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Characteristics of fine dust pollution $PM_{2.5}$ in Hanoi in 2021

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Abstract: Fine particulate matter ($PM_{2.5}$) is one of the most dangerous pollutions in the atmosphere in the Hanoi capital. $PM_{2.5}$ fine dust pollution characteristics in Hanoi in the duration from 5/2021 to 3/2022 were studied. The concentration of main chemical elements (such as As, Br, Ca, Cd, Ce, Cl, Cu, Fe, K, Mn, Pb, S, Sr, Ti, Zn, Zr…), main water-soluble ions (such as Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, NO_3^-, F^-, NO_2^-) and black carbon (BC) in the $PM_{2.5}$ sample were analyzed. The average $PM_{2.5}$ fine dust concentration was (78.09 ± 51.71) µg/m^3 and ranged from 17.55 to 271.39 µg/m^3. $PM_{2.5}$ tended to increase and is about 3.12 times larger than Who Air Quality Guidelines 2005 (25 µg/m^3 for $PM_{2.5}$ 24h). The average $PM_{2.5}$ concentration in the rainy season from 5/2021 to 9/2021 was (51.97 ± 16.40) µg/m^3. This value for the dry season from 10/2021 to 3/2022 was (104.70 ± 61.19) µg/m^3. It was about 2.01 times higher than that in the rainy season. The major contributors were the secondary components such as NH_4^+, SO_4^{2-}, NO_3^- and BC... The main pollution contribution sources and the potential pollution areas map were identified. This research shows a worrying picture of fine dust $PM_{2.5}$ in Hanoi in the studying duration.

Keywords: *$PM_{2.5}$ fine dust in Hanoi 2021, major chemical elements and ions concentrations, main pollution sources, PSCF maps.*

I. INTRODUCTION

Currently, dust pollution in general in densely populated cities is one of the most complicated and difficult problems that many scientists and managers are concerned about, because it is one of the leading causes of air pollution directly affects human health and the ecosystem, especially $PM_{2.5}$ fine dust (fine particles with a diameter of less than 2.5 µm) [1, 13]. This type of dust could penetrate the lungs, harming the lungs, skin and eyes. Dust particles with a diameter of less than 1 µm can partly enter the bloodstream causing heart disease and dementia [12, 21]. Water-soluble inorganic ions such as sulfate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) are often considered the main contributors to atmospheric aerosols [19, 4]. According to the 2019 World Air Quality Report [11], about 6.67 million people in the world died due to exposure to air pollution, including 4.14 million deaths due to $PM_{2.5}$ dust caused by air. More than 90% of pollution-related deaths occur in low- and middle-income countries [5]. In Vietnam, air pollution is one of the top five risk factors causing the burden of disease and premature death, behind only by high blood pressure, smoking, diabetes and risk related to nutritional factors. Countries and territories in East Asia, Southeast Asia and South Asia are experiencing the highest average annual concentrations of $PM_{2.5}$. During the period 2019-2020, Vietnam was the country with the 21st highest average $PM_{2.5}$ dust concentration (µg/m^3) in the list of 106 countries surveyed [11]. Vietnam suffers

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economic losses of 10.8-13.2 billion USD each year due to air pollution, equivalent to about 5% of the country's GDP [20].

The average annual concentration of $PM_{2.5}$ in Vietnam was 34.1 $\mu g/m^3$ in 2019 (Hanoi was 46.9 $\mu g/m^3$). This is a concentration level that is not good for everyone, especially sensitive people at risk of allergic and respiratory problems. WHO recommends an average annual $PM_{2.5}$ exposure threshold of 10 $\mu g/m^3$ to minimize health risks to humans [17]. Statistics from the Hanoi Department of Natural Resources and Environment shown that Hanoi currently has about 35,000 honeycomb charcoal stoves, using about 528 tons of coal every day, emitting about 1,870 tons of CO_2, which is one of the sources of the most emissions. As of the first quarter of 2019, Hanoi has over 700 thousand cars and over 5 million motorbikes of all types. Therefore, traffic activities are also a major source of emissions. Burning post-harvest straw and construction projects also cause major emissions for Hanoi city. Vietnam's coal consumption has doubled and oil consumption has increased by 30% in the past five years [2].

