Electronic Journal of University of Aden for Basic and Applied Sciences
EJUA-BA Vol. 3 No. 3 (2022)
https://doi.org/10.47372/ejua-ba.2022.3.187
ISSN: 2708-0684

RESEARCH ARTICLE

CONCENTRATION OF FINE PARTICULATE MATTER ($PM_{2.5}$) AND BLACK CARBON (BC) IN AEROSOL SAMPLES IN AL-ZUBAIRY AREA IN SANA'A, YEMEN

Ahmed Khalid Abdul-Rahim[1,*], Nabilah Ali Al-Sowaidi[2] and Zaid Abdullah Eadan[2]

[1] *Dept. of Physics, Faculty of Science, University of Sana'a, Yemen*
[2] *National Atomic Energy Commission, Sana'a, Yemen*

***Corresponding author: Ahmed Khalid Abdul-Rahim; E-mail: aabdulra@gmail.com**

Received: 04 September 2022 / Accepted: 20 September 2022 / Published online: 30 September 2022

Abstract

This research aims to study the air pollution due to fine Particulate Matter of radius less than 2.5µm ($PM_{2.5}$) and Black Carbon concentration (BC) in air samples. Aerosol $PM_{2.5}$ samples were collected from the rooftop of the National Oncology Center site in Al-Zubairy area in Sana'a Yemen. A Microprocessor Controlled Aerosol Sampling device ISAP1050e (Gerhard Schulze Automation Engineering, Germany company) was used to collect samples. The mass concentration of $PM_{2.5}$ of collected samples ranged from 14.27 to 159.09 µg/m^3 with an average of 32.66µg/m^3. The $PM_{2.5}$ results were compared with the World Health Organization (WHO) 2005 guideline of $PM_{2.5}$ concentration in air. Statistical analysis showed a positive correlation between $PM_{2.5}$ concentrations and temperature for both fall and summer samples. However, analysis showed a positive correlation between $PM_{2.5}$ concentrations and relative humidity for fall samples and a negative correlation for summer samples. The black carbon (BC) concentrations in $PM_{2.5}$ samples were measured using a Smoke Stain Reflectometer (SSR) device. The BC concentration ranged from 1.84 to 3.90 µg/m^3 with an average of 2.90 µg/m^3. The BC results were compared with some international reported results. The Air Quality Index (AQI) of 78.95% of $PM_{2.5}$ concentrations was higher than the standard limit (AQI < 100) developed by the United States Environmental Protection Agency (EPA).

Keywords: Particulate Matter, Black carbon, Concentration, Air Quality Index, Correlation.

Introduction

Air Pollution is considered to be one of the biggest challenges in the world. It represents a high-risk factor for human health, climate and the environment [1]. The World Health Organization (WHO) reported that air pollution causes seven million deaths every year [2]. Air Pollution occurs when high concentrations of air components exceed the normal ratio of the naturally existing components of air. It also occurs when the abnormal or toxic components of elements are present in the air. Volcanos, dust storms, and forest fires are natural sources of air pollution. Fossil and wood fuel, exhaust emission from vehicles, construction activities, industrial manufacturing and oil refineries are anthropogenic sources that contribute seriously to air pollution [3, 4]. EPA classified the air pollutants into six common groups: ground-level ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, lead and particulate matter [5]. Fine Particulate Matter $PM_{2.5}$ are particles of radius less than 2.5µm. $PM_{2.5}$ particles are an atmospheric aerosol that consist of a mixture of tiny particles or liquid droplets suspended in the atmosphere. Particulate Matter may contain sulfate, ammonium nitrate, sodium, chloride, trace metals, carbonaceous, crustal elements [2]. Primary Particulate matter such as fly ash and dust are emitted directly into the atmosphere whereas secondary Particulate matter are formed in the atmosphere by the reaction of the primary particulate and gases [6, 7]. The lifetime of $PM_{2.5}$ can be several days to months and they can be transported hundreds or thousands of kilometers from their source of origin [8]. Domestic and global pollutant emission sources, and the meteorological conditions have various effects on $PM_{2.5}$ mass concentration [9]. Particulate matter $PM_{2.5}$ may cause some serious health complications in respiratory

and cardiovascular systems since they can get deep into the lung and may get into the bloodstream [10]. The black carbon (BC) is one constituent of $PM_{2.5}$ [11]. It is a solid form of pure carbon that absorbs sunlight at all wavelengths. BC warms the air, and it is considered to be the second contributor of global warming after CO_2 [12]. BC is emitted directly into the atmosphere due to the incomplete combustion of fossil fuels, biofuels and biomass [13, 14]. It was reported that the global emissions of BC are due to various causes such as house activities, transportation, industrial production, and fossil fuels [13]. In this study, mass concentrations of $PM_{2.5}$ collected from the study area were measured and compared with the guideline of WHO of $PM_{2.5}$ concentrations. The limiting values stated by WHO (2005) guideline for $PM_{2.5}$ concentration in air are 10 µg/m^3 as annual limit and 25 µg/m3 as twenty -four hours limit [1, 15]. Furthermore, our study measured the black carbon concentrations in $PM_{2.5}$ samples and results were compared with some international studies. Finally, the study investigated the air quality of the study area through finding the Air Quality Index (AQI) for collected samples.

