported in several studies. As according to Núñez-Alonso and Pérez-Arribas *et al.* [9], cluster analysis classified 22 monitoring stations into six air quality groups based on the characteristics of pollutants such as NO, NO_2, O_3 and PM_{10} [9]. According to Giao [20], assessing the air quality in Can Tho city by cluster analysis, four quality groups have been formed from the data of seven environmental variables including temperature, humidity, wind speed, noise, TSP, SO_2 and NO_2 at 15 monitoring locations [20]. Similarly, to assess the air quality in Hong Kong, Northern China, the cluster analysis method has been effectively applied in former studies [2, 58].

Cluster analysis (CA) of variation over time of observation with eight surveys (April, May, June, July, August, September, November and December) formed four air quality groups based on environmental variables. environment belongs to the group of microclimates and air pollution components (Fig. 4b). Each air quality group includes two observations. Group I collected the monitoring periods at the end of the dry season (April–May) and the beginning of the rainy season (May-June), air pollutants such as TSP (194.17 μg/m^3), SO_2 (26.49 μg/m^3) and NO_2 (26.69 μg/m^3) was assessed as the lowest among all groups (Table VIII). Groups II and III, each group collects the monitoring months of the rainy season, June-July and August-September, respectively. The concentrations of pollutants in these two groups are relatively low, similar to the study of Giao [20], detailed values of air components are shown in Table VIII. While, the dry season (November and December) are classified in group IV, the air quality in this group is the most polluted, the concentrations of TSP, SO_2, NO_2 reach 262.86 μg/m^3, 40.45 μg/m^3 and 39.08 μg/m^3, respectively. The worst air quality occurs the beginning of dry season, which was also recorded in northern Iraq but in contrast to the study in Taiwan [59, 60]. The CA analysis results show that, with just four observations, representing the dry and rainy seasons, it is possible to assess the southern air quality changes over time in a comprehensive and economical way saving 50% of all relevant monitoring costs.

