NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

# Evaluating Air Quality in Hau Giang Province, Vietnam Using Multivariate Statistical Analysis

***Nguyen Thanh Giao***

[1]College of Environment and Natural Resources, Can Tho University, Vietnam
[*]Corresponding Author Email: ntgiao@ctu.edu.vn

**Article Info**

*Received 03 May 2021*
*Revised 17 May 2021*
*Accepted 28 May 2021*
*Available online 31 August 2021*

***Keywords*:**
*air quality, noise, Hau Giang province, background monitoring, impact monitoring.*

https://doi.org/10.37933/nipes/3.3.2021.2

**https://nipesjournals.org.ng**


**Abstract**

*Air pollution not only has serious impacts on public health, but also affects ecosystems and increases the impact of climate change. This study evaluated air quality at 13 locations (one base station (KK01) and 12 impact stations (KK02, KK03, KK04, KK05, KK06, KK07, KK08, KK11, KK12, KK14, KK19 and KK28)) belonging to eight districts, towns and cities in Hau Giang province with a frequency of six times/year (January, March, May, July, September, and November) with four replicates in each monitoring phase. Noise, total suspended particles (TSP), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), carbon monoxide (CO) and hydrogen sulfide ($H_2S$) parameters are used to evaluate the quality of the air environment. Noise is compared with national technical regulations on noise (QCVN 26: 2010/BTNMT), $H_2S$ is compared with national technical regulations on some hazardous substances in ambient air (QCVN 06: 2009/BTBMT), while the remaining indicators are evaluated using national technical regulations on ambient air quality (QCVN 05: 2013/BTNMT). Methods of cluster analysis (CA) and principal component analysis (PCA) are used to group air quality and main indicators affecting the quality of the air environment. Research results show that, the air environment in Hau Giang province in 2020 is mainly noise pollution. The criteria including TSP, $NO_2$, $SO_2$, CO and $H_2S$ are within the permissible limits of current regulations. The PCA results show that 6 indicators selected for the initial monitoring all contribute to the impact on air quality in the area. Sources of air pollutants generated by vehicles in main traffic axes, centers, industrial activities, coal-making villages, gases generated from landfills, people's activities through cooking process. Analysis of CA according to the observed frequency shows that air quality is divided into two groups mainly due to TSP. The CA results by locations show that the choice of the base ambient air monitoring location is satisfactory because the base and impact monitoring points are classified into two distinct groups. Research results provide important information on environmental quality and the significance of the monitoring indicators selection.*

## 1. Introduction

Over the past years, with the trend of innovation in international integration and cooperation, Vietnam has made breakthrough economic developments, making people's lives better. Along with the rapid economic development, the environments have been increasingly polluted affecting human health. Needs of rapid economic development with high profit target, people have deliberately

ignored the environmental impacts. Among the environmental components, the atmospheric environment is vital to sustaining life on Earth, including human life. However, air is also the fastest spreading medium of gaseous pollutants of the three environmental components: soil, water, and gas. Air pollution is not only a problem in urban areas, cities, industrial zones, but it has spread to the whole society and become a common concern of the world. Air pollution caused by emissions from transport, industry and daily activities becomes more and more serious and affects the health of urban residents, especially for some vulnerable people such as the elderly and children [1]. It was reported that more than 95% of the world's population is breathing in polluted air, and up to 60% of people live in areas that do not meet the basic standards of world health organizations. Accordingly, air pollution is the fourth highest cause of death in the world, second only to high blood pressure, malnutrition and smoking. Air pollution is related to human health on the basis of ecological problems, which are related not only to humans but also to the life of plants and animals. During the time, air pollutants will be present in soil, water, even in human food [2]. Typical pollutants in urban and industrial air environments are total suspended particles (TSP), suspended particles less than 10 µm (PM10) in diameter, sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), carbon dioxide ($CO_2$), hydrogen sulfur ($H_2S$) and hydrogen fluoride (HF), lead (Pb), $SO_2$ and $NO_2$ [2].

Hau Giang has a favorable geographical position, located on the important waterway transportation routes of the western sub-region of Hau River. The province has major economic exchange points with Soc Trang, Bac Lieu, Kien Giang and Can Tho City - the central urban area of the Mekong Delta region. The above prime location creates favorable conditions for the province to develop economy, to build modern industrial zones for export, agricultural product processing industry, satellite port and transit for Cai Cui port, urban population and concentrated commercial area corresponding to the pace of industrialization and modernization of Can Tho City as well as the entire Mekong Delta region. Hau Giang promotes agricultural economic development associated with building a new countryside, developing many production models based on existing strengths. In parallel with oriented agricultural development, Hau Giang has gradually transformed the economic structure, gradually reduced the proportion of agriculture, towards the development of industry, trade and investment attraction. The socio-economic infrastructure is constantly developing. Many projects have been completed and put into use, practically serving the province's socio-economic development. Transport infrastructure has built a synchronous, step-by-step traffic network connecting hamlets to communes, districts and provinces and connecting to the national highway system, creating favorable conditions for the transportation of goods. Urban infrastructure is also invested and developed. Education and training infrastructure, science and technology develop rapidly. Hau Giang has the highest GRDP growth rate in the Mekong River Delta and ranks $20^{th}$ in the country. Currently, the province has over 176 enterprises and more than 4,644 individual processing establishments operating in industrial production. With the economy on the rise of Hau Giang province, the trend of reducing the proportion of agriculture, increasing the proportion of industry, construction, commerce and tourism, the speed of urban development as well as industrialization in the area. The province table took place quickly. Stemming from the above problems and realizing the importance of habitat quality, this study evaluates the air environment quality of Hau Giang province by 2020 using multivariate statistics.

