Egypt. J. Chem. Vol. 67, SI: M. R. Mahran, pp. **1127 - 1135** (2024)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Evaluation of the impacts of occupational exposure to PM and PAH on cardiovascular problems in wastewater treatment plant workers

Amal Saad-Hussein[1*], Safia Beshir[1], Weam Shaheen[1], Inas A. Saleh[2], Salwa Hafez[1], Atef M.F. Mohammed[2]

[1] Environmental & Occupational medicine department, [2] Air Pollution Research Department Environment & Climate Change Research Institute, National Research Centre, Egypt

Abstract:
Introduction: Workers in wastewater treatment plant (WWTPs) are at high risk to develop cardiovascular diseases (CVDs). This study aimed to estimate concentrations of 16 EPA priority polycyclic aromatic hydrocarbons **(**PAHs) and particulate matters (PM) in WWTP workplace, to evaluate potential risk of developing CVDs in the workers, and to identify the risky work tasks. **Methodology:** PM, and individual PAHs were measured. Cross-sectional study was done on 142 WWTP workers. All participants were subjected to questionnaire, electrocardiogram (ECG), measuring of blood pressure, serum APO-A, APO-B, APO-E, and Lipoprotein α (Lpα). **Results:** Annual mean concentrations of PM were lower than Egyptian limit. EPA 16 PAHs were detected in all samples, lower molecular weight PAHs were the most predominant PAHs. The most predominant wind direction of the selected WWPT is placed downwind to the surrounding areas. About 50% of the workers were complaining of dyspnea. 30.9% were hypertensive. Ventricular extra systole was the highest prevalent ECG abnormality followed by left ventricular enlargement. APO-B and APO-B/APO-A ratio were significantly higher in operator workers compared to the administrators and laboratory workers. While, APO-E was significantly lower in operator workers compared to the administrators and laboratory workers. **Conclusion:** PM and PAH exposure maybe associated with potential risk of developing CVDs in WWTP workers. PAHs in the WWTP could be from fuel used for the machines in the operator department, but the most contributed sources were from the surrounding areas. APO-B or APO-B/APO-A holds a promising biomarkers for evaluating CVDs risk, the potential risky task was operation.

Keywords: Wastewater treatment plant workers; Cardiovascular; Polycyclic Aromatic Hydrocarbons (PAHs); Particulate matters (PM); Apolipoprotein A (APO-A); Apolipoprotein B (APO-B); Apolipoprotein E (APO-E); Lipoprotein α (Lpα).

1.INTRODUCTION

Suspended particulate matter (SPM) is considered to be a risk factor for development of cardiovascular disease (CVDs) (1). The health importance of particulate matters (PMs) depend on their aerodynamic equivalent diameter, the coarse $PM_{10\text{-}2.5}$ (10 µm, > 2.5 µm), fine $PM_{2.5\text{-}0.1}$ (2.5 µm, > 0.1 µm), and ultrafine particles (UFP), (0.1 µm), (2). UFPs serve as polycyclic aromatic hydrocarbons (PAHs) transporters (3).

There are hundreds of PAHs in the environment, but only 16 compounds are on the US Environmental Protection Agency's (EPA) priority list of hazardous pollutants (4). There are two categories of anthropogenic sources of PAHs: petrogenic (wood, grass, and industrial combustion activities), and pyrogenic (including coal combustion and vehicular emissions), (5). To identify the potential sources of PAHs, molecular ratio has been used. Low molecular weight (LMW) PAHs (2+3-rings), intermediate (4-rings), and high molecular weight (HMW)–(5 + 6-rings) are the three categories listed in EPA among the 16 PAHs priority (6).

Occupational exposures to high levels of PAHs are mainly through inhalation, skin contact, or even ingestion of tainted food at their workplaces, or occupational exposure to industrial effluents, or cigarette smoke (7). Atmosphere receives the majority of the PAHs environmental load, making it the most important means of dispersing PAHs throughout the environment (8).

The primary contributor to CVDs is atherosclerosis (9). It was found a link between chronic exposure to PMs and the development of CVDs (10). Previously, epidemiology study reported that both short and long-term exposures to high levels of ambient PMs are associated with elevation of the CVDs risk (9). The interaction between the inhaled UFPs and PAHs was

*Corresponding Author: al.hussein@nrc.sci.eg / amel_h@hotmail.com (Amal Saad-Hussein)
Receive Date: 03 July 2024, Revise Date: 25 July 2024, Accept Date: 07 August 2024
DOI: 10.21608/ejchem.2024.301062.9937

found to have direct impacts on the blood arteries and the lining of the heart, damaging endothelial cells and activating inflammatory pathways and oxidative stress, all of which may help to promote atherosclerosis (2).

