Ten Years Variation of Air Quality over An Giang Province, Vietnam

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***Abstract*—The study aimed to assess the evolution of ambient air quality in An Giang province during 2010-2020. Air samples collected in urban areas, traffic, tourism, industrial clusters, brick kilns, quarries, landfills, and background areas were analyzed for temperature (T), noise, total suspended particulates (TSP), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxides (SO_2), ozone (O_3), ammonia (NH_3), hydrogen sulfide (H_2S), and hydrogen fluoride (HF). The findings were compared with the Vietnamese standard on air quality. Pearson correlation and principal component analysis (PCA) were performed to recognize the correlation between pollutants and potential pollution sources. The results showed that the average values of air quality parameters in An Giang province during the study period temporally fluctuated but within the allowable limits. Moreover, the air quality parameters were well correlated, especially temperature and ozone. Three PCs obtained from PCA could explain 87.50% of the air quality variations with a significant contribution of all parameters. It is found that CO, NO_2 and SO_2 originated mainly from traffic and urban areas. While NH_3 and H_2S were dominant in the landfill areas, HF was from brick kilns. Consequently, the traffic and urban areas are considered the most influential contributors to air pollution in the study area.**

***Index Terms*—An Giang, air quality, pollutants, ozone, PCA.**

I. INTRODUCTION

Air pollution is not only a hot issue concentrated in developed cities and industrial zones but a top concern worldwide [1]. It is considered one of the major threats to human health. For example, exposure to air pollutants, such as PM10 and sulfur dioxide (SO_2), contributes to approximately 30% of health impacts [2]. Once SO_2 goes into the body via inhalation, it increases the risks of acute myocardial infarction and chronic obstructive pulmonary disease [3]. Moreover, carbon dioxide (CO_2), carbon monoxide (CO), SO_2, and small particles can cause serious repercussions on the lungs, namely asthma, bronchitis, pneumonia, and lung cancer [4]. Air pollution is also associated with climate-sensitive diseases, such as pneumonia and asthma [5]. This problem is not only a concern for human health but also economic issues. It causes deposition phenomena, acid rain, ecosystem destruction, and corrosion that reduce the durability of constructions [6]. In addition, high CO_2 and nitrogen oxides (NO_x) concentrations in the atmosphere have resulted in the greenhouse effect, which accelerates climate change [6]. Anthropogenic sources, such as industrial emissions, domestic fuel combustion, emissions from power plants and transportation activities, are deemed the main sources of air pollution. The primary pollutants are carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides (SO_x), nitrous oxides (NO_x), ammonia (NH_3), particulate matter (PM), and chlorofluorocarbons (CFCs) [1].

In Vietnam, Hanoi Capital and Ho Chi Minh City had the highest levels of air pollution in the country [7]. In the context of rapid industrialization and modernization, excessive dust and emissions are generated from construction activities, industrial production facilities, fossil fuel incinerators, cement production, chemicals, fertilizers and vehicles [1]. This problem not only exists in these two cities but in other provinces. However, the number of studies is still limited, which causes difficulties in building strategies to control air pollution in the country. Moreover, air pollutants can travel far away from their origin, even leading to transboundary air pollution. Thus, it is necessary to conduct more studies on the status of air quality in more regions to promptly have solutions to prevent air pollution as well as its effects on public health.

An Giang is one of four provinces in the key economic region of the Mekong Delta, Vietnam, and also has the largest population. The rapid economic and population growth in the region has negatively deteriorated air quality [8]. The multivariate statistical analysis has been widely applied to interpret big datasets of various environmental compartments [9]. Principal component analysis (PCA), one of the effective multivariate statistical tools, determines the potential sources of air pollutants. For example, the results of PCA suggested that the primary air pollution sources in Malaysia were vehicles, planes, industries, and densely populated areas [10]. Thus, the study was conducted to evaluate air quality during the 10-year period from 2010 to 2020 and determine the potential pollution sources using correlation analysis and PCA, which helps in taking measures to prevent and control the sources of air pollution in An Giang province in the future.