Methodology

Aerosol $PM_{2.5}$ samples were collected during summer and fall seasons of 2017. Samples

were collected using Teflon filters employing the Microprocessor Controlled Aerosol Sampling device ISAP1050e (model 1050e PKPM 10& 2.5& 1.0/2.3, I S A P Gerhard Schulze Automation Engineering, Germany). For each sample, the total mass, in microgram, was weighed using a sensitive balance with a sensitivity of 10µg. The black carbon content in the each sample was measured using Smoke Stain Reflectometer EEl (Model 43D(Diffusion Systems Ltd., London).

Sampling and PM2.5 mass concentration analysis:

The sampler was located on the rooftop of the National Oncology Center building at the Republican Hospital in Al-Zubairy area in Sana'a, the capital of Yemen. The sampling inlet was set 2 meters above the ground to avoid the re-suspension of dust in the samples [16]. After downloading the filter on the sampler, the aerosols were deposited on the Teflon filters. The air in the sampling inlet is drawn through a slit, which is directed towards a collecting plate (impaction plate). Higher diameter particles deviate from the sampler streamlines and impact on the first plate (PM >10). Smaller particles move to the next impaction plate (PM $_{2.5\text{-}10}$), and finally the smallest particles continue moving to the last impaction plate ($PM_{2.5}$).

The procedure of collection of samples includes four steps [17]: preparation of filters before sampling, pre-weighing the filters before sampling, filters loading and un loading on the ISAP1050e sampler, and finally post-weighing of the filters after sampling. Before sampling, the filters are inspected visually for any defects such as holes, dirt and those defected filters were discarded. One day prior to pre-and post-weighing, the filters were left in a clean hood or box for equilibrium. After pre-weighing, the filter is loaded on the ISAP1050e sampler and the sampler is programed to start at midnight of sampling day and stop at midnight of next day. When the period of sampling is completed, the filter is unloaded from the ISAP1050e sampler and then the filter is post-weighed. Furthermore, simultaneously with sampling, the meteorological conditions are measured using a temperature, relative humidity and pressure sensor (model ISAP^R TPsP/I SAP^{R}TPrHsP Gerhard Schulze Automation Engineering, Germany) which measures temperature, pressure and relative humidity every five minutes during the sampling process just as the device was set up by the manufacturer.

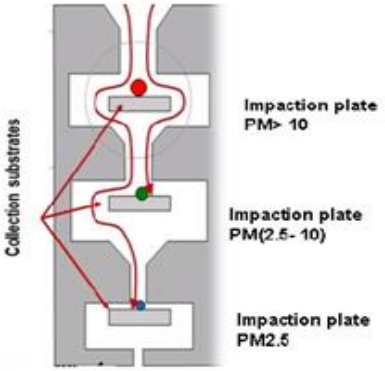
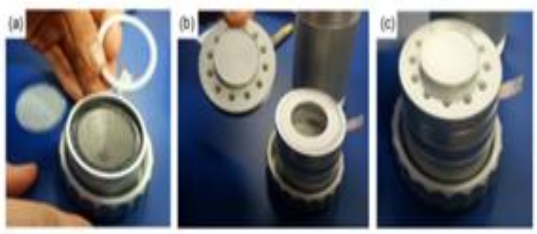


Fig. 1: Impactor working principle



(a) **(b)** **(c)**

Fig. 2: Filters and their locations within ISAP1050e aerosol sample: **(a)** Fine particles ($PM_{2.5}$), **(b)** coarse particles PM_{10}-$PM_{2.5}$, **(c)** coarse particles

The samples were weighed before and after sampling using Sartorius/CP225D sensitive balance as demonstrated in figure (3) with a sensitivity of 10µg. Before and after 24 hours of the weighing process, the samples (filters) were conditioned in a desiccator. The mass concentration of $PM_{2.5}$ is calculated as follows:

Mass concentration $(\mu g/m^3)$ = (final mass – initial mass)/volume

The volume of the air in the filter (sample) was corrected to take into account metrological conditions of pressure and temperature compared to standard conditions as follows [18]:

If Q_a is the average sampler flow rate (2.3 m^3/h), Ta is the average actual temperature in K, Pa is the average actual pressure in KPa, t is the total elapsed sampling time, then the corrected average flow and the corrected volume are calculated as follows:

$$Q_{corrected} = Q_a(P_{std}T_a/P_aT_{std})$$

And the corrected volume is given by:

$$V_{corrected} = Q_{corrected} \times t$$

where: $T_{std} = 298.15\ K\ and\ P_{std} = 101.3KPa$

Black Carbon Analysis:

A Smoke Stain Reflectometer (SSR) was used for Black Carbon measurements such that measurements were performed three times for each sample and the average value was used in the calculations. In the SSR, the light from a tungsten lamp shines its light on the filter, and it is reflected back to a photocell located in a black housing (head). The reflectance of the exposed filter (aerosol sample) is obtained directly from the digital readout which is represented by R (in percentage) and the Reflectance of a clean filter (blank) is represented by R_o ,100% [14].

To calculate the concentration of BC in $PM_{2.5}$, we used the following equation [14]:

$$\mathrm{BC}\left(\frac{\mu g}{m^3}\right) = \frac{100A}{2\,\varepsilon\,V} Ln\left(\frac{R_\circ}{R}\right)$$

Where:

A is the filter area in cm^2, V is the volume of air in the filter in m^3,

ε is the mass absorption coefficient and equals 7 m^2/g at the given wavelength 520nm,

R_o (=100%) is the reading of the light reflection using the clean filter (blank filter), and

R is the reading of the light reflection using the exposed filter (aerosol samples).