## 2. Materials and methods

### *2.1 Description of the study area*

Hau Giang is a province in the center of the Mekong River delta, the capital city of Vi Thanh province, 240km southwest of Ho Chi Minh City along the national highways and waterways; 60km from Can Tho city along Highway 61 and 40km from the road connecting Vi Thanh city - Can Tho city. Hau Giang's topography is relatively flat, with lower elevation from North to South and from East to West. Hau Giang province is located in the tropical monsoon climate, divided into two

distinct seasons. Rainy season has southwest wind from May to November, dry season has northeast wind from December to April next year. Hau Giang province in the North borders Can Tho city - the driving force center to attract resources of the Mekong River Delta region; the South borders Soc Trang province; The East borders on the Hau River with great potentials for fresh water supply, river and sea transportation, river sand exploitation and leveling and Vinh Long province - the main waterway to Cai Cui and Can Tho international ports; the West borders Kien Giang province and Bac Lieu province.

In addition to the two National Highway 1A and Highway 61 running through, Hau Giang has a very convenient network of rivers and canals with an important waterway traffic axis, the Hau River - one of the two major river branches of the Mekong River. Xa No canal and Phung Hiep canal are a national waterway from Ho Chi Minh City across the delta to the West Sea, connecting the Mekong Delta provinces to Cambodia, the East Sea and Southeast Asian countries. Thanks to its convenient location, Hau Giang province has built many industrial parks into operation. Hau River Industrial Urban Area, scale of 3,275ha; Tan Phu Thanh industrial cluster, scale of 201ha; Vi Thanh industrial cluster with an area of 53ha; Nga Bay industrial cluster, scale of 25ha. Currently, the industrial zones and clusters in the area attract many investors to register for production and business activities, gradually filling the area. Not only that, Hau Giang is also a land that preserves many historical and cultural relics imbued with national identity in the Southern region of the river, very convenient for tourism development.

### *2.2 Sampling and analysis of air quality*

To assess the air quality in Hau Giang province in 2020, the study collected air quality data from the Department of Natural Resources and Environment of Hau Giang province at 13 monitoring locations representing eight districts, towns and cities in the province in urban areas, industrial zones, landfills, busy traffic routes, intersections, and places where the air environment is heavily affected (Figure 1). Specifically, the air samples were collected at three locations in Phung Hiep District (KK01, KK07, KK19); two points in Vi Thanh city (KK02, KK14), two points in Chau Thanh A district (KK04, KK12), and two points in Nga Bay 2 town (KK06, KK11); Vi Thuy district, Chau Thanh district, Long My town and Long My district were collected one monitoring location, respectively KK03, KK05, KK08, KK28. In which, there is one base monitoring station (KK01), the remaining positions belong to the impact monitoring station. The air environment components are sampled with a frequency of 6 times/year in months (January, March, May, July, September, and November) with four replicates in each monitoring phase with four replications. Evaluating the air quality of Hau Giang province in 2020 through six indicators including noise, total suspended particles (TSP), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), carbon monoxide (CO) and hydrogen sulfide ($H_2S$). The parameters of noise, TSP, $NO_2$, $SO_2$ and CO are collected at all monitoring positions. Particularly, $H_2S$ is only collected at three locations (KK12, KK14, and KK19). Noise was measured in the field. The remaining indicators including TSP, $NO_2$, $SO_2$ and CO were analyzed at the Laboratory of Center for Natural Resources and Environment Monitoring in Hau Giang province by standard methods (Table 1).

### *2.3 Data processing*

The data on air quality (noise, TSP, $NO_2$, $SO_2$, CO and $H_2S$) are presented as Mean ± SD. The difference in air environment quality values between sampling locations were analyzed using one-way analysis of variance, Duncan test at 95% confidence level using SPSS statistical software. In this study, the noise was assessed using the national technical regulation on noise (QCVN 26: 2010/BTNMT) [3], the $H_2S$ was compared with the national technical regulation on some hazardous substances in the surrounding air (QCVN 06: 2009/BTBMT) [4], while the remaining indicators are evaluated using national technical regulations on ambient air quality (QCVN 05: 2013/BTNMT) [5] (Table 1). Principal Component Analysis (PCA) is used to determine the main factors affecting air quality in the study area. Analysis of principal components is based on a set of data on average

values of the air environment components at each monitoring location. PCA reduces computation costs on the original data set, builds new coordinate axes, instead of keeping the axes of the old space, but is equally good at data representation and ensures variability of the data on each new dimension. These cuts are made by converting the data into a new set of key variables (PCs). Cluster analysis (CA) to determine the air quality of the study area classified by similar groups based on the average value data of the air environment components by each location and monitoring time. All calculations and statistical analysis were performed using Excel version 2016 software (Microsoft Crop., Washington, DC, USA), SPSS version 20 software (IBM Crop., Armonk, NY, USA) and Primer software version 5 (Primer-E Ltd.), Plymouth, UK).