Hazards of PAHs; as mediators of PM-induced CVDs, has received limited attention by the toxicologists. The present study aimed to estimate the concentrations of 16 EPA priority PAHs and the PMs with different sizes in air of WWTP, and to evaluate the potential risk of developing CVDs among occupational exposed workers, in addition to identify the CVDs` risky work tasks in the WWTPs processes.

Subjects and Methods

Study design and population

Cross-sectional study was conducted on Abu-Rawash WWTP workers; 13 administrators, 33 laboratories and 96 operators. The other WWTP workers were excluded because not occupy the inclusion criteria that were:

- Non-smoker workers employed for more than 5 years,
- Workers with no medical history of hypertension or CVDs previously to their employment in the WWTP.

Ethical approval (No. 17085) was obtained from the Medical Research Ethics Committee, National Research Centre, Egypt. Written consents were obtained from all the included workers.

Environmental Assessment Methods:

Abu-Rawash WWTP is located at Western Sector of Giza, Egypt (at coordinates: 30° 4'5.41"N and 31° 4'30.14"E).

- **Monitoring Particulate Matters (PMs)**

Monitoring PMs with different fraction sizes (PM_1, $PM_{2.5}$, PM_{10}, and TSP) were carried out by using CEL-712 Casella Micro-Dust Pro Particulate Monitor at the different operational and processes workplaces in Abu-Rawash WWTP. Seasonal and annual mean concentrations of the different PMs sizes were calculated.

- **Wind Rose Plots for Meteorological Data (WRPLOT View)**

Wind-Rose version 4.41 was used to plot meteorological data (WRPLOT View) for Abu-Rawash WWTP. It provides visual wind rose plots and wind speed classes for a given location and time period using Lakes Software (11).

- **Sampling of Suspended particulate matter (SPM)**

Bimonthly samples of SPM were collected through glass fiber filters of Whatmann GFA type by using high volume sampler (HVS) for 24 months from air at working areas. Loaded filters were weighed before and after sampling to evaluate the weight of suspended particulate matter. The SPM samples were stored in unused standard plastic bags and transferred to the laboratory. All samples were air-dried at room temperature in dark place (12).

- **Evaluation of individual Polycyclic Aromatic Hydrocarbons (PAHs)**

Samples were put in glass vial and extracted with 10 ml of dichloromethane/n-hexane (1:1) in an ultrasonic bath for 10 min, three times at room temperature. The extract was transferred to a clean vial, and concentrated to about 2 ml using rotary evaporator (13). The concentrated extracts were fractionated by column chromatography. Qualitative and quantitative determinations of individual PAHs were done by Gas chromatograph (GC) (14). GC using conventional packed columns can identify the 16 EPA PAHs. The concentrations of individual PAHs were calculated and expressed in ng/m^3. The GC was calibrated with a diluted standard solution of 16 PAH compounds (Supelco, Inc., Bellefonte, PA).

Molecular diagnostic ratios of selected PAHs including: ANT/ (ANT + PHE), FLU/ (FLU + PYR), BAA/ (BAA + CRY), IND/ (IND + BGP), FLU/PYR, and LMW/HMW are used for identification of possible sources of PAHs (15).

Medical Assessment:

- Questionnaire:

After exclusion of the workers not occupy the inclusion criteria, 142 workers from Abu-Rawash WWTP were interviewed to fulfill personal, medical and occupational questionnaire.

- Electrocardiogram (ECG)

ECG was done for all the included workers using CARDIMAX portable apparatus, FX-7102 electrocardiograph Ver.02. FUKUDA DENSHI CO., LTD. Japan. The ECG was interpreted by a clinician (one of the authors) according to Goldberger et al. (16).

- Measurement of blood pressure (BP)

A standard mercury sphygmomanometer with a 14-cm cuff was used to measure systolic BP (SBP) and diastolic BP (DBP) in the sitting position for the workers. According to Blood Pressure UK Association, high blood pressure was considered if the SBP was 140 or more regardless the DBP, or the DBP was 90 or more regardless the SBP refers (17).