Air Quality Index (AQI):

Air Quality Index (AQI) is defined as an index for reporting the quality of the ambient air and it is an indicator to how the air pollution affects the human health. The Air Quality Index (AQI) has been developed by the United States Environmental Protection Agency (EPA). The AQI is mainly categorized into six zones as summarized in table 1.

Fig. 3: Sartorius/CP225D sensitive balance

Fig. 4: EEL43M Smoke Stain Reflectometer (SSR)

Table (1): Air Quality Index Categories

Group Icon	AQI Values(range)	Descriptor	Color Code	Health Advisory
A	0-50	Good	Green	None
B	51-100	Moderate	Yellow	The air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very few/specific number of people who are unusually sensitive to air pollution
C	101-150	Unhealthy for Sensitive Groups	Orange	People with heart or lung diseases, older adults, and children should reduce prolonged or heavy exertion
D	151-200	Unhealthy	Red	People with heart or lung diseases, older adults, and children should avoid prolonged or heavy exertion. Everyone else should reduce prolonged or heavy exertion.
E	201-300	Very Unhealthy	Purple	People with heart or lung diseases, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.
F	301 and above	Hazardous	Maroon	Everyone should avoid all outdoor exertion

EPA has set the air quality standard limit of 100 to protect public health. If AQI values were at or below 100 (AQI < 100), the air quality is acceptable and if AQI values were above 100 (AQI >100), the air quality is considered to be unhealthy for everyone [19, 20].

Results and Discussion

The mass concentration of $PM_{2.5}$ in the study region during the sampling period was in the range 14.27-159.09 µg/m^3 with an average of 32.66µg/m^3. Referring to tables (2) and (3) for $PM_{2.5}$, it was found that the mass concentration of $PM_{2.5}$ in summer season was higher than in fall season. As shown in figure (6), the mass concentration in summer season was in the range 16.91-159.09µg/m^3 with an average of 45.50µg/m^3. On the other hand, the mass concentration of $PM_{2.5}$ in fall season was in the range 14.27-35.48 µg/m^3 with an average of 20.75µg/m^3 as shown in figure (5)

Table (2): PM $_{2.5}$ mass and Black Carbon concentrations for summer samples

Sample No.	Date of sampling	PM2.5. (µg/m^3)	BC (µg/m^3)	BC/PM2.5 (%)	Meteorological Conditions			AQI (µg/m^3)	AQI Rate
					T(K)	P(KPa)	RH(%)		
1	11-Jun	36.55	3.90	10.66	297.33	77.26	24.66	152.31	D
2	18-Jun	43.52	2.81	6.46	299.14	77.24	32.44	181.35	D
3	21-Jun	25.68	2.84	11.07	298.55	77.27	37.67	107.01	C
4	25-Jun	37.30	1.84	4.93	296.88	77.26	41.58	155.43	D
5	28-Jun	21.86	2.15	9.84	297.46	77.30	31.86	91.09	B
6	2-Jul	25.74	2.46	9.57	299.13	77.17	22.84	107.26	C
7	5-Jul	69.32	1.85	2.67	297.77	77.27	42.60	171.33	D
8	12-Jul	45.51	2.06	4.54	299.26	77.22	30.38	189.64	D
9	16-Jul	42.93	2.71	6.31	298.96	77.22	31.85	178.87	D
10	19-Jul	39.48	2.31	5.86	294.86	77.25	55.81	164.50	D
11	23-Jul	36.24	3.02	8.33	297.60	77.13	43.12	150.99	D
12	30-Jul	35.65	2.83	7.93	297.01	77.17	45.33	148.55	C
13	02-Aug	123.65	3.24	2.62	296.09	77.41	54.43	318.05	F
14	06-Aug	159.09	3.77	19.52	297.09	77.11	47.51	204.49	E
15	09-Aug	19.32	3.28	2.01	291.80	77.37	72.83	80.50	B
16	13-Aug	22.96	3.90	17.01	293.00	77.27	69.15	95.65	B
17	16-Aug	16.91	3.70	21.87	293.47	77.25	65.38	70.45	B
18	20-Aug	30.76	3.57	11.61	296.10	77.23	49.14	128.18	C
19	23-Aug	31.98	3.49	10.92	298.54	77.02	33.00	133.26	C