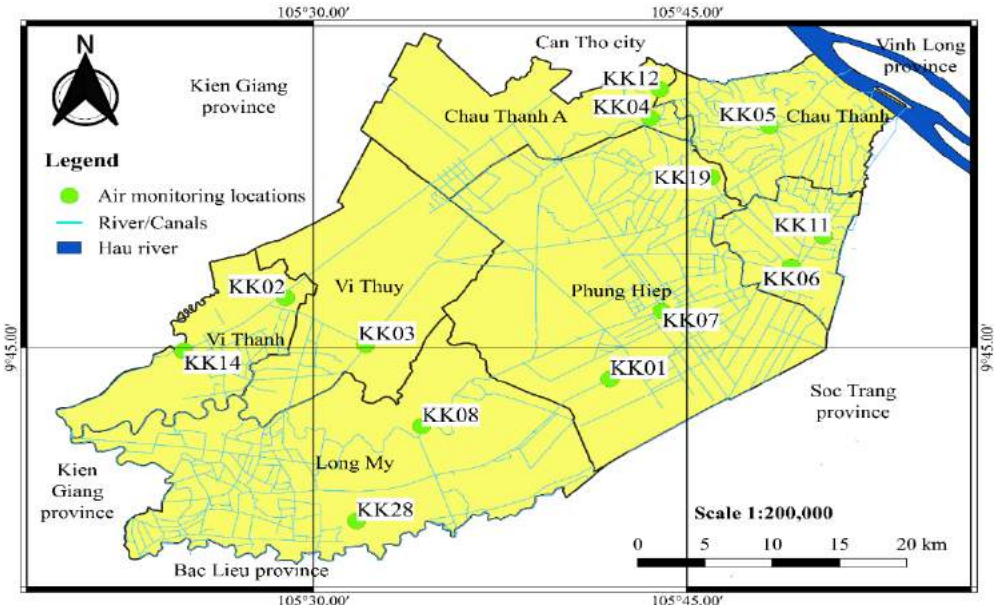


**Figure 1. Map of the air monitoring sites in Hau Giang province in 2020**

**Table 1. Analytical methods and limit values of the air quality parameters**

| No. | Variables | Methods | Limit values | | |
|---|---|---|---|---|---|
| | | | QCVN 26:2010/BTNMT | QCVN 05:2013/BTNMT (Mean of 1hr) | QCVN 06:2009/BTNMT (Mean of 1hr) |
| 1 | Noise (dBA) | TCVN 7878-2:2010 | 70 | | |
| 2 | TSP (µg/m³) | TCVN 5067:1995 | | 300 | |
| 3 | $NO_2$ (µg/m³) | TCVN 6137:2009 | | 200 | |
| 4 | $SO_2$ (µg/m³) | TCVN 5971:1995 | | 350 | |
| 5 | CO (µg/m³) | HDCV.TN-CO | | 30000 | |
| 6 | $H_2S$ (µg/m³) | TQKT/2002/BYT | | | 42 |

## 3. Results and discussion

### *3.1 Evolution of air quality in Hau Giang province in 2020*

#### *3.1.1 Noise*

Noise is a very common form of pollution in urban, industrial and transportation, the bigger the city, the busier the city, the more traffic and production develops, the heavier the noise pollution. The study shows that noise at each location over the observed months of the year ranges from 57-76 dBA (Figure 2a) with an average of 59.67 ± 1.51-72.67 ± 2.07 dBA (Table 2). Analysis results at points KK02 - the intersection of Vo Nguyen Giap Boulevard with Vo Van Kiet Street (July, September and November), KK03 - in front of the post office gate of Vi Thuy district (May, July and September), KK04 - Cai Tac junction (January, March, May, July, September, November),

KK05 - next to the District People's Committee, Nga Sau town (May, September, November), KK06 – National Road 1A fork to Nga Bay market (January , May, July, September), KK07 - in front of the gate of Phung Hiep District People's Committee (May), KK08 - The crossroads to the new bridge (May, July), KK12 - in front of the gate of Tan Phu Thanh Industrial Park (May, July, September, November), KK14 - 50m from Vi Thanh Street Enterprise (January, March) and KK19 - Near Tan Long landfill (May, July, September, and November) has a value exceeding the permitted standard QCVN 26: 2010/BTNMT [3] from 1.0-1.1 times. The above monitoring places are areas with densely populated areas, with vehicles moving often, especially at peak hours with more traffic volume. In Ho Chi Minh City, it was also shown that noise exceeded the permitted limit ranging from 70.5-81.6 dBA (exceeding 1.0-1.17 times) in the period 2010-2017, mainly caused by traffic activities [6]. Viet and Kim (2008) [7] also showed that in areas with heavy traffic volume, at bus stations, main traffic axes noise exceeded the permitted limit. Particularly point KK01 - Lung Ngoc Hoang Nature Reserve over the observed months of the year has a lower value than the remaining impact monitoring points ranging from 57-61 dBA.