II. MATERIALS AND METHODS

A. Description of the Study Area

An Giang is the upstream province of the Mekong River in Vietnam, with convenient water and land transportation system [8]. The province belongs to the tropical monsoon area, with high temperatures and high humidity (82-85%). There are two distinct seasons: dry season (November to April) and wet season (May to October). The average rainfall is about 1,500 mm/year, and the total average sunshine hours are 2,152 hours. There are two wind regimes in An Giang province, including southwest monsoon and northeast monsoon, with an average wind speed of about 3 m/s.

The local traffic system is part of an important national and

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inter-regional transport network, with border gates such as Tinh Bien, Vinh Xuong - Tan Chau and Long Binh - An Phu districts. Total revenue from transportation, warehousing, and transportation support services reached VND 5.56 trillion, of which road revenue contributed VND 2.8 trillion in 2020. Besides the advantages of developing agriculture, An Giang also has rich and diverse mineral resources, such as granite, sandstone, kaolin, and peat [8]. Furthermore, the province possesses many famous tourist destinations to develop the tourism industry. Most industrial zones have leased out of the existing area to enterprises, such as Binh Hoa and Binh Long industrial zones, with occupancy rates of 91% and 100%, respectively [8]. The favorable natural conditions and the regional availability of raw materials and fuel resources have facilitated a strong economic growth rate. Therefore, these wide ranges of activities have developed the dynamic economy but simultaneously caused environmental issues, especially air pollution.

B. Data Collection

Data on monitoring air quality from 2010 to 2020 was collected from the Department of Natural Resources and Environment of An Giang province with 10 parameters, including temperature, noise, total suspended particulate (TSP), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), ammonia (NH_3), hydrosulfide (H_2S) and hydrogen fluoride (HF). These collected samples were distributed in the areas representing the impacts of urban activities, transportation, tourism, industries, brick kilns, and quarries. The samples were also collected in the background site. Temperature, noise, TSP, CO, NO_2, SO_2, O_3 were measured on the air samples collected in background areas, urban areas, traffic, tourism, industrial zones and clusters, and quarries. Industrial areas were analyzed for more NH_3 and H_2S. HF was more analyzed in samples of brick kilns. The landfill area only monitored temperature, noise, TSP, NH_3, H_2S and O_3. Data on these monitoring parameters was collected in both dry and wet seasons. The temperature and noise indicators were measured directly in the field, and the remaining indicators were preserved and analyzed at the laboratory of An Giang Provincial Center for Natural Resources and Environment Technology and Monitoring according to standard methods.

C. Data Analysis

The analysis results were compared with QCVN 06:2009/BTNMT – National technical regulation on some hazardous substances in the surrounding air (1 hour average) [11], QCVN 05:2013/BTNMT – Technical regulation National ambient air quality (average 1 hour) [12] and QCVN 26:2010/BTNMT – National technical regulation on noise (6 hours to 21 hours) [13] (Table I). One-way ANOVA with Ducan post hoc test was applied to test the difference between years in air quality parameters. In addition, a Pearson correlation analysis was conducted based on the average data of air pollutants and meteorological parameters at each type of impact to interpret the significant correlation between these factors [14], [15]. These works were performed using IBM SPSS Statistics 20 software. The average values of these parameters were continued to use in PCA, which could show the most important variables and the source of the contamination. The principal components (PCs) with eigenvalues greater than 1 will be used and considered important [16]. The absolute values of the varimax coefficient were classified into three levels: strong correlation (>0.75), moderate correlation (0.5-0.75), and a weak one (0.3-0.5). PCA analysis was performed using Primer 5.2 for Windows software.

TABLE I: THE ALLOWABLE LIMITS OF AIR ENVIRONMENT PARAMETERS

Parameter	Unit	QCVN 26:2010/BTNMT	QCVN 05:2013/BTNMT	QCVN 06:2009/BTNMT
Noise	dBA	70	-	-
TSP	mg/m^3	-	0.3	-
CO	mg/m^3	-	30	-
NO_2	mg/m^3	-	0.2	-
SO_2	mg/m^3	-	0.35	-
O_3	$\mu g/m^3$	-	0.2	-
NH_3	mg/m^3	-	-	0.2
H_2S	mg/m^3	-	-	0.042
HF	mg/m^3	-	-	0.02

Source: [11]-[13]