Thus, Vietnam is a country at high risk due to dust pollution. Activities to research the characteristics, evaluate the impact of air pollution on human health and develop air quality control policies are urgent issues today in Vietnam as well as worldwide.

To determine the characteristics of $PM_{2.5}$ fine dust pollution in Hanoi in 2021, 109 $PM_{2.5}$ samples collected in the duration from May 2021 to March 2022 were studied through the implementation of the project coded DTCB.14.21/VKHKTHN. This report will present some of the research results obtained, including $PM_{2.5}$ pollution levels, main pollution sources and maps of potential pollution areas.

II. EXPERIMENT AND RESEARCH METHODOLOGY

A. $PM_{2.5}$ collection

$PM_{2.5}$ fine dust samples were collected at the Institute for Nuclear Science and Technology (KH&KTHN) located on Hoang Quoc Viet Street in Nghia Do ward, Cau Giay district, Hanoi City, near the intersection of Hoang Quoc Viet Street and Nguyen Van Huyen Street coordinate 105.85336^{o}E; 21.06908^{o}N. This location is in an area that includes many scientific research agencies such as the Vietnam Academy of Sciences (including many affiliated research institutes), the Quality Assurance and Testing Center 1, Vietnam - Russia Tropical Center, Ethnology Museum... and quite a few high-rises, densely populated apartments. Traffic density is quite high and congestion often occurs, especially during rush hours (early morning and late afternoon).

The 47 mm diameter Teflon filter from PALL Life Sciences was used to collect samples. Filters before and after sampling were stored in a desiccator. The initial filter mass and $PM_{2.5}$ sample were determined using an AT20 microgram analytical balance, METTLER TOLEDO manufactured in the USA.

$PM_{2.5}$ sample was collected on TWIN DUST device from Zambelli, Aquaria Srl, Italy with cyclone suction head SCC-2.229, BGI Inc., USA. The sampling location was about 12 m above the ground (on the rooftop of a 3-storey building). In this study, $PM_{2.5}$ samples were collected with an average frequency of 2 samples/week (every Monday and Thursday) within a period of about 23.5 hours each to obtain a representative sample for a 24-hour (one day night) starting from 7:00 the previous day to 6:30 am the next day. The airflow through the filter was maintained at 16.7 liters/minute average. During the

period from May 2021 to March 2022, 109 $PM_{2.5}$ samples were collected for the research. Images of the filter and sample are illustrated in Figure 2.

Fig. 1. Location of $PM_{2.5}$ collection at the Institute for Nuclear Science and Technology

B. Analyzing the chemical components of $PM_{2.5}$

1. Analyzing the content of chemical elements

The content of main chemical elements was analyzed on the ED-XRF energy-resolved X-ray fluorescence spectrometer system (Seiko SEA-2110, Japan) according to the basic parameter method with the support of SRM filter standard sample NIST- 2783 and urban dust standard SRM NIST-1648. The spectrometer uses a Si(Li) semiconductor detector, a vacuum measuring chamber, an X-ray tube with Rh target and a fluorescence spectrum processed with X-ray Station software version 6.11.0.0 developed by the Japanese Seiko company [18]. The measurement time for each sample is 1200 seconds. The blank sample (unused filter) and the measured sample were analyzed under the same conditions. The elemental content in the blank sample has been excluded from the reported results.