### *3.1.2 TSP*

Total suspended particles is a parameter evaluating the degree of air pollution by solid particles originating from many different sources. They are particles with very poor settling rate and persist in natural air. The size of these dust particles is quite small to very small, they directly affect the respiratory tract and are able to penetrate inside the alveoli causing many serious human lung diseases. The total suspended dust (TSP) at each location over the months of observation in the year ranges from 17-319 µg/m$^3$ (Figure 2b) with an average of 53.83 ± 29.96-187.83 ± 98.04 µg/m$^3$ (Table 2). Compared to another study in Son La city in the period of 2017 through three monitoring phases, air pollution is mainly TSP concentrated mainly in the junction areas, intersections where the intersections are located main road axis, bus station, market gate, hospital gate, where major construction activities take place, typically the city bus intersection monitoring point. Son La has a TSP content exceeding the standard 2.9-3.35 times higher than the standard, the Cau Trang intersection area exceeds 2.52-4.12 times the standard [8]. According to research by Duyen et al. (2014) [9], dust content in the survey area of Tien Yen district, Quang Nam province is still within the allowable limit ranging from 62-282 µg/m$^3$. In summary, in the study area, the TSP content is still within the permitted limit QCVN 05: 2013/BTNMT [5], except for the location KK11 - Coal Craft Village (March) whose value exceeds the permitted limit by 1.06 times.

### *3.1.3 $NO_2$*

There are many types of nitrogen oxides, but the most common are NO and $NO_2$. This gas is formed when nitrogen and oxygen in the air combined at high temperature. Therefore, it is only commonly found in industrial zones and large urban areas. In the atmosphere, $NO_2$ combines with the OH radicals in the air to form $HNO_3$. When it rains $NO_2$ and $HNO_3$ molecules fall to the ground by rain, reducing the pH of rainwater. People who are exposed to $NO_2$ at 0.06 ppm will increase respiratory diseases. People can recognize the smell of $NO_2$ when the air contains $NO_2$ with a concentration greater than or equal to 0.12 ppm. With a concentration of 5 ppm, $NO_2$ is harmful to the respiratory apparatus after a few minutes and at a concentration between 1.5 and 50 ppm, $NO_2$ will harm the heart and lungs for a few hours. In the study area, the $NO_2$ content at each location over 6 monitoring times a year has the value ranging from 0-140 µg/m$^3$ (Figure 2c) with an average of 0-109.33 ± 16.75 µg/m$^3$ (Table 2). According to Hung et al. (2020) [10], the $NO^2$ content at the Lao Cai city monitoring points is lower than the current study area, ranging from 6-18 µg/m$^3$. Another study in Tien Yen district, Quang Nam province also has a lower value of $NO^2$ from 15.4-28.7 µg/m$^3$ [9]. According to Le Huy Ba (2000) [11], pollution caused by traffic is generated from chimneys, exhaust pipes of vehicles containing a lot of $NO_2$, in addition to industrial activities such as brewing, alcohol production, paper, coal burning, oil burning. Through the research results, the

$NO_2$ content in the surveyed area is still within the allowable limits QCVN 05: 2013/BTNMT [5] and the background monitoring area - Conservation area Naturally, Lung Ngoc Hoang did not detect the $NO_2$ content.