III. RESULTS AND DISCUSSION

A. Air Quality Evolution in An Giang Province in the Period of 2010-2020

The fluctuations of air quality parameters during 2010-2020 are illustrated in Fig. 1. The temperature during the study period ranged from 30.15±1.28-32.71±2.20^oC, with an average of 31.67±2.57^oC. There was a significant difference in the variations of temperature over time ($p<0.05$). Regarding the types of impacts, the average temperature ranged from 31.24±2.66^oC-32.20± 2.7^oC. The average temperatures were the lowest in the background area (25-39^oC) and the highest in the urban area (27.4-41^oC). As presented in Fig. 2, slightly higher temperature in the dry season was observed in different areas, ranging from 27.50-38.93^oC. Moreover, dense traffic areas, industrial zones and clusters, and brick kilns had relatively high temperatures, even higher than 40^oC. Heat emitted from fuel combustion and machinery operation is likely to contribute to high ambient temperature in these areas.

The average noise fluctuations were in the range of 63.09-68.27 dBA, with the 10-year mean value of 66.61±6.33 dBA. This variation was statistically significant ($p<0.05$). The average noise was the lowest in 2015 (52-70.5 dBA) and the highest in 2012 (52.5-87.5 dBA). The results of noise variations under different sources showed that urban areas had the highest value of noise by 71.92±3.91 dBA, with the range of 63-81 dBA (Fig. 2). This is because these areas have high population densities and many socio-economic activities. In contrast, the tourist areas caused the lowest noise level, with an average value of 63.08±5.71 dBA, ranging from 47.5-77.5 dBA. The average noise values from 2010-2020 were generally within the allowable limit. However, the noise levels at some locations, such as congested traffic areas, crowded urban areas, quarries and brick kilns, exceeded the limit QCVN 26:2009/BTNMT. This is associated with the operation of machines and vehicles. The noise measured in the wet season was from 51-85.5 dBA, which is higher than in the dry season (55.17-78.25 dBA). It is consistent with the previous study that the highest noise level in Nigeria was 83.8 dBA in the rainy season due to natural factors (e.g., wind speed) and anthropogenic activities (e.g., automobiles and acoustic systems) [17]. According to Chi and Ha [18], noise pollution is proportional to urban development, which means that the more urban areas developed, the higher the noise pollution level, consequently influencing about 78% of human health.

The concentration of TSP fluctuated with time from 0.108±0.07-0.332±0.2 mg/m^3, reaching the 10-year average value of 0.216±0.16 mg/m^3. The average concentration of TSP was highest in 2010 (0.033-1.103 mg/m^3) and lowest in 2019 (0.042-0.427 mg/m^3). As presented in Fig. 1, TSP concentration tended to decrease over the years, which is a significant difference ($p<0.05$). It is noticed that some locations detected TSP values exceeding the prescribed threshold. In different types of impacts (Fig. 2), the average TSP concentration varied in the range of 0.124±0.06-0.482±0.31 mg/m^3. Tourist areas found the lowest TSP levels (0.033-0.345 mg/m^3), while the highest was observed in the quarries (0.051-1.103 mg/m^3). It is related to mining activities such as granite, sandstone, kaolin and intensive operations of heavy-duty vehicles. Moreover, the highest TSP in the dry and wet seasons was found in quarrying areas, with an average of 0.53±0.25 and 0.43±0.33 mg/m^3, respectively. Lower TSP in the rainy season is associated with wet deposition of TSP with precipitation. Generally, the average fluctuation of TSP concentration over time and type of impact was still within the allowable limit, except for 2010 and the quarries. According to Sairanen *et al*. [19], the operation of quarries, including drilling, crushing, and transportation, generates TSP into the atmosphere. Of these processes, crushing and sieving obtain the most TSP. Although drilling and blasting also cause dust emissions, their impact is generally insignificant [20]. In addition, human activities like traffic volume, vehicle speed, and natural impacts such as regional conditions and weather can impact the enrichment of TSP concentrations [21].