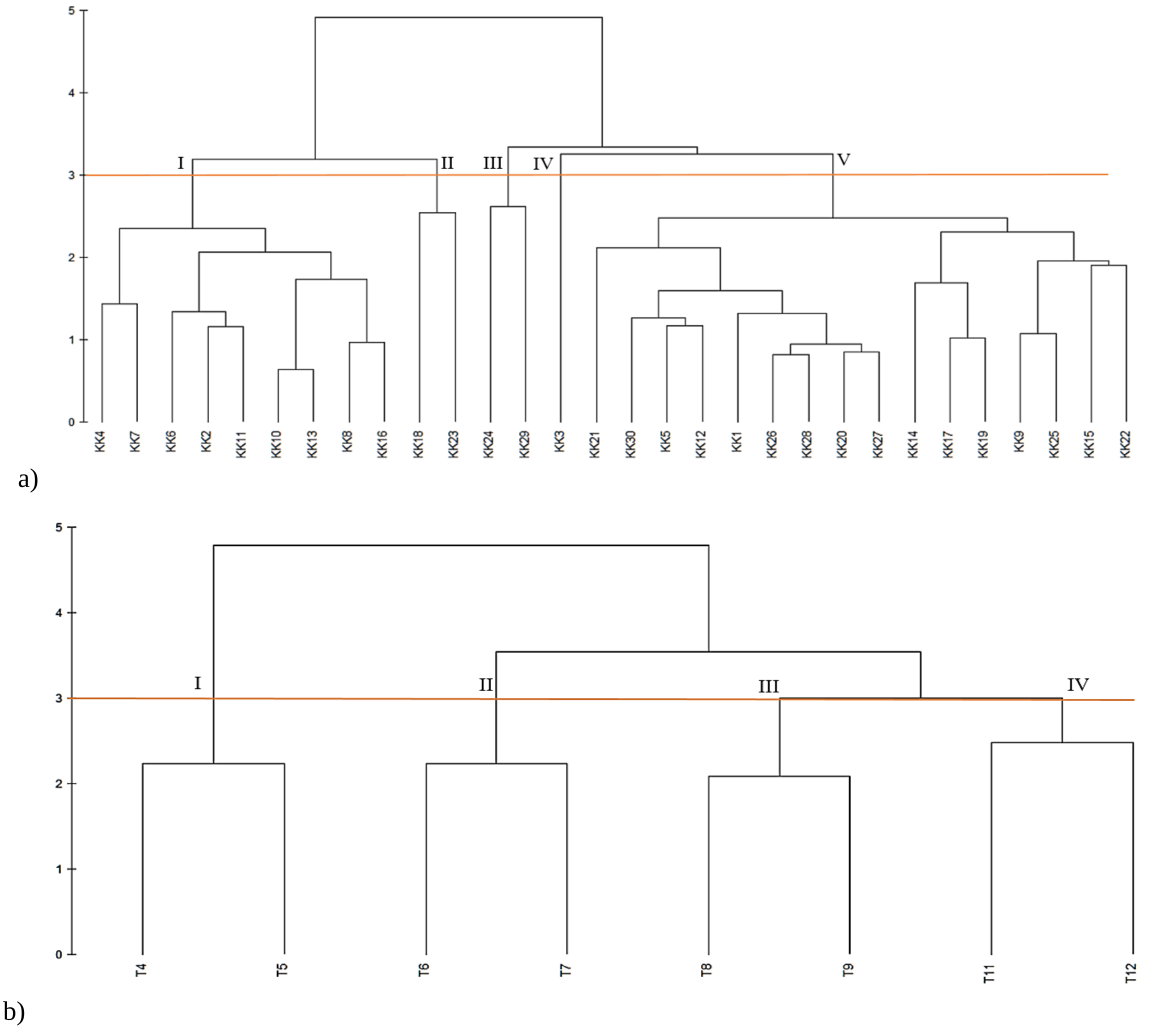

Fig. 4. Air quality classification a) by space and b) monitoring time.

TABLE VIII: Values of Air Quality Parameters at Identified Clusters

Parameters	Unit	Spatial Variation					Temporal Variation			
		I	II	III	IV	V	I	II	III	IV
Temp.	oC	29.42	31.49	31.06	31.52	31.97	34.01	31.82	31.61	30.87
Humidity	%	57.85	71.15	71.99	68.08	67.58	60.71	70.52	70.38	66.96
Wind Speed	m/s	0.68	0.66	1.29	0.67	0.67	0.78	0.62	0.87	0.68
Pressure	mbar	906.74	1010.56	1009.58	1010.76	1008.60	1009.70	1007.82	1007.47	1009.16
Noise	dBA	68.17	68.05	71.48	55.15	70.47	71.17	71.82	71.28	71.52
TSP	µg/m^3	393.88	358.06	194.81	39.38	131.36	194.17	238.95	262.11	262.86
SO$_2$	µg/m^3	41.58	29.21	22.77	16.46	25.40	26.49	26.24	32.50	40.45
NO$_2$	µg/m^3	50.65	29.29	23.02	13.17	25.65	29.69	33.14	36.04	39.08

Overall, from the research results, potential strategies are suggested to improve air quality in the study area:

For industrial activities and garbage treatment plant, air pollution can be reduced by improving machineries, manufacturing processes and better monitoring technologies to reduce emissions from factories. Besides, switching from coal, oil to natural gas reduced operating costs and extend plant's life and keep pollutants level within limits.

The public transport system allows the transportation of many people daily (restriction on private transport) is an environmentally friendly transport option is to improve air quality in traffic. It is important to convert to using fewer polluting fuels, switching to low-carbon fuels and electric vehicles. The transition to electric vehicles could have great potential to reduce emissions that cause air pollution (CO, NO$_x$, VOC, PM$_{2.5}$, O$_3$ and SO$_2$).

It is necessary to increase greenery activities, urban green spaces such as parks, rooftop gardens, roadside greenery systems and tree walls, which can protect city dwellers in urban areas from air pollution by reducing certain pollutants that negatively affect health such as PM$_{2.5}$, PM$_{10}$, NO$_x$ and O$_3$.

Reducing energy consumption helps reduce air pollution in tourist areas. This is the most effective way to reduce greenhouse gases emissions, mainly CO$_2$ ones, which are an inevitable by-product of tourism activities.

IV. Conclusions

Air quality in traffic and urban areas had the highest concentrations of air pollution, while tourist areas had the lowest air pollution. Most of the air pollutants had statistically significant differences between the types of impacts. Seasonal variation of air quality showed that the pollutant concentration tends to be lower in the rainy season but not statistically significantly difference between the seasons. Noise exceeded the permissible limit of QCVN 26:2010/BTNMT and TSP in urban areas exceeded the acceptable limit of QCVN 05:2013/BTNMT. Correlation analysis indicated that air pollution components had a moderate to strong linear correlation, while microclimate factors negatively affect air pollutants at a weak level. Vehicle traffic and noise measured in the study area had a positive correlation, and motorbike traffic is assessed to have the most significant influence on noise pollution. Three components could explain 81.2% and 83.4% of the total variance in space and time, respectively. The sources of air pollution come from traffic, urban, residential areas, industrial production, garbage treatment plant. The results of cluster analysis recommended the air quality monitoring in southern Vietnam could be performed with only 25 sites and four periods. The findings provide scientific information on air variations in the study areas.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

N.T.G. designed the research and methodologies; L.T.D.M. conducted the research, analyzed the data and drafted the manuscript; N.T.G. revised and finalized the manuscript; all authors had approved the final version.

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