Table (3): $PM_{2.5}$ mass and Black Carbon concentrations for fall samples

Sample #	Date of sampling	PM2.5 (µg/m³)	BC (µg/m³)	BC/PM2.5 (%)	Meteorological Conditions			AQI (µg/m³)	AQI Rate
					T(K)	P(KPa)	RH(%)		
1	3-Sep	28.34	3.17	11.20	295.57	77.23	54.52	118.06	C
2	6-Sep	24.44	3.12	12.78	296.71	77.38	44.37	101.84	C
3	10-Sep	21.68	2.78	12.84	296.25	77.32	26.40	90.33	B
4	13-Sep	35.48	1.86	5.24	296.91	77.41	28.80	147.82	C
5	17-Sep	16.12	3.19	19.81	295.89	77.46	24.32	67.15	B
6	24-Sep	18.98	3.02	15.92	295.16	77.49	20.27	79.08	B
7	1-Oct	14.28	2.96	20.71	293.89	77.61	24.77	59.49	B
8	4-Oct	19.93	3.65	18.30	293.70	77.56	25.07	83.04	B
9	8-Oct	14.98	2.49	16.65	292.36	77.48	33.72	62.40	B
10	18-Oct	21.42	2.83	13.21	293.18	77.49	25.78	89.23	B
11	22-Oct	23.76	2.84	11.94	292.69	77.58	28.73	98.99	B
12	25-Oct	21.03	2.70	12.83	291.44	77.74	28.34	87.61	B
13	1-Nov	14.27	2.94	20.58	290.72	77.58	27.26	59.44	B
14	5-Nov	17.13	3.10	18.10	290.48	77.52	31.64	71.39	B
15	8-Nov	22.33	3.26	14.58	289.61	77.61	32.87	93.04	B
16	12-Nov	17.72	2.86	16.14	293.30	76.98	31.19	73.84	B
17	15-Nov	23.75	2.84	11.97	288.03	77.60	31.69	98.97	B
18	26-Nov	21.83	2.78	12.72	289.79	77.86	52.92	90.98	B
19	29-Nov	16.84	2.58	15.34	289.30	77.82	38.80	70.16	B

BC: Black Carbon, **T:** Temperature in Kelvin, **P:** Pressure in Kpa, **RH:** Relative humidity, **AQI:** Air Quality Index
B: Good, **C:** Unhealthy for sensitive groups, **D:** Unhealthy, **E:** Very unhealthy, **F:** Hazardous