CO is a colorless, odorless, and non-irritating but highly toxic gas. It is the byproduct of incomplete combustion of fuels such as natural gas, coal or wood, and vehicle exhaust, which can damage the heart and central nervous systems [4]. The temporal fluctuations of CO concentration during 2010-2020 were in the range of 4.40-7.26 mg/m^3, with an average of 5.87±2.36 mg/m^3. The average CO concentration was the lowest in 2011 and the highest in 2015. The variations in CO concentration over the years are significantly different ($p<0.05$). In the first 5-year period, the CO concentrations generally increased. After 2015, the concentrations started to reduce until 2019. As depicted in Fig. 2, the CO concentration from different emission sources varied 4.18-7.57 mg/m^3. The lowest and the highest CO concentrations were found in the tourist destinations and crowded vehicle areas, respectively. The findings of CO in the dry and wet seasons ranged from 2.48-13.27 and 2.82-10.64 mg/m^3, respectively. The average CO concentrations were within the allowable limit of QCVN 05:2013/BTNMT. The areas with heavy traffic activities caused the most impact on air quality, followed by urban areas with various socio-economic activities. According to Elminir [22], the high concentration of CO in Great Cairo was explained by the high emission of motor vehicles. The CO concentrations in the big cities of Pakistan ranged from 1.18 to 6.01 mg/m^3, and 85-95% of total CO concentrations were from vehicular emissions [23]. In addition, other sources of CO emissions include industrial processes and solid waste treatment processes [24].

NO_2, a reddish-brown toxic gas with a pungent odor, is emitted from high-temperature fuel combustion [4]. It is also one of the most prominent air pollutants, which can damage lung tissue and aggravate asthma. The evolution of NO_2 concentration over the years ranged from 0.049-0.097 mg/m^3, with the 10-year average value of 0.075±0.03 mg/m^3. The lowest and highest NO_2 concentrations were in 2016 and 2018 with values ranging from 0.025-0.095 mg/m^3 and 0.0131-0.075 mg/m^3, respectively. It is noticed that the mean NO_2 line tended to go down from 2010 to 2016. Before continuing to decrease, the NO_2 concentration experienced an increase in 2017 and 2018. One sampling location in the traffic area in 2010 had NO_2 concentration exceeding the limit by 1.19 times. There were significant temporal variations in the average concentration of NO_2 in the air during 2010-2020 ($p<0.05$). Besides, NO_2 concentration fluctuated by impact ranged from 0.062-0.089 mg/m^3. Seasonal variations in NO_2 concentrations over different areas were observed in Fig. 2, with the maximum values in the dry and rainy seasons in background and traffic areas, respectively. These values were below the threshold specified in QCVN 05:2013/BTNMT. The traffic and urban areas had the most impact on the NO_2 concentrations. According to Narasimhan and Vanitha [1], the findings of NO_2 during 2000-2016 in the United States ranged from 1-132 mg/m^3. Bhanarkar *et al*. [25] pointed out that industrial activities using fossil fuels, such as cast iron, coal, coke, oil, contributed 68% of total NO_2 emissions, and vehicular emissions contributed about 28% of NO_2 emissions. In two cities of Romania, transportation emitted higher NO_2 emissions into the air environment than industrial activities [26]. This conclusion was then confirmed again in the study of He *et al*. [27] in China. Moreover, NO_2 is a precursor to form O_3, particulate matter (PM), and acid rain [28].

The evolution of SO_2 concentration over time in the period 2010-2020 ranged from 0.063-0.1139 mg/m^3, which is statistically different ($p<0.05$). The lowest and highest SO_2 concentrations were found in 2012 and 2017. The 10-year average was 0.078±0.05 mg/m^3. In general, the SO_2 concentrations over time in the study period were within the allowable limit. However, there were exceptions to some sampling locations in the traffic, tourism, and quarrying areas in 2010 and 2016. These exceeded the limit from 1.21, 1.69 and 1.49 times, respectively. As shown in Fig. 2, SO_2 concentration depends on the characteristic of different emission sources, ranging from 0.065-0.097 mg/m^3. Traffic activities primarily cause an increase in SO_2. SO_2 concentration in the dry season was higher than in the rainy season in different study areas, except in heavy traffic areas. A former study reported that SO_2 is considered a gas generated in traffic activities using gasoline and oil [3]. SO_2 concentrations in the period 2010-2020 were below the allowable limit, except for some locations in traffic, tourist and quarrying areas. The concentrations of SO_2 in Nigeria were temporally varied from 26 to 2000 mg/m^3 [17]. These values were higher in the major cities of Pakistan, ranging from 15.60-110.52 μg/m^3 [23]. According to Sharma *et al*. [4], SO_2 is derived from the combustion of coal and petroleum (about 80%) because the fuels contain sulfur compounds. Moreover, Marković *et al*. [29] also reported that SO_2 is a byproduct of metal smelting. In the presence of a catalyst like NO_2, it would form H_2SO_4, which causes acid rain. In addition, the main health problems associated with SO_2 emissions are respiratory tract irritation, bronchitis, bronchospasm, and eye damage [30].