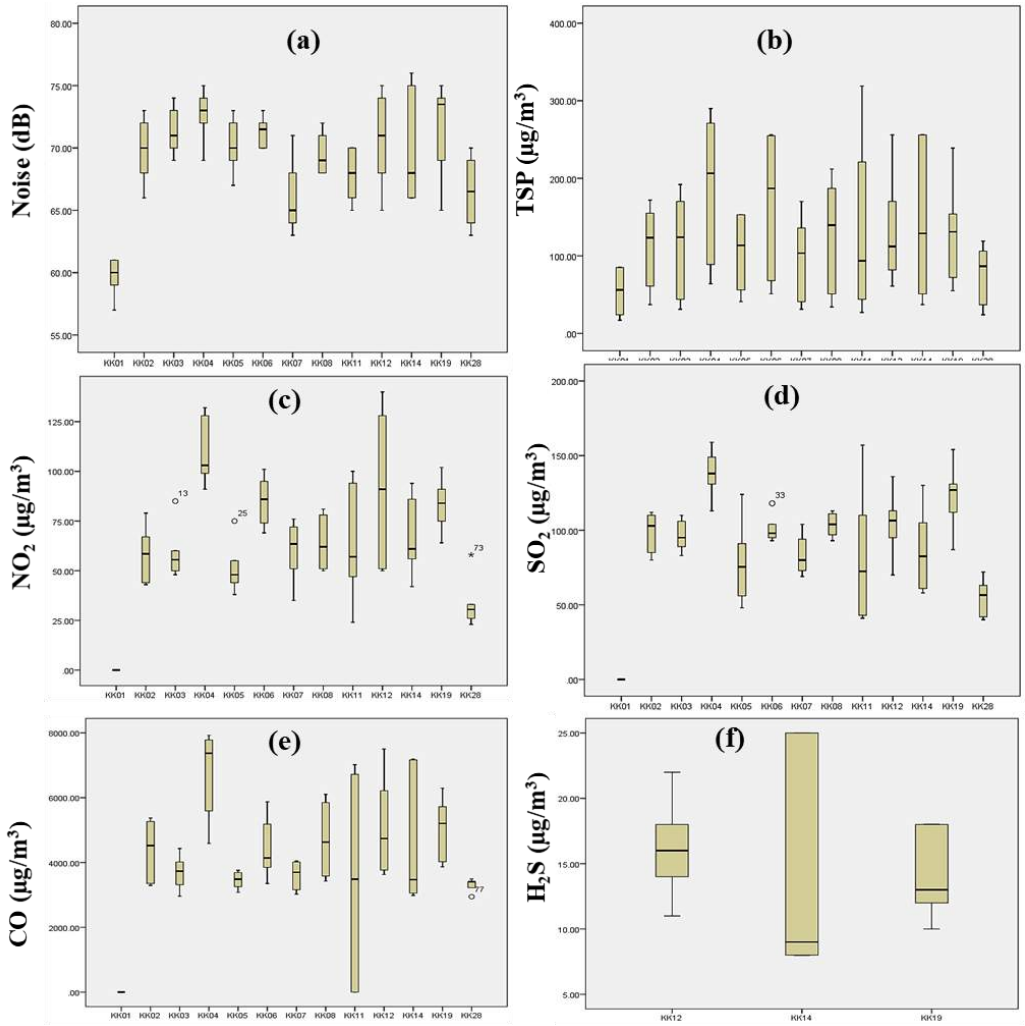


**Figure 2. Variation of Air quality in Hau Giang province in 2020**

### *3.1.4 $SO_2$*

$SO_2$ is considered to be the most important pollutant in the sulfur oxide family, a colorless, non-flammable gas with a pungent taste when it has a concentration in the air of less than one part per million (1 ppm), it has a pungent taste strong and has an irritating taste when its concentration is about three parts per million [2]. The results of the study showed that the concentration of $SO_2$ fluctuated in the range of 0-159 µg/m$^3$ (Figure 2d) with an average ranging from 0-138.00 ± 16.04 µg/m$^3$ (Table 2). In the monitoring area in the center of Hue city in the period 2005-2007, the $SO_2$ content fluctuated in the range of 8-49 µg/m$^3$, in Chan May and Phu Bai industrial zones in the period 2005-2007, the mean $SO_2$ is about 7-33 µg/m$^3$, within the permitted limits of QCVN 05: 2013/BTNMT [7]. According to Hai et al. (2004) [12], $SO_2$ content in pottery production villages in Bat Trang commune is relatively high, ranging from 680-1150 µg/m$^3$, exceeding 1.94-3.29 times in QCVN 05: 2013/BTNMT [5], emissions from burning fuels such as gas, coal, firewood, straw and the burning reactions in the production process along with emissions from vehicles and people's daily life. According to Nhu et al. (2019)[13], $SO_2$ is produced during coal production but mainly in the later stages because when the temperature rises, the sulfur in the wood is burned, the amount of oxygen is less and less, and more $SO_2$ is produced. In summary, in the study area, the concentration of $SO_2$ is still within the allowable limit of the QCVN 05: 2013/BTNMT [5] standard

and the background monitoring station - Lung Ngoc Hoang Nature Reserve does not detect $SO_2$. Similar to $NO_2$, $SO_2$ is also generated from vehicle engines powered by gasoline, oil, and coal-fired furnaces.

**Table 2. Average values of air parameters in Hau Giang province in 2020**

| Parameter | Noise (dBA) | TSP (µg/m$^3$) | $NO_2$ (µg/m$^3$) | $SO_2$ (µg/m$^3$) | CO (µg/m$^3$) | $H_2S$ (µg/m$^3$) |
|---|---|---|---|---|---|---|
| **KK01** | 59.67±1.51 | 53.83±29.96 | 0.00 | 0.00 | 0.00 | |
| **KK02** | 69.83±2.86 | 112.00±53.59 | 58.33±14.53 | 98.83±13.63 | 4388.33±920.16 | |
| **KK03** | 71.33±1.97 | 114.17±67.66 | 59.00±13.48 | 96.33±10.46 | 3698.83±533.17 | |
| **KK04** | 72.67±2.07 | 187.83±98.04 | 109.33±16.75 | 138.00±16.04 | 6771.33±1362.73 | |
| **KK05** | 70.17±2.23 | 105.00±52.48 | 51.33±12.86 | 78.33±27.35 | 3459.33±273.21 | |
| **KK06** | 71.33±1.21 | 167.33±98.96 | 85.17±12.91 | 101.00±9.12 | 4423.33±933.54 | |
| **KK07** | 66.00±2.97 | 97.50±54.60 | 60.17±15.97 | 83.33±13.60 | 3607.67±429.29 | |
| **KK08** | 69.50±1.64 | 127.17±74.06 | 64.00±14.04 | 103.67±8.14 | 4703.50±1260.43 | |
| **KK11** | 67.83±2.04 | 133.00±114.82 | 63.17±29.25 | 82.67±47.09 | 3451.33±3073.21 | |
| **KK12** | 70.67±3.72 | 132.17±71.22 | 91.83±37.55 | 104.50±21.70 | 5099.00±1521.26 | 16.17±3.71 |
| **KK14** | 69.83±4.49 | 143.00±98.99 | 66.67±19.54 | 86.50±28.26 | 4557.00±2041.07 | 14.00±8.53 |
| **KK19** | 71.67±3.88 | 130.33±66.48 | 83.33±13.11 | 123.00±22.28 | 5052.83±953.30 | 14.00±3.29 |
| **KK28** | 66.50±2.74 | 76.50±37.94 | 33.50±12.57 | 55.00±12.46 | 3314.17±200.98 | |
| **QCVN** | 70 | 300 | 200 | 350 | 30000 | 42 |