- Laboratory investigations:

Blood sample was collected by venipuncture with 5 ml syringes from each subject. Clotted blood centrifuged to separate serum. Quantitative detection of human serum Apolipoprotein (APO-A, APO-B, and APO-E), and Lipoprotein α (Lpα) were done using ELISA kit purchased from Bioassay Technology Laboratory China.

Statistical analysis

The collected data were statistically analyzed using SPSS package version 24. Quantitative data were represented as mean ± standard deviation (SD). Quantitative comparisons with normal distribution were done through Analysis of Variance (ANOVA) and Least Significant difference (LSD). The difference was considered significant at P-value ≤ 0.05 levels.

Results

Figure (1) showed Wind speed and directions, which were collected during sampling periods. It was found that the most predominant wind direction was from North-West, therefore, Abu-Rawash WWPT is placed downwind the surrounding areas.

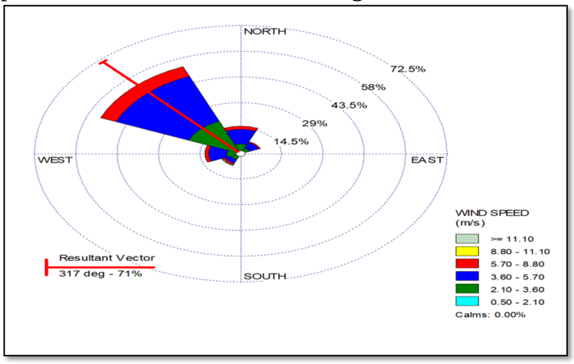

Figure (1): Wind-Rose plot of meteorological data for Abu-Rawash WWTP

Table (1) showed that, higher seasonal PMs concentrations were monitored during winter season, while the lower levels were during summer season. The average levels of PMs were in the order: office of chemists > secretary room > primary sludge raising station > reference laboratory > sludge Building area > Maintenance building area > Lift station area > Parking area > Administration area > Laboratory. The annual mean concentration levels of PMs ($PM_{2.5}$, PM_{10} and TSP) were lower than Egyptian limit in environmental workplaces. But, there is no Egyptian limit for PM_1 concentration levels in environment work and ambient air.

Table (2) showed the seasonal and annual mean concentrations of individual PAHs in SPM. Higher ∑PAHs concentrations were monitored during winter season, while lower concentrations were during summer season. The annual ∑PAHs in the current study were lower than the OSHA, NIOSH, and ACGIH (18).

Figure (2) showed that the EPA 16 PAH compounds were detected in all samples, lower molecular weight PAHs (LMW, 2–3 rings) are the predominant, and higher molecular weights PAHs (HMW, 4, 5–6 rings) were the less in all samples.

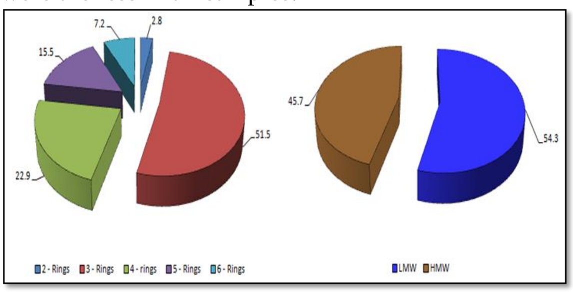

Figure (2): Rings and Molecular weight (MW) percentages of EPA 16 PAHs

Figure (3) showed molecular diagnostic ratios of selected PAHs, which are used for identification of possible sources of PAHs. The ratios of ANT/(ANT + PHE), FLU/(FLU + PYR), BAA/(BAA + CRY) and IND/(IND + BGP) in the current study were 0.3, 0.4, 0.2, 0.3 respectively. The ratios of FLU/PYR and LMW/HMW were 0.8 and 1.2 respectively.

The mean age of the workers was (47.5±9.83 years), and their employment duration was (19.5±9.4 years). About 50% of the workers were complaining of dyspnea on mild exertion, while, only 4.2% of the workers were complaining of palpitation. Among the WWTP workers mean level of systolic blood pressure was (129.4±16.81 mmHg), diastolic blood pressure was (86±11.14 mmHg), pulse rate was (74.6±12.3 beat/min), and edema was detected in 3 workers only.