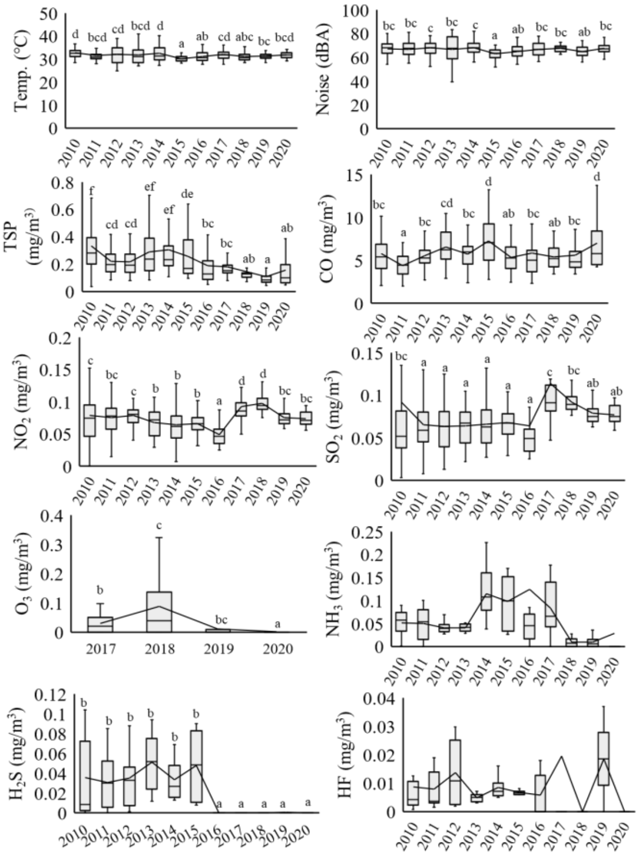

Fig. 1. Boxplot showing the variations of air quality parameters during 2010-2020. Different letters indicate significant differences between years (p<0.05). The top-, mid-, and bottom-line of each boxplot show the 75th, 50th, and 25th percentiles, respectively; The horizontal lines represent minimum and maximum values. A single connect line connects the mean values of the box plot.

In Vietnam, ozone (O_3) depletion began to receive attention in 2017, and O_3 concentration was started to monitor then. The evolution of O_3 concentration in the period 2017-2020 had an average range of 0.001-0.088 mg/m^3, with an average of 0.031±0.07 mg/m^3. The variations in O_3 during this period were significantly different (p<0.05). In general, the average O_3 concentration was within the allowable limit of QCVN 05:2013/BTNMT. However, some positions with O_3 concentration in 2018 exceeded the limit by 1.02-2.07 times. Regarding different impacts, O_3 concentration fluctuated on average from 0.027±0.06-0.041±0.09 mg/m^3. The tourist areas had the most impact on average O_3 concentrations, while the least was found in industrial clusters. Generally, higher O_3 generation was recorded in the dry season because higher temperatures can speed up O_3 production. The fluctuations of O_3 concentrations in traffic areas, brick kilns and landfills were within the limit. However, the O_3 concentration in the background, urban areas, tourist areas, industrial zones and quarries exceeded the limit by 1.10, 1.02, 1.42-1.06, 1.11-1.61 and 1.46 times, respectively. The findings of O_3 in Abbassiya ranged from 6 to 79 μg/m^3 [21]. The average O_3 concentration in US air quality observations was 103.94±106.65 mg/m^3 [1]. According to Soleimani *et al*. [30], O_3 reduces growth rate and yield, and affects plant microflora due to its antibacterial ability. In addition, O_3 increases DNA damage in epidermal keratinocytes and leads to any decline in cell function. O_3 concentration depends on the intensity and emission rate of precursors (e.g., NO_x and VOCs), photochemical reaction and weather conditions [31].