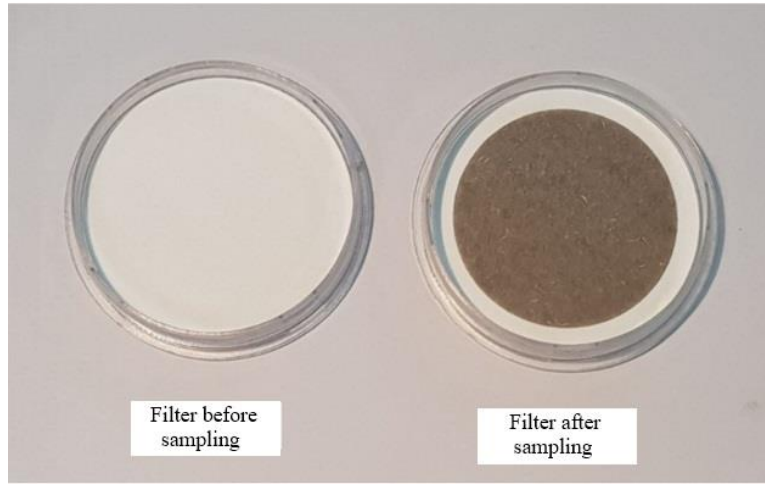

Fig. 2. Filter before (left) and after (right) sampling

3. Analyzing the content of dissolved ions

The content of dissolved ions is mainly analyzed on a US-made DIONEX-600 ion chromatograph using a chemical suppressor and conductivity detector. The sample was extracted in deionized water with a resistivity of 18 MΩ cm^{-1} for 20 minutes and then filtered to remove insoluble residue. Weak basic eluent (1.7 mM $NaHCO_3$ + 1.8 mM Na_2CO_3) with a flow rate of 2.5 mL min^{-1} was used when the content of dissolved anions was analyzed. Weak acid eluent (22 mm H_2SO_4) with a flow rate of 2 mL min^{-1} was used when the content of dissolved cations was analyzed. Mixed ion standard solutions IV-STOCK-59 and IC-6-1 were used to construct analytical standard curves.

C. Research Methods

1. Identifying major pollution sources

To identify sources of $PM_{2.5}$ dust pollution, the PMF (Positive Matrix Factorization) collection point model developed by Paatero and Taper in 1994 was applied [16]. EPA has developed this model as a research tool to identify sources of air pollution [6]. The basic mathematical model of PMF is generally expressed as follows:

$$x_{ij} = \sum_{k=1}^{p} g_{ik}.f_{kj} + e_{ij} \quad (1)$$

In which:

i = (1 ÷ n), n is the number of samples analyzed;

j = (1 ÷ m), m number of analytical parameters;

p is the number of pollutions sources and k = (1 ÷ p);

X is the concentration matrix whose elements are x_{ij} and X = (x_{ij});

G is the contribution matrix of pollution sources with elements g_{ik} and G = (g_{ik});

F is the pollution source composition matrix with elements f_{kj} and F = (f_{kj});

E is the model uncertainty matrix whose elements are e_{ij} and E = (e_{ij}).

In the PMF model, the elements of matrices G and F are constrained to be non-negative values so that the influence of the model's input concentration values is weighted based on its measurement uncertainty [6, 14, 16].

The model is optimal when the following objective function reaches its minimum value.

$$Q = \sum_{i=1}^{n}.\sum_{j=1}^{m}.\left[\frac{x_{ij} - \sum_{k=1}^{p} g_{ik}.f_{kj}}{u_{ij}}\right] \quad (2)$$

In which, u_{ij} is the analytical error of the parameters.

$$Q_{true} = n.m - p(n+m) \quad (3)$$

2. Identifying potential contaminated areas

To identify potential pollution areas that affect the pollution level at the sample collection location, the 5-day BTs (Back Trajectories) orbits to the monitoring location during the sample collection days will be calculated by HYSPLIT 4 model to create orbit data files (https://www.ready.noaa.gov/HYSPLIT.php) [10] as input data for the potential source contribution function (PSCF).

Use PSCF to establish potential source distribution maps. The PSCF values are the conditional probability of a concentration being higher than the standard value associated with the movement of air masses passing through ij^{th} cell during their transport from pollution sources to sample collection location and calculated according to the following equation:

$$PSCF_{ij} = \frac{m_{ij}}{n_{ij}} \quad (4)$$

In which, m_{ij} is the number of points of the trajectory with content greater than the selected threshold value and n_{ij} is the number of

points at the end of the trajectory to the ij^{th} grid cell [9].