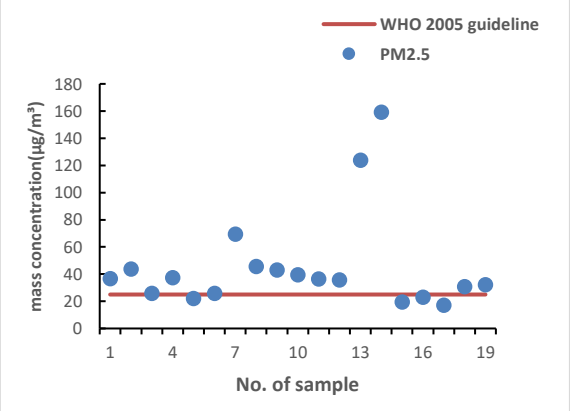


Fig. 5: mass concentration for Fall samples

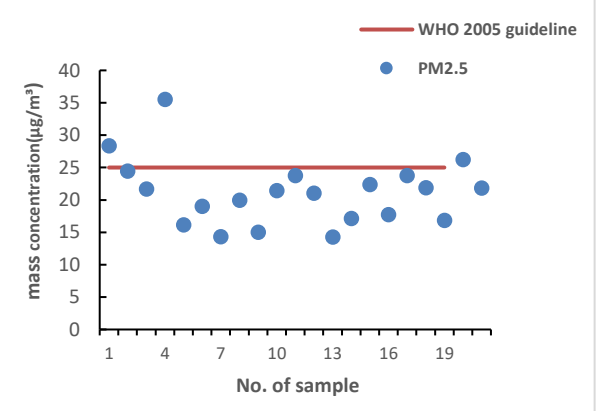


Fig. 6: mass concentration for Summer samples

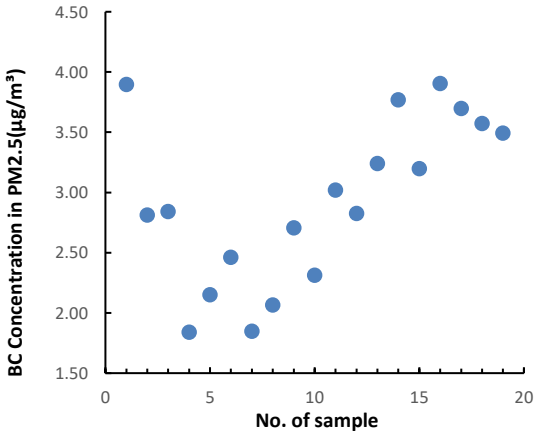


Fig. 7: The Black Carbon Concentration in Summer

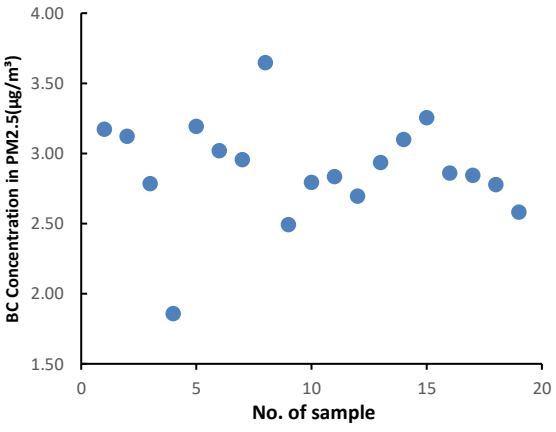


Fig. 8: The Black Carbon concentration in Fall

Results showed that 68.4% of the samples in summer season had higher $PM_{2.5}$ concentrations than the (2005) guideline of WHO, 25µg/m^3, while 89.47% of the samples in fall season had lower $PM_{2.5}$ concentrations than WHO guideline. Furthermore, the Air Quality Index (AQI) for about half of the samples was acceptable. Monthly average of Air Quality Index of $PM_{2.5}$ showed that AQI in July was the highest due to dust storms and that AQI in October and November were the lowest. It was noted that, in summer the AQI of 78.95% of $PM_{2.5}$ concentrations was higher than the standard limit, <100, in which 26.31% of the cases AQI was found to be "unhealthy for sensitive people level", 42.11% "unhealthy level", 5.26% "very unhealthy level", and 5.26% "Hazardous level". In fall season, the AQI of 84.21% of $PM_{2.5}$ concentrations was moderate level whereas the AQI of 15.79% was higher than the standard limit and classified as "unhealthy for sensitive groups level". Moreover, results show that black carbon concentration in the study area during the sampling period was in the range (1.84-3.90) µg/m^3 with an average 2.90 µg/m^3. Black carbon concentration in summer ranged from 1.84 µg/m^3 to 3.90 µg/m^3 with an average of 2.91 µg/m^3 and it ranged from 1.86 µg/m^3 to 3.65 µg/m^3 with an average of 2.89 µg/m^3 in fall season. The lowest monthly average of concentration of black carbon (BC) was 1.84 µg/m^3 in June and the highest concentration of Black Carbon (BC) was 3.90 µg/m^3 in August. Moreover, the percentage of BC in $PM_{2.5}$ varied from 2.01% to 21.87% during the period of study.

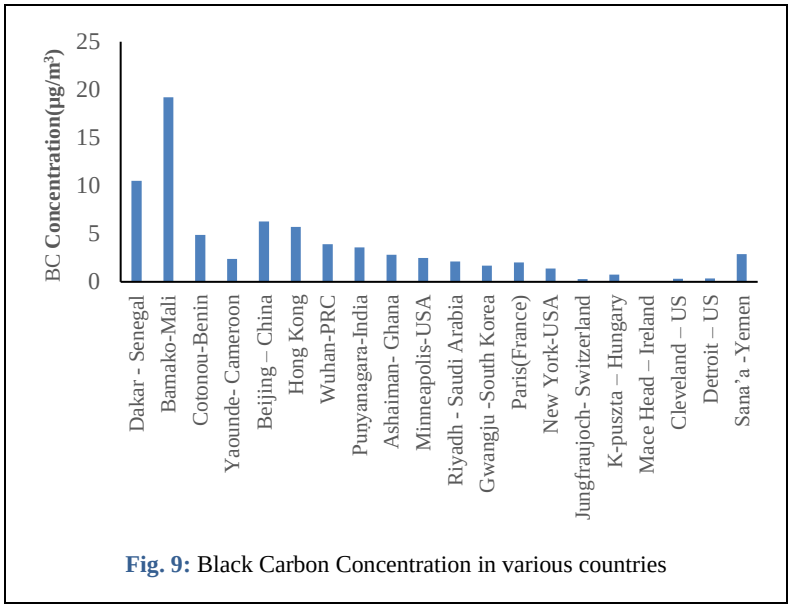
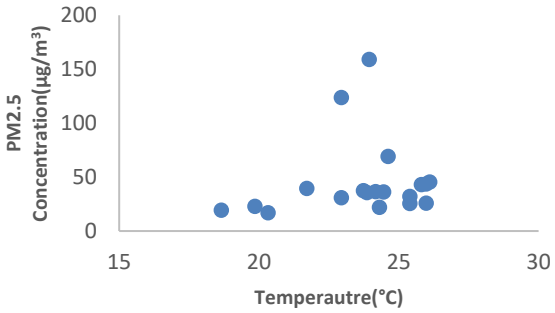


Fig. 9: Black Carbon Concentration in various countries

Moreover, It was noted that 66% of the monthly Black Carbon (BC) percentage in $PM_{2.5}$ had higher value than twelve percent. Those values of relatively high percentage of BC in $PM_{2.5}$ may cause significant health risk to the public and the long-term average BC exposure could be associated with a variety of health effects [22]. Figure (9) shows a comparison between Black Carbon (BC) concentrations in this study and some other reported studies such as Ashaiman-Ghana, Minneapolis-USA, Riyadh-Saudi Arabia, Punyanagara-India, Wuhan-PRC, Urban Hong Kong, and Beijing-China. Details of these international studies were referred in [23, 24, 25, 26, 27, 28, 29].

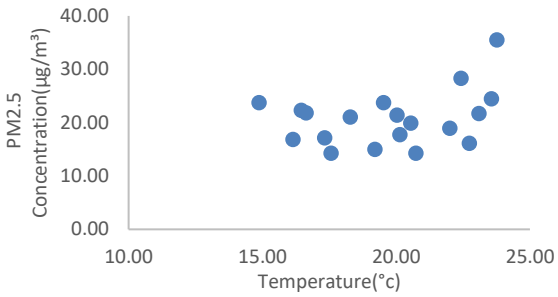
Statistical analysis

The Pearson correlation method was used in our statistical analysis. As demonstrated in figures (10 to 15). Results show that there were correlations between $PM_{2.5}$ concentrations with temperature and relative humidity during the study period. However, there was no correlation between $PM_{2.5}$ concentrations and pressure. Specifically, there was a moderate significant positive correlation between $PM_{2.5}$ concentration and temperature with r = 0.638 and P value = 0.003 in summer and r = 0.50 and P value = 0.02 in fall. For relative humidity there was a moderate significant positive correlation with r = 0.52 and P =0.013 in fall; however, there was a moderate significant negative correlation in summer with r = 0.513 and P = 0.042. Analysis may be interpreted as a temperature increases, the $PM_{2.5}$ concentration increases in both fall and summer seasons. The statistical analysis gives us some suggestions to explain the variation of $PM_{2.5}$ concentration during the sampling period, however we should not ignore other main reasons such as dust concentration in the atmosphere and dust storms.