### *3.1.5 CO*

CO generated in the incomplete combustion of carbon-based fuels such as coal, firewood, oil, gases. CO is colorless, odorless, in the air, CO is slowly oxidized to $CO_2$ [11]. The harm of CO is mainly to humans and animals because CO has a very strong affinity for red blood cells in the blood, leading to fatal complications due to lack of oxygen in the blood. The CO mixture in the air at the limited concentration will become an explosive mixture. CO is a particularly dangerous gas for electrostatic dust filters when filtering kiln flue or furnace flue gases that accumulate in enclosed spaces. In the study area, the CO content at each location over 6 monitoring times a year has the value ranging from 0-7952 µg/m$^3$ (Figure 2e) with an average of 0-6771.33 ± 1362.73 µg/m$^3$ (Table 2). In Ho Chi Minh City in the period 2010-2017, the CO content was higher than the current study area, ranging from 5,140.8-15,660 µg/m$^3$, although higher, the CO content was still within the permitted limit [6]. According to Le Huy Ba (2000) [11], transport activity is the source of emissions that generate the most CO from burning fuel. In the Bilbao area, the amount of CO affected by vehicles ranged from 0.4-3.925 µg/m$^3$ [14]. In addition, according to Msuya et al. (2011) [15], charcoal is the process of burning wood charcoal in the absence of oxygen in a closed furnace, creating a large amount of $CO_2$ and CO. In summary, the analytical results showed that the CO concentration in the study area was still within the allowable limits QCVN 05: 2013/BTNMT [5] and CO remained undetectable in Lung Ngoc Hoang area - the background monitoring station.

### *3.1.6 $H_2S$*

Hydrogen sulfide is a toxic gas with no color but with a very unpleasant rotten smell. In nature, $H_2S$ is caused by organic matters, rotten vegetables, especially in shallow water, shallow rivers and lakes. It is also produced in drains and coal mines, landfills. In industrial production, $H_2S$ is produced by the use of sulfur-containing fuels. $H_2S$ damages plant leaves, defoliates and reduces plant growth. Low levels of $H_2S$ have caused headaches and mental fatigue. High concentrations cause coma and can be fatal. The study only conducted monitoring at three locations, Tan Phu Thanh Industrial Park, near Vi Thanh Road Enterprise (50m away) and near Tan Long landfill with values ranging from 8-25 µg/m$^3$ (Figure 2f) with an average of 14.00 ± 3.29-16.17 ± 3.71 µg/m$^3$ (Table 2). Some of the characteristics of a landfill are odor. The odor arises during waste decomposition, most of which are emitted shortly after dumping and gradually decreases with the onset of the methane

generation phase [16]. Vi Thanh Sugar Enterprise, the main source of input materials for sugarcane, created an equivalent amount of cane fiber after being pressed, some impurities from sugarcane including young leaves and tops. The amount of solid waste together with wastewater in the production process will create if not handled properly, over time decomposition forms an unpleasant odor. In Tan Phu Thanh Industrial Park, there are many enterprises with different types. According to research Quang et al. (2018) [17], in some seafood processing facilities, the $H_2S$ content ranges from 14-141 µg/m$^3$. In the area of concentrated livestock activities in Tan Thanh district, Ba Ria - Vung Tau province, the average maximum concentration of one hour of $H_2S$ is 57.4 µg/m$^3$, 1.37 times higher than the current standard [18]. According to Thao and Lang (2013) [19], also at the Can Tho seafood processing facility, the odor arises from fish materials, from wastewater, sewers, especially fish organs, which often contain enzymes and bacteria, in the digestive system quickly rancid and causes bad smell ranging from 340-400 µg/m$^3$. The research results in the surveyed areas, the concentration of $H_2S$ is still within the allowable limits of the QCVN 06: 2009/BTNMT standard [4].

### 3.2 The main factors affecting the air quality of Hau Giang province in 2020

PCA determines the main factors affecting air quality in the study area, and at the same time identifying the main emission sources in the area. According to Feher et al. (2016) [20], correlations between major components and baseline data variables are explained by weighted correlation data. Absolute values for weighting factors below 0.5 are weak, mean correlations between 0.5-0.75 and above 0.75 are believed to be strongly correlated [21].