III. RESULTS AND DISCUSSION

A. $PM_{2.5}$ pollution concentration and chemical components

109 $PM_{2.5}$ samples from May 2021 to March 2022 were collected for research. The mass of $PM_{2.5}$ dust was determined using an AT20 microbalance, METTLER TOLEDO. The $PM_{2.5}$ concentration during this period was quite high with the average value of (78.09 ± 51.71) μg/m^3 and fluctuating in the range from 17.55 to 271.39 μg/m^3. This average value is 1.47 times larger than the average value during the period from April 2018 to September 2018 (53 ± 17) μg/m^3 (42 $PM_{2.5}$ samples) [22]; 1.75 times larger than the average value during the period from November 2015 to June 2016 (44.5 ± 21.0) μg/m^3 (85 $PM_{2.5}$ samples) [15] Average from 2002 - 2005 (35.84 ± 15.52) μg/m^3 (160 $PM_{2.5}$ samples) [8] 2.18 times (same sample collection location). So, it is clear that $PM_{2.5}$ tends to increase and is about 3.12 times larger than Who Air Quality Guidelines 2005 (25 μg/m^3 for $PM_{2.5}$ 24h). However, if compared with QCVN issued by the Ministry of Natural Resources and Environment in 2013 (50 μg/m^3), the average $PM_{2.5}$ during the study period was only 1.56 times larger and the number of days exceeding this standard accounted for 66.06% of sample collection days; Compared to AQG's recommendation in 2021, it will be 5.21 times (Table I) and the number of days exceeding this standard accounts for 97.25%. $PM_{2.5}$ is highest in November and December and 100% of days in these months have $PM_{2.5}$ exceeding standards and recommendations, even on some days $PM_{2.5}$ exceeds QCVN by 4 to 5 times.

Table I. Temporal variation of PM2.5 at the INST

$PM_{2.5}$, μg/m^3	Sample collection time	24h-$PM_{2.5}$ sample number	Ratio compared to WAQG	References
78.09 ± 51.71	5/2021 - 3/2022	109	**3.12**	This study
53.0 ± 17.0	4/2018 – 9/2018	42	2.12	Quang, Bac et al., 2023
44.5 ± 21.0	11/2015 - 6/2016	85	1.78	Hien, Bac et al., 2021
35.84 ± 15.52	2002 - 2005	160	1.43	Hopke et al., 2008
25			3.12	Who Air Quality Guidelines (WAQG) 2005
50			1.56	QCVN 05:2013/BTNMT
15			5.21	2021 AQG recommends

Timeseries of $PM_{2.5}$ during the study period is shown in Figure 3. The difference in $PM_{2.5}$ between the rainy season from April to September and the dry season from October to March of the following year is very clear. $PM_{2.5}$ average in the dry season is about 2.01 times greater than that in the rainy season.

Black carbon (BC) content was determined by the method of light reflection on the sample surface using a Smoke Stain Reflectometer device [7, 8]. The average BC in the dry season (4711.4 ng/m^3) is 1.39 times larger than the average BC in the rainy season (3395.6 ng/m^3).