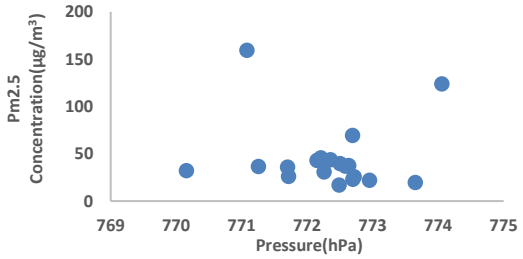
Pearson Correlation with r =0.638 and p=0.003
Regression Analysis: MC = -41.21+3.166T

Fig. 10: variation of $PM_{2.5}$ with Temperature in summer



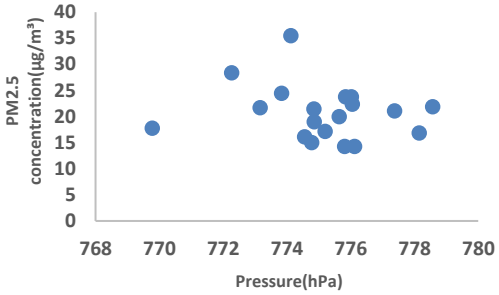
Pearson Correlation with r =0.491 and p=0.02
Regression Analysis: MC = 1.146+1.014T

Fig 11: variation of $PM_{2.5}$ with Temperature in fall



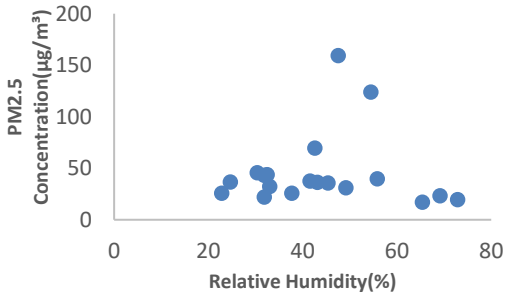
Pearson Correlation with r =-0.312 and p=0.239

Fig. 12: variation of $PM_{2.5}$ with Pressure in summer



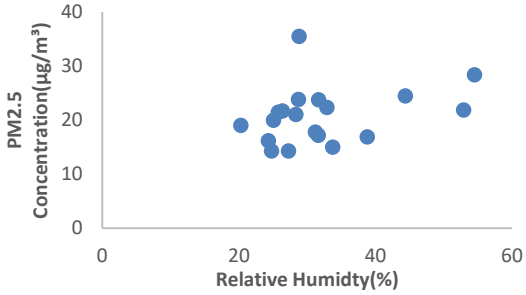
Pearson Correlation with r =-0.177 and p=0.431

Fig. 13: variation of $PM_{2.5}$ with Pressure in fall



Pearson Correlation with r =- 0.513 and p=0.042
Regression Analysis: MC = 44.74 - 0.296RH

Fig. 14: variation of $PM_{2.5}$ with relative humidity in summer



Pearson Correlation with r =0.521 and p=0.013
Regression Analysis: MC = 11.10-0.3077RH

Fig. 15: variation of $PM_{2.5}$ with relative humidity in fall

Conclusion

The concentrations of $PM_{2.5}$ of aerosol samples and Black Carbon content in $PM_{2.5}$ of the study area were studied. We concluded that, most of aerosol $PM_{2.5}$ concentrations in summer were above the WHO 2005 guideline. The $PM_{2.5}$ concentrations in summer were higher than in fall season due to the dust storms in June and July. Additionally, it was concluded that the Air Quality Index (AQI) of $PM_{2.5}$ concentrations for about half of the samples were higher than the EPA standard limit and ranged from "unhealthy for sensitive groups level" to "hazardous level". The Air Quality Index (AQI) for about half of the samples was acceptable. The monthly average of Air Quality Index of $PM_{2.5}$ showed that AQI in July was the highest and that AQI in October and November were the lowest. Furthermore, it was found that the air pollution due to $PM_{2.5}$ in the summer is more than in the fall because of dust storms in summer season. Moreover, it was found that the percentage of BC in $PM_{2.5}$ in fall was higher than the percentage in summer season. The reason could be explained as: the more usage of wood and coal in fall season causes the high percentage of BC occurrence. Furthermore, even though our study region is urban and is not industrial, the black carbon concentrations were relatively high. This suggests that the source of black carbon in our study is local pollution sources such as kerosene fuel, charcoal,

firewood, diesel generator etc. Compared with some other international studies, the BC concentrations in $PM_{2.5}$ in our study were higher than twelve international studies.

Funding

This work was supported by the National Atomic Energy Commission of Yemen.

References

[1] WHO, "Air Quality Guidelines Global Update 2005, " WHO Regional Office for Europe, (2006), ISBN 92 890 2192 6.