**Table 3. The main factors affecting air quality in Hau Giang province by 2020**

| Variable | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Noise | **0.432** | -0.08 | **0.508** | **-0.702** |
| TSP | **0.422** | -0.158 | **-0.741** | **-0.344** |
| $NO_2$ | **0.451** | -0.002 | -0.257 | 0.264 |
| $SO_2$ | **0.448** | -0.106 | **0.309** | 0.263 |
| CO | **0.447** | -0.047 | 0.173 | **0.496** |
| $H_2S$ | 0.175 | **0.977** | -0.037 | -0.06 |
| **Eigenvalues** | 4.69 | 0.9 | 0.23 | 0.12 |
| **%Variation** | 78.2 | 14.9 | 3.8 | 1.9 |
| **Cum.%Variation** | 78.2 | 93.2 | 97 | 98.9 |

The results of main component analysis (PCA) showed that there are 4 factors that explain 98.9% of the variation in air quality in the study area of Hau Giang province by 2020 (Table 3). According to Shrestha & Kazama (2007), a PC with an eigenvalues value greater than 1 is considered significant. In the analysis, PC2, PC3, PC4 are all less than 1, but PC2 has the contributions of $H_2S$ at a very close correlation, PC3 and PC4 have the contributions of TSP and noise, respectively. The eigenvalues values sorted in descending order are 4.69, 0.9, 0.23, 0.12, respectively. PC1 accounts for 78.2% of the total variation of the obtained data. PC1 is affected by positive coefficients with weak correlation of noise (0.432), TSP (0.422), $NO_2$ (0.451), $SO_2$ (0.448) and CO (0.447). PC1 shows the regional air quality affected by most sources of emissions such as emissions from vehicles, manufacturing through fuel combustion, engine operation in the area. PC2 explains 14.9% of the total variation of the obtained data, which is strongly correlated with $H_2S$ (0.977), equivalent to the $H_2S$ study results in three areas near Tan Phu Thanh Industrial Park, near Vi Thanh Street Enterprise and Tan Long landfill. PC3 correlates on average with noise (0.508) and TSP (-0.741), weakly correlated with $SO_2$ (0.309). PC3 explains 3.8% of the total variation is influenced mainly by traffic activity in the locality. PC4 explained 1.9% of the variation in regional air quality at medium correlation with noise (-0.702), weak correlation with TSP (-0.344) and CO (0.496). PC4

is not influenced by transportation, but also from production from the largest coal craft village in the world. From the PCA results, it shows that the 6 selected initial monitoring indicators are representative of the sources of pollution in the area. Thus, the possibility that Hau Giang province can cause air pollution from traffic activities, industrial production, craft villages, daily activities of households and a part of the contribution from the landfill in the area. Thus, it can be seen that six indicators including noise, TSP, $NO_2$, $SO_2$, CO and $H_2S$ should be further included in the monitoring program to monitor air quality fluctuations in Hau Giang province.

### 3.3 Clustering Air quality in Hau Giang province in 2020

Cluster analysis (CA) results according to monitoring frequency, divided air quality into two clusters of air quality (Figure 3). Cluster I consist of July, September and November representing the rainy season months. Cluster II includes 2 months of the dry season (January and March) and the first month of the rainy season (May). The differences between the two clusters are mainly due to the total suspended particles (TSP) content, specifically Cluster II is 2.78 times higher than Cluster I (Table 4), Cluster II focuses on hot and windy months affecting pollutant dispersion. Thus, the monitoring frequency can be shortened, from 6 times/year to 2 times/year.