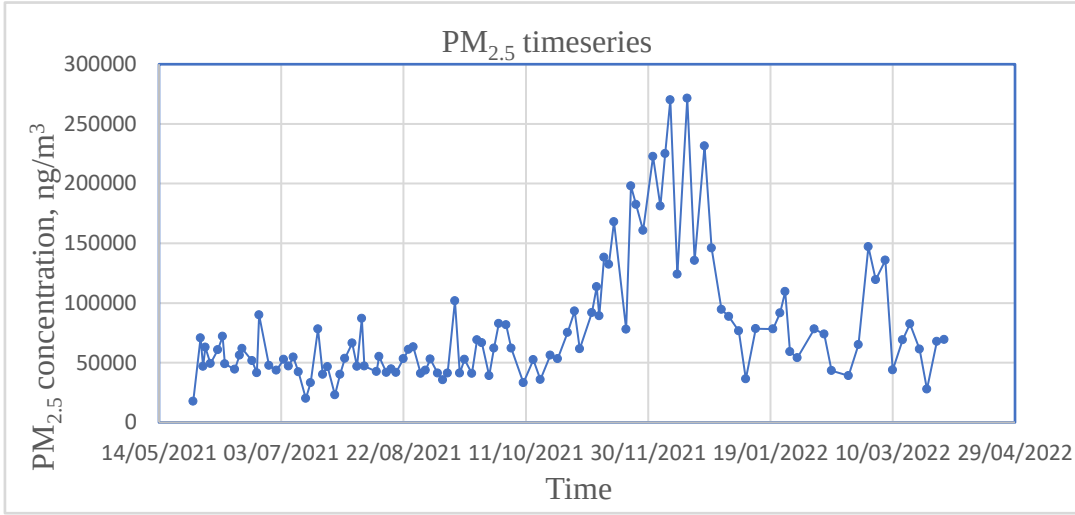

Fig. 3. $PM_{2.5}$ time series

The content of chemical elements such as As, Ca, Cd, Ce, Cu, Fe, K, Pb, Sr, Ti, Zn, Zr, Br, Cl, Mn and S were determined using the ED-XRF technique above. Energy-resolved fluorescence spectrometer ED-XRF Sea-2110. The content of soluable cations (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}) and anions (F^-, Cl^-, NO_3^-, NO_2^-, SO_4^{2-}) were analyzed on a DIONEX-600 ion chromatograph. Detection limits (DL) were determined to be approximately 5 ng/m^3 for SO_4^{2-}, NH_4^+, Na^+, Ca^{2+}, and 10 ng/m^3 for Cl^-, NO_3^-, K^+, F^- and Mg^{2+}. The error in ion content is estimated to be < 20%, especially for Mg^{2+} it is about 30%.

The average content of $PM_{2.5}$, BC and chemical components are listed in Table II. The average content of seasonal parameters is listed in Table III. Most of the content of chemical components in $PM_{2.5}$ dust in the dry season is much higher than in the rainy season.

Table II. Statistics on concentration of $PM_{2.5}$ and main chemical components in the sample (ng/m^3)

Para-meter	Min	Max	Average	Std.Dev.	Para-meter	Min	Max	Average	Std.Dev.
$PM_{2.5}$	17553.7	271388.9	78091.3	51704.6	**Ce**	31.3	1585.1	531.1	320.0
Zn	30.6	86470.8	15631.3	16539.5	**Cl^-**	13.1	2274.0	503.6	527.9
S	245.4	29052.7	8703.6	6683.3	**Br**	10.2	4876.1	492.8	794.9
Ti	583.5	52911.8	6368.5	8756.4	**Mn**	14.4	1433.4	344.4	308.7
Fe	89.4	16094.1	5164.5	3624.6	**As**	17.2	1280.1	319.3	251.8
SO_4^{2-}	6.0	18530.8	4957.1	3704.3	**Sr**	107.8	1271.0	244.2	209.3
NH_4^+	3.4	17090.0	4774.6	4286.4	**Na^+**	4.3	1492.0	234.4	242.7
BC	655.5	11081.5	4047.5	2060.5	**Zr**	15.2	557.3	187.2	102.1
NO_3^-	51.7	14289.8	2785.4	3751.2	**NO_2^-**	0.7	421.5	89.5	81.7
Cl	60.1	3578.2	1606.1	750.0	**Pb**	7.2	320.9	81.1	66.8

Ca	67.2	8866.6	1555.6	1373.0	**Mg^{2+}**	2.4	465.6	66.1	75.2
Ca^{2+}	20.1	3135.9	998.5	759.7	**Cd**	8.2	249.3	56.2	36.9
K	30.6	3470.3	913.7	804.3	**F^-**	1.3	224.3	46.7	35.0
K^+	3.9	2362.3	632.3	490.0	**Cu**	12.0	72.3	32.8	14.3