[2] S. Fuzzi, U. Baltensperger, K. Carslaw, S. Decesari, H. Denier Van der Gon., M. C. Faccini, D. Flowler, I. Koren, B. Langford, U. Lohmann, E. Nemitz, S.Pandis, I. Riipinen, Y. Rudich, M. Schaap, J. G. Slowik, D. V. Spracklen, E. Vignati, M. Wild, M. William, and S. Gilardoni, " Particulate matter, air quality and climate :lessons learned and future needs, "J.Atmospheric Chemistry and Physics, (2015) 15, pp. 8217-8299.

[3] G. K. Mohammed, "Trace Elemental Composition in PM10 and PM2.5 Collected in Cardiff, Wales, " Energy Procedia, (2017), 540-547.

[4] P. Kothai, I.V. Saradhi, G. Pandit, A. Markwitz, V.D. Puranik, "Chemical Characterization and Source Identification of Particulate Matter at an Urban Site of Navi Mumbai, India, " Aerosol and Air Quality Research, (2011): 560-569.

[5] EPA, "Criteria Air pollution, Retrieved August 16, 2021, from EPA: http://www.epa.gov/criteria-air-polltants. 2021.

[6] M.Y. Khan, M. Kumar, S. K. Awasthi," Particulate: Sources, Effects and Control, ", 2017 Retrieved from Research Gate: http://www.researchgate.net/publication/318647965.

[7] J. H. Murillo, S. R. Roman, J. F. R. Marin, A. C. Ramos, S. B. Jimenez, B. C. Gonzalez, D. G. Baum gardner, "Chemical characterization and source apportionment of PM_{10} and $PM_{2.5}$ in the metropolitan area of Costa Rica, Central America," Atmospheric Pollution Research, (2013): 181-190.

[8] M. Lippmann, R. B. Schlesinger, " Toxicological Bases for The Setting of Health-Related Air Pollution Standards, " J. Annu. Rev. Public Health, (2000) 21: 309-333.

[9] J. Wang, S. Ogawa, " Effects of Meteorological Conditions on PM2.5 Concentrations in Nagasaki, Japan, " International Journal of Environmental Research and Public Health, (2015): 9089-9101.

[10] EPA, "Particulate Matter (PM) Pollution, "Retrieved from United States Environmental Protection Agency: http://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM, (2022).

[11] P. Venkatachari, L. Zhou, P. Hopke, D. Felton, O. Rattigan, J. Schwab, K. Demerjia, "Spatial and temporal variability of black carbon in New York City". J. Geophysical Research, (2006) 111, D10S05, doi:10.1029/2005JD006314. 2006.

[12] C. Sota, M. Kane, J. Mazorra, J., Youm, I. Lambreras, M. Viana, " Intercomparison of methods to estimate black carbon emissions from cook stoves, " Science of The Total Environment, (2017): 886-893.

[13] Climate & Clean Air Coalition, " Black Carbon, " Retrieved from Climate & Clean Air Coalition: http://www.ccacoalition.org/en/slcps/black-carbon, (2018).

[14] G. Taha, P. B. Box, D. D. Cohen, E. Stelcer, " Black Carbon Measurement using Laser Integrating Plate Method, "Aerosol Science and Technology, (2007): 266–276.

[15] I. P. S. Araujo, D. B. Costa, "Measurement and monitoring of Particulate matter in construction sites: guidelines for gravimetric approach, " Sustainability, (2022) 14:558. 2022.

[16] WMO/GAW report No.227, "Aerosol Measurement Procedures, Guidelines, and Recommendations, "2nd edition, (2016) Published by the World Meteorological Organization and the Global Atmosphere Watch.

[17] M. Roumie, "The collaborative IAEA TC project on the investigation of fine and coarse atmospheric particulate matter in Arasia region, "AccApp'17, Quebec, Canada, July 31-Augest, 147-154, (2017).

[18] T. William, "Sampling of ambient air for total suspended particulate matter (SPM) and PM_{10} using high volume (HV) sampler, "EPA/625/R-96/010a, (1999).

[19] F. Fazelinia, A. A. Khodabandehlou, L. Rafati, A. H. Mahvi, " Investigation of Air Quality Index and PM_{10} and $PM_{2.5}$ in Arak, "Iranian journal of health sciences, (2013):12-17.

[20] O.J. Osimobi, B. Yorkor, C.A. Nwankwo, " Evaluation of daily pollutant standard index and air quality index in a university campus in Nigeria using PM_{10} and $PM_{2.5}$ particulate matter, " Journal of Science, Technology and Environment Informatics, (2019) 07(02):517-532.

[21] EPA, "Air Quality Index, A guide to air quality and your health, " Published by U.S. Environmental

Protection Agency, and Office of Air Quality Planning and Standards Outreach and Information Division Research Triangle Park, NC, EPA-456/F-14-002, (2014).

[22] EPA, " Report to Congress on Black Carbon, " Published by the Office of Air and Radiation, and Office of Air Quality Planning and Standards, and Research Triangle Park, NC. Retrieved March 2012, EPA-450/R-12-001.

[23] S. Q. Dotse, J. K. Asane, F. G. Ofosu, I. J. K. Aboh, "Particulate Matter and Black Carbon Concentration Levels in Ashaiman, a Semi-Urban Area of Ghana, 2008, "Research Journal of Environmental and Earth Sciences, (2012) 4(1), ISSN:2041-0492,20-25.