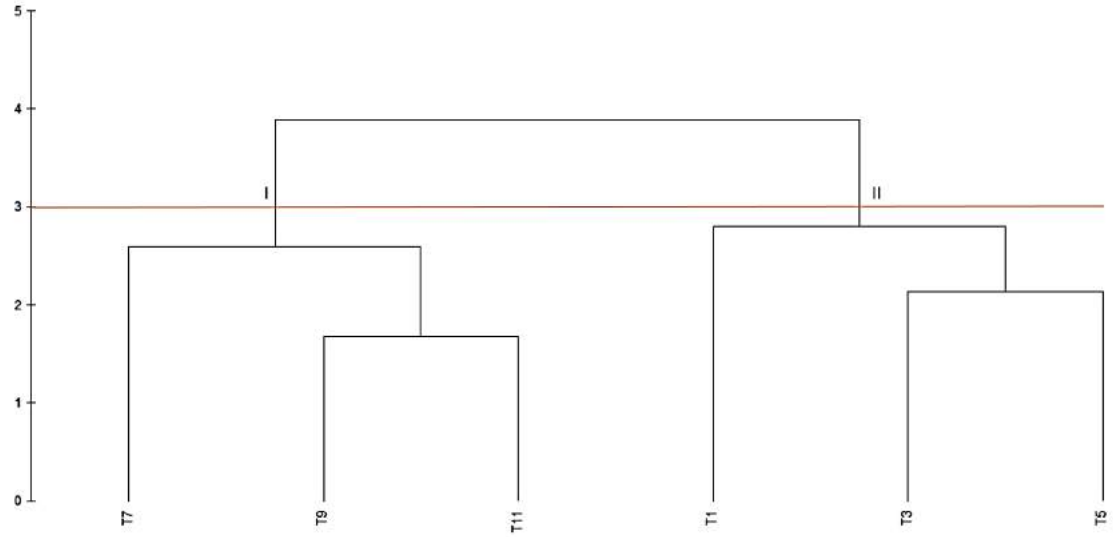


**Figure 3. Cluster analysis by sampling frequency**

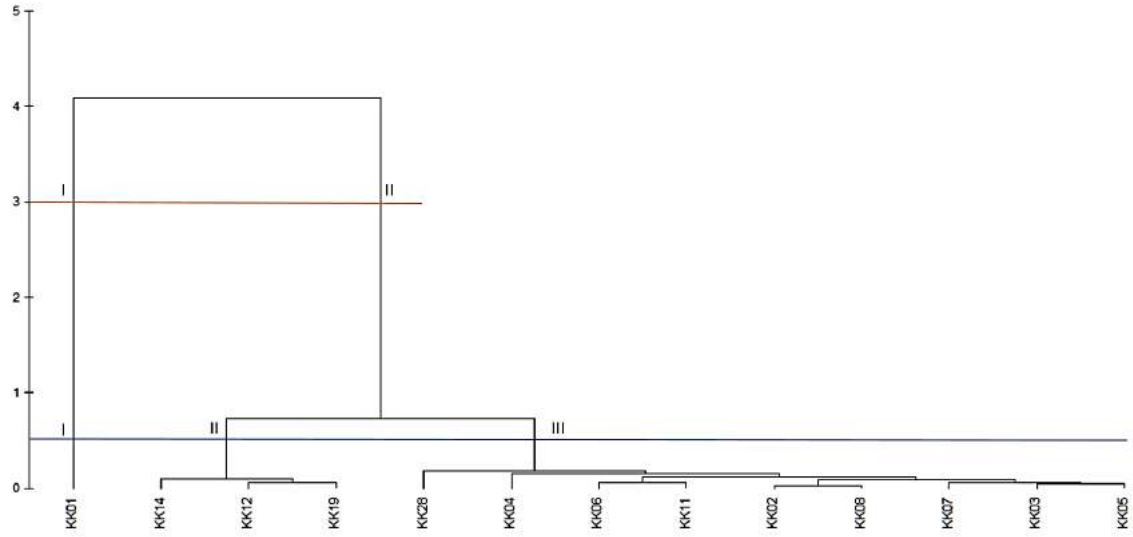


**Figure 4. Cluster analysis by monitoring locations**

In addition to cluster analysis according to the monitoring period, the average data of parameters at each location is also analyzed to determine the locations with similar air quality. Through CA results, air quality is divided into two similar cluster (red line), similar to the choice of monitoring type (Figure 4). Specifically, Cluster I (KK01-Lung Ngoc Hoang Nature Reserve) is the base station, least affected, mainly manifested through two environmental components of noise and TSP (Table 4); Cluster II includes the remaining locations, the impact monitoring station affected by emissions from engines, vehicles, production and daily activities in the area, along with emissions from landfills area. To see more clearly the air quality of Hau Giang province in 2020 (green line), Cluster analysis further divided air monitoring locations into three clusters (Figure 4) in which cluster I is similar as shown above. Cluster II and Cluster III are in the same branch, but Cluster II has the additional contribution of $H_2S$ (Table 4).

**Table 4. Results of cluster analysis by monitoring time and location**

| Parameter | Time | | Sampling | | | QCVN |
|---|---|---|---|---|---|---|
| | Cluster I | Cluster II | Cluster I | Cluster II | Cluster III | |
| Noise | 69.31 | 68.69 | 59.67 | 70.72 | 69.46 | 70.00 |
| TSP | **64.31** | **178.74** | 53.83 | 135.17 | 124.50 | 300.00 |
| $NO_2$ | 62.69 | 64.36 | **0.00** | 80.61 | 64.89 | 200.00 |
| $SO_2$ | 78.92 | 98.18 | **0.00** | 104.67 | 93.02 | 350.00 |
| CO | 3460.72 | 4620.31 | **0.00** | 4902.94 | 4201.98 | 30000.00 |
| $H_2S$ | 11.67 | 17.78 | - | **14.72** | - | 42.00 |

## 4. Conclusion

Air quality in Hau Giang province in 2020 is mainly noise pollution, 1.0-1.1 times higher than QCVN 26: 2010/BTNMT. The air quality criteria comprising of TSP, $NO_2$, $SO_2$, CO and $H_2S$ are still within the permissible limits of current regulations. At the base monitoring station - Lung Ngoc Hoang Nature Reserve, the air quality is better than the remaining impact monitoring locations. Noise in the study area arises mainly from the traffic vehicles in main roads, centers, and densely populated areas, areas where production and business activities are concentrated. Through analysis of main components, 6 indicators (noise, TSP, $NO_2$, $SO_2$, CO and $H_2S$) all contribute to the influence on the air quality in the study area. The main source of pollution is traffic activities, industrial production-trade villages, daily activities of households, and gas emitted from the local landfill. Cluster analysis by monitoring frequency divided air quality into two clusters due TSP content in which Cluster II has TSP 2.78 times higher than that in Cluster I. Cluster analysis according to monitoring locations divided air quality into two clusters in which baseline station formed one cluster (Cluster I) while all sites of the impact monitoring locations made the other cluster (Cluster II). This suggests that the selection of Lung Ngoc Hoang as baseline site for air quality monitoring is appropriate.

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