Table III. Average content of parameters in the 2 seasons (ng/m^3)

Para-meter	Rainy season	Dry season	Dry/Rainy	Para-meter	Rainy season	Dry season	Dry/Rainy
$PM_{2.5}$	51969.5	104696.8	**2.01**	**K^+**	522.5	792.1	1.52
Zn	13501.2	17152.7	1.27	**Br**	272.9	611.1	2.24
S	7017.7	10584.2	1.51	**Ce**	631.4	376.4	0.60
Ti	5167.5	8370.1	1.62	**As**	287.1	357.0	1.24
NH_4^+	2884.4	7524.2	2.61	**Mn**	406.8	325.6	0.80
SO_4^{2-}	3542.3	7014.9	1.98	**Na^+**	173.0	323.7	1.87
Fe	3728.5	6121.9	1.64	**Sr**	243.7	245.1	1.01
NO_3^-	780.8	5701.3	7.30	**Zr**	204.8	148.6	0.73
BC	3395.6	4711.4	1.39	**Mg^{2+}**	39.7	104.6	2.63
Cl	1418.8	1742.1	1.23	**Pb**	78.6	83.0	1.06
Ca	1790.1	1300.4	0.73	**NO_2^-**	98.5	77.4	0.79
K	593.5	1239.8	2.09	**F^-**	35.9	62.4	1.74
Ca^{2+}	1026.5	964.7	0.94	**Cd**	52.3	59.7	1.14
Cl^-	270.3	842.8	3.12	**Cu**	29.7	35.9	1.21

B. Main sources of pollution

PMF model version 5.0 was used to identify pollution sources. The input data matrix was the content of major chemical and ionic components in 109 $PM_{2.5}$ samples. The 2 input data matrices for the PMF model were the concentration matrix of analytical parameters (24 parameters x 109 samples) including $PM_{2.5}$ and BC and the corresponding error matrix of the analytical parameters had similar dimensions.

With Fpeak = -0.5, the objective function Q reached the smallest value and the ratio Q/Q_{true} was 0.91 (7862/8678) when p = 6. As a result, 6 sources of pollution were identified, including:

- The source of pollution due to long-distance transmission (LRT) contains a lot of NH_4^+, SO_4^{2-}, NO_3^- and BC. This source accounts for (31.81 ± 7.41) %.

- The source of pollution from burning biomass and coal accounts for (18.07 ± 4.21) % containing a lot of K^+, BC, NH_4^+ và SO_4^{2-}.

- Emissions from vehicles account for (14.87 ± 3.46) % containing a lot of Zn and BC.

- The source of pollution is soil, rock and construction dust accounting for (14.83 ± 3.45) % containing a lot of Ca_{2+}, Fe, SO_4^{2-}.

- Pollution sources due to industrial activities account for a fairly high percentage of

(16.45 ± 3.83) % containing quite a lot of Zn, BC, Ti, Ce... and

- Marine aerosol sources contain Na^+, Cl^- ... accounting for about (3.96 ± 0.92) %.

The components of identified pollution sources and their proportions have relatively clear changes compared to research results from 2001 to 2008 in Hanoi [3].

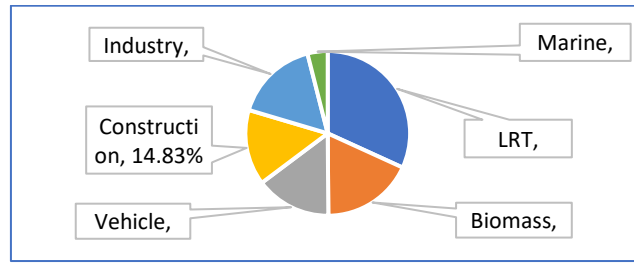

Fig. 4. Distribution of $PM_{2.5}$ pollution sources

C. Map of potential pollution areas

The backward trajectory (BT) of air masses spreading to the sample collection location over a period of 5 days, at an altitude of 500 m with different distances was calculated by using the HYSPLIT 4 model [10]. The shorter the time gap between orbits, the more accurate the identification results. The BTs after each 3 hours during sample collection days in this study were calculated.