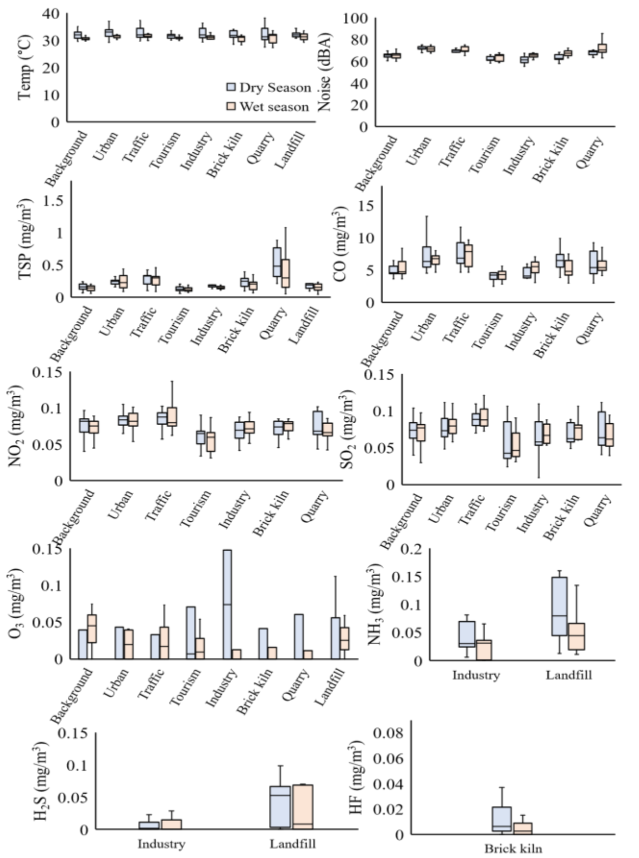

Fig. 2. Boxplot of seasonal air quality parameters at each type of impact during 2010-2020. The top-, mid-, and bottom-line of each boxplot show the 75th, 50th, and 25th percentiles, respectively; The horizontal lines represent minimum and maximum values.

NH_3 and H_2S gases were mostly concentrated in industrial zones and landfills. In the course of time, the NH_3 concentration fluctuated on average from 0.009±0.01-0.115±0.06 mg/m^3, with the 10-year average of 0.059±0.1 mg/m^3. The variations in NH_3 concentration were statistically insignificant (p>0.05). The lowest NH_3 concentration was in 2018, and the highest was in 2016. In general, the average concentrations of NH_3 were still within the allowable limit and the variations over time was insignificant (p>0.05). However, the concentration of NH_3 at some locations in 2014, 2016 and 2020 exceeded the limit by 1.13, 5.25 and 1.89 times, respectively. These points were concentrated in the landfill areas. The average value of NH_3 in landfills was 0.085±0.13 mg/m^3 higher than in the industrial areas by 2.93 times. According to Sharma *et al*. [32], the average NH_3 value in India was 43.4±7 mg/m^3. The average evolution of H_2S concentration during the study ranged from

0-0.051±0.04 mg/m^3, with the 10-year average reaching 0.02±0.103 mg/m^3. H_2S concentration in the period of 2016-2020 was below the detection limit. In general, the average H_2S concentration was under the allowable limit of QCVN 05:2013/BTNMT, except in 2013. The evolution of H_2S concentration in the impact area with the average value ranging from 0.009-0.033 mg/m^3. The H_2S concentration was highest in the landfill area, and it was 3.67 times higher than that in the other areas. The average H_2S concentration was still within the allowable limit. Higher H_2S concentrations were reported in Nigeria, with the highest value of 200 mg/m^3 in the dry season [17]. NH_3 and H_2S contributed more to the atmospheric pollution in the dumping sites. Odor is considered the biggest nuisance associated with open dumping sites in India [33]. Garbage disposal and food waste are the main cause of odor [34]. Bad odors are generated from waste decomposition under anaerobic conditions [35]. Due to improper waste treatment, odor generation will greatly affect human health and the surrounding environment [36]. Moreover, the concentrations of these substances were found to be higher in the dry season in different areas, which can be associated with the higher temperature to increase the speed of chemical reactions.