[24] S. Hankey, J. D. Marshall, "On-bicycle exposure to particulate air pollution: Particle number, black carbon, $PM_{2.5}$, and particle size, "Atmospheric Environment, (2015):65-73.

[25] Q. Bian, B. Alharbi, M. M. Shareef, T. Husain, M. J. Pasha, S.A. Atwood, S. M. Kreidenweis, "Sources of $PM_{2.5}$ carbonaceous aerosol in Riyadh, Saudi Arabia, " Atmospheric Chemistry and Physics, (2018): 3969–3985.

[26] P. D. Safai, M. P. Raju, K. B. Budhavant, P. S. P. Rao, P. C. S. Devara, " Long term studies on characteristics of black carbon aerosols over a tropical urban station pune, "India. Atmospheric Research, (2013) vol.132-133,ISSN:0169-8095:173-184.

[27] Z. Jinhui, H. Chao, Y. Zhe, D .T . Tian, H. C. Ping, K. Qun, "The transmission and distribution regulation of the urban black carbon aerosol in the middle reach of Yangtze River," Earth Sciences & Environmental Studies, (2020) 5(1) pp:1-12.

[28] K. F. Ho, S. C. Lee, J. J. Cao, Y. S. Li, J. C. Chow, J. G. Watson, K. Fung, " Variability of organic and elemental carbon, water soluble organic carbon, and isotopes in Hong Kong, " Atmospheric Chemistry and Physics,(2006):4569–4576.

[29] P. D. Zhao, "Characteristics of carbonaceous aerosol in the region of Beijing, Tianjin, and Hebei, China, "Atmospheric Environment, (2013):389–398.

مقالة بحثية

تركيز الجسيمات الهوائية الدقيقة ($PM_{2.5}$) وتركيز الكربون الأسود (BC) في عينات الهواء في منطقة الزبيري- صنعاء

أحمد خالد عبدالرحيم[1،*]، نبيله علي السويدي[2] و زايد عبدالله عيدان[2]

[1] قسم الفيزياء، كلّيّة العلوم، جامعة صنعاء، اليمن
[2] اللجنة الوطنية للطاقة الذرية، صنعاء، اليمن

* الباحث الممثّل: أحمد خالد عبدالرحيم؛ البريد الالكتروني: aabdulra@gmail.com

استلم في: 04 سبتمبر 2022 / قبل في: 20 سبتمبر 2022 / نشر في 30 سبتمبر 2022

المُلخّص

يهدف هذا البحث إلي دراسة تلوث الهواء الناتج عن الجسيمات الهوائية الدقيقة ($PM_{2.5}$) التي لها نصف قطر أقل من 2.5µm ومحتوى الكربون الأسود (BC) في عينات الهواء المُجمعة من موقع أعلى سطح المركز الوطني للأورام في منطقة الزبيري صنعاء – اليمن. أُستخدام مجمع العينات ISAP 1050e لتجميع عينات الجسيمات الهوائية $PM_{2.5}$ الدقيقة ووُجد أن التركيز الكتلي لعينات الجسيمات الهوائية $PM_{2.5}$ الدقيقة تراوح بين 14.27 إلي 159.09 µg/m بمتوسط 32.66µg/m^3 . تم مقارنة نتائج تركيز عينات الجسيمات الهوائية الدقيقة$PM_{2.5}$ مع الدليل الإرشادي لسنة (2005) لمنظمة الصحة العالمية الخاص بالجسيمات الهوائية الدقيقة $PM_{2.5}$.

بينت التحليلات الإحصائية وجود ارتباط موجب بين تركيز الجسيمات $PM_{2.5}$ مع درجة الحرارة في كل من فصلي الصيف والخريف. في الجانب الآخر بينت التحليلات الإحصائية وجود ارتباط موجب بين تركيز الجسيمات $PM_{2.5}$ والرطوبة النسبية في عينات فصل الخريف وارتباط سلبي بين تركيز$PM_{2.5}$ والرطوبة النسبية في عينات فصل الصيف . كذلك أُستخدم جهاز الانعكاس SSR لقياس تركيز الكربون الأسود (BC) في عينات $PM_{2.5}$ وبينت النتائج أن تركيز الكربون الأسود (BC) تراوح بين 1.84 إلي 3.90 µg/m^3 بمتوسط 2.90 µg/m^3. كذلك تم مقارنة نتائج تركيز الكربون الأسود (BC) مع بعض الدراسات في مجموعة من الأقطار العالمية. أيضاً بينت التحليلات أن معامل الهواء النوعي (AQI) ل 78.95% من عينات جسيمات الهواء$PM_{2.5}$ الدقيقة أعلى من الحد المعياري (AQI < 100) المنصوص به من قبل منظمة حماية البيئة الأمريكية (EPA).

الكلمات المفتاحية: الجسيمات الدقيقة، الكربون الأسود، التركيز، المعامل النوعي للهواء، الارتباط.

How to cite this article:

A. K. Abdul-Rahim, N. A. Al-Sowaidi and Z. A. Eadan, "CONCENTRATION OF FINE PARTICULATE MATTER (PM2.5) AND BLACK CARBON (BC) IN AEROSOL SAMPLES IN AL-ZUBAIRY AREA IN SANA'A, YEMEN", *Electron. J. Univ. Aden Basic Appl. Sci.*, vol. 3, no. 3, pp. 204-213, Sept. 2022. DOI: https://doi.org/10.47372/ejua-ba.2022.3.187