PSCF was calculated by using Trajstat software version 1.4.4R5 in meteoinfomap software Version 1.4.8R1 and illustrated by using ArcGIS 10.8 (Esri Inc., USA). The selected threshold value was 75% of the interested parameter. PSCF maps for $PM_{2.5}$, BC, NH_4^+, SO_4^{2-} are shown in Figure 5.

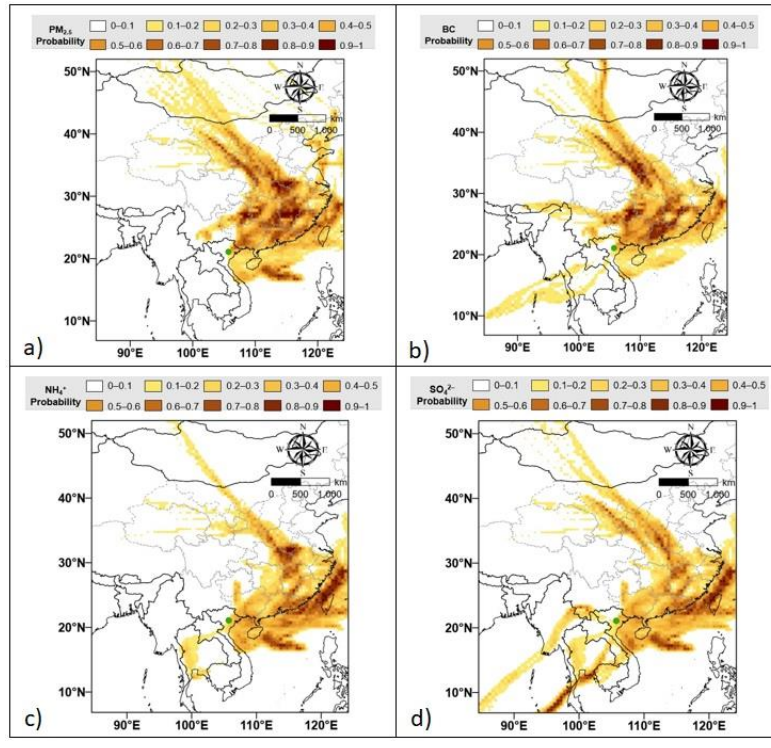

Fig. 5. PSCF maps for: a) $PM_{2.5}$, b) BC, c) NH_4^+ và d) SO_4^{2-}

Figure 5 shows that $PM_{2.5}$ and main pollution components such as BC, NH_4^+, SO_4^{2-} all originate mainly from the North and Northeast. Particularly, SO_4^{2-} partly originates from the southwest. This can be explained because our country is greatly influenced by the monsoon regime. The prevailing Northeast wind in the dry season will transport pollutants from far away.

IV. CONCLUSION

The characteristics of $PM_{2.5}$ pollution during the period from May 2021 to March 2022 in Hanoi, Vietnam were studied. The $PM_{2.5}$ concentrations tend to increase. The average $PM_{2.5}$ concentration during the study period was 1.56 times greater than QCVN 2013 (66.06% of sample collection days had $PM_{2.5}$ exceeding this standard), 3.12 times greater than WAQG-2005 (97.25% of days had $PM_{2.5}$ exceeding this guideline). The average of $PM_{2.5}$ in the dry season is 2.01 times greater than that in the rainy season. The components that mainly contribute to $PM_{2.5}$ concentration are Zn, S, Ti, NH_4^+, SO_4^{2-}, Fe, NO_3^-, and BC. The main sources of pollution contributing to $PM_{2.5}$ are components due to long-range transportation, traffic activities, biomass burning, fossil fuels and BC... The main sources of pollution and the map of potentially contaminated areas were identified. This study shows a warning picture of $PM_{2.5}$ fine dust in Hanoi during the study period compared to many years ago.

V. ACKNOWLEDGEMENTS

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