HF, a toxic plant pollutant, is released from industrial sources such as ceramic factories and brick kilns [37]. The average evolution of HF concentration in the brick kiln area during 2010-2020 ranged from 0-0.02 mg/m^3, with the 10-year average value of 0.009±0.02 mg/m^3. This difference was insignificant (p>0.05). The highest concentration of HF in the air in 2017 showed signs of pollution. Meanwhile, there was almost no HF detection in 2018 and 2020 at the brick kiln areas. In general, the average HF concentration in the period 2010-2020 was still within the allowable limit. However, a few monitoring positions in 2010, 2012, 2017 and 2019 exceeded the limit by 1.42, 1.38-1.49, 5.85 and 1.85 times, respectively. Similar to NH_3 and H_2S, the HF concentration was higher in the dry season. According to Saleem *et al*. [38], brick kilns are considered an important source of fluoride emissions that affect human health and damage vegetation and ecosystems in general. In brick production, fluoride is released from high temperatures (900-1150^{o}C) of coal combustion in the form of HF [39]. Besides, Qasim *et al*. [40] suggested that the production process at brick kilns involves heating bricks obtained from fine clay (up to 1100^{o}C), consequently resulting in high concentrations of HF.

B. The Relationship among the Air Quality Parameters

The Pearson correlation coefficient between air pollutants and meteorological parameters was presented in Table II. The results showed an inverse correlation between temperature and O_3 with a correlation coefficient of -0.724 at a significant level of p<0.05. The noise was strongly and positively correlated with CO (0.934), NO_2 (0.978) and SO_2 (0.962) 724 at a significant level of p<0.01. This showed that densely populated areas, congested traffic areas, industrial activities, the demand for raw materials and fuels lead to the emission of various polluting gases. Similarly, pollutants of CO, NO_2, SO_2 were all positively correlated with each other with correlation coefficients of 0.970, 0.948 and 0.980 at the significance level of p<0.01, respectively. It is suggested that these pollutants were derived from similar sources [41]. The pollutants of CO, NO_2, SO_2 and TSP were negatively correlated with NH_3 and H_2S. Another correlation was also detected in the study, which is between NH_3 and H_2S with a positive correlation. Their coefficient was 0.998 at the significance level of p<0.01. In general, air pollutants and meteorological parameters are highly correlated.

TABLE II: THE RESULTS OF AIR QUALITY PARAMETER CORRELATION ANALYSIS

Parameter	Temp.	Noise	TSP	CO	NO_2	SO_2	NH_3	H_2S	HF	O_3
Temp.	**1**									
Noise	0.188	**1**								
TSP	0.282	0.253	**1**							
CO	0.480	**0.934****	0.350	**1**						
NO_2	0.291	**0.978****	0.218	**0.970****	**1**					
SO_2	0.238	**0.962****	0.331	**0.948****	**0.980****	**1**				
NH_3	-0.118	**-0.951****	-0.263	**-0.882****	**-0.916****	**-0.902****	**1**			
H_2S	-0.112	**-0.967****	-0.245	**-0.892****	**-0.933****	**-0.920****	**0.998****	**1**		
HF	-0.001	0.105	0.019	0.143	0.079	0.094	-0.190	-0.182	**1**	
O_3	**-0.724***	-0.192	-0.035	-0.429	-0.303	-0.206	0.022	0.044	-0.165	**1**

*Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).*

C. Key Parameters Influencing Air Quality in An Giang Province

PCA was performed on concentrations of nine air pollutants and one meteorological parameter. The results of PCA analysis are presented in Table III. Three factors could explain 87.50% of the variation in the changes in air quality in the study area. PC1, PC2, and PC3 explained 59.80%, 17.30% and 10.40% of the total variance, respectively. As can be seen, PC1 gathered the most influential factors and was positively correlated with NH_3 (0.386) and H_2S (0.390), but negatively correlated with noise (-0.399), CO (-0.403), NO_2 (-0.402), SO_2 (-0.397). These correlations were considered to be weak. According to Lan [42], NH_3 and H_2S were released from landfills by anaerobic digestion of organic matter. This was also reported in Viet [43] study about the municipal waste landfill in Ho Chi Minh city, Vietnam. These pollutants are associated with food processing plants, seafood processing, and the decomposition of organic substances [44]. The gases of CO, NO_2 and SO_2 could be released from human activities such as incomplete fuel combustion during industrial production [24] and vehicular emissions [29], and fuel combustion in the brick kilns [45]. PC2 had a positive correlation with O_3 (0.660) and a negative correlation with temperature (-0.656), which were moderate correlations. O_3 was a secondary pollutant produced from anthropogenic precursors including industrial and vehicular emissions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) [46]. PC3 was weakly correlated with TSP (0.464) and negatively correlated with HF (-0.849) at a strong level. According to Ahmad *et al*. [37], HF is generated from brick kiln operations in South Asia. TSP was from industrial activities and transportation in Temon district [21]. Due to high loading values of temperature, noise, TSP, CO, NO_2, SO_2, O_3, NH_3, H_2S, and HF, it is suggested that these measured parameters were the most influential factors of air quality in the study area. The primary contributor to air pollution can be human activities [47].

TABLE III: THE RESULTS OF PRINCIPAL COMPONENT ANALYSIS FOR AIR QUALITY IN THE STUDY AREA

Parameter	PC1	PC2	PC3
Temp.	-0.140	-0.656	0.135
Noise	-0.399	0.112	0.004
TSP	-0.141	-0.124	0.464
CO	-0.403	-0.124	0.017
NO_2	-0.402	0.023	0.007
SO_2	-0.397	0.069	0.058
NH_3	0.386	-0.207	0.047
H_2S	0.390	-0.204	0.052
HF	-0.067	-0.043	-0.849
O_3	0.120	0.660	0.193
Eigenvalues	5.98	1.73	1.04
%Variation	59.80	17.30	10.40
Cum. %Variation	59.80	77.10	87.50

In the study of Phung *et al*. [7], the emission load from traffic and industrial activities in Ho Chi Minh city, Vietnam, were calculated to support further prediction. The inventory of air pollution emissions from different human activities was recognized by combining bottom-up and top-down approaches to predict the emission formation in Can Tho city, Vietnam [47]. Studies in Vietnam mostly focus on the application of different models to predict air quality in the future. Meanwhile, the study on air quality assessment in Malaysia employed principal component analysis to determine major sources of air pollution, including transportation, industries and densely populated areas [10]. The ambient air quality of some large cities in Pakistan was evaluated by comparing it with the national environmental quality standards and air quality index [23]. In this study, the variations of air quality in An Giang province during 10 years over seasons and different impacts were evaluated. Moreover, the application of PCA and correlation analysis has effectively exploited the huge monitoring data to unravel the important factors controlling air quality and potential pollution sources. Therefore, the findings of this study can contribute to halting the impairment of air quality. Moreover, it is required to apply models to predict the evolution of air quality under the impacts of climate change and humans in further studies and health risks.

IV. CONCLUSIONS

The evolution of air quality in An Giang province in the period 2010-2020 was within the allowable limits. However, the concentrations of some air pollutants (TSP, HF) in quarries and brick kilns exceeded the limits. There were significant differences in all parameters during the study period, except NH_3 and HF. The concentrations of these parameters found in different areas tended to be higher in the dry seasons. Pollutants and meteorological parameters were both significantly correlated. The results from PCA revealed that three PCs obtained from PCA could explain 87% of the total variance. All selected parameters to analyze in this study significantly contributed to the variations in air quality. The results showed that traffic and urban areas release significant amounts of CO, NO_2 and SO_2 into the atmosphere. NH_3 and H_2S were mainly contributed from the landfill area with the anaerobic decomposition of organic matters. HF was a concentrated gas at brick kilns. It is suggested that these analyzed parameters should be maintained in future air quality monitoring programs in order to establish prompt emission control solutions.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Dr. Nguyen Thanh Giao designed the research and methodologies; Ms. Huynh Thi Hong Nhien and Ms. Le Thi Diem Mi conducted the research, analyzed the data and drafted the manuscript; Dr. Nguyen Thanh Giao revised and finalized the manuscript; all authors had approved the final version.

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