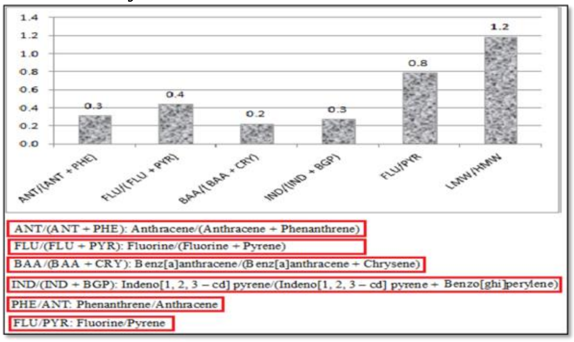

Figure (3): Molecular diagnostic ratios of selected PAHs

Table (3) showed that hypertension was higher among the operators followed by the administrators and laboratories. ECG abnormalities were found in 26/142 WWTP workers. Ventricular extra systole was the highest ECG abnormality followed by left ventricular enlargement. ECG abnormalities were detected more among operators, followed by administrators and laboratories.

Table (4) showed that, Lpα and APO-A were higher among the operators compared to the other two groups, but no significant difference was detected between the three groups. While, APO- B and APO-B/APO-A ratio were significantly higher in the operators compared to the other groups. While, APO-E was significantly lower in the operators compared to the other groups.

Discussion

Concentrations of environmental pollutants in selected WWTP in the present study were varied depending on meteorological parameters and different tasks done in each workplace. According to windrose of meteorological parameters, it was found that the predominant wind direction was from North-West direction. Therefore, the WWPT is placed downwind to the surrounding areas, and most pollutants could be transferred from surrounding areas. The surrounding areas of WWTP are complex areas, containing agriculture activities, heavy traffic roads, and other different industrial activities.

Table (1): Seasonal and annual mean concentration levels of PM (PM_1, $PM_{2.5}$, PM_{10} and TSP) in Abu-Rawash WWTP at the different departments

Site	Concentration (mg/m^3)											
	Winter	**Spring**	**Summer**	**Autumn**	**Annual**	**Egyptian limit***	**Winter**	**Spring**	**Summer**	**Autumn**	**Annual**	**Egyptian limit***
PM				**PM_1**						**PM_{10}**		
Maintenance building area	0.088	0.077	0.048	0.081	0.073	-	0.213	0.146	0.129	0.207	0.174	**3**
Lift station area	0.076	0.068	0.067	0.072	0.071		0.194	0.15	0.134	0.168	0.162	
Sludge Building area	0.11	0.105	0.068	0.107	0.097		0.223	0.16	0.15	0.208	0.185	
Primary sludge raising station	0.132	0.08	0.075	0.118	0.101		0.203	0.184	0.124	0.198	0.177	
Secretary room	0.152	0.094	0.079	0.101	0.107		0.259	0.225	0.17	0.25	0.226	
Laboratory	0.053	0.031	0.028	0.048	0.04		0.138	0.093	0.089	0.122	0.111	
Parking area	0.096	0.073	0.049	0.091	0.077		0.182	0.146	0.131	0.157	0.154	
Administration area	0.074	0.042	0.037	0.064	0.054		0.176	0.139	0.133	0.152	0.15	
Reference Laboratory	0.155	0.096	0.028	0.117	0.099		0.252	0.175	0.129	0.236	0.198	
Office of Chemists	0.185	0.091	0.085	0.124	0.121		0.266	0.221	0.202	0.256	0.236	
PM				**$PM_{2.5}$**						**TSP**		
Maintenance building area	0.138	0.108	0.092	0.118	0.114	**3**	0.304	0.223	0.21	0.296	0.258	**10**
Lift station area	0.118	0.115	0.102	0.107	0.111		0.242	0.236	0.231	0.237	0.237	
Sludge Building area	0.159	0.122	0.11	0.149	0.135		0.283	0.26	0.227	0.278	0.262	
Primary sludge raising station	0.165	0.122	0.111	0.161	0.14		0.34	0.303	0.247	0.331	0.305	
Secretary room	0.211	0.152	0.142	0.164	0.167		0.464	0.351	0.316	0.376	0.377	
Laboratory	0.085	0.063	0.058	0.07	0.069		0.166	0.144	0.14	0.155	0.151	
Parking area	0.13	0.096	0.092	0.109	0.107		0.244	0.182	0.174	0.219	0.205	
Administration area	0.112	0.085	0.059	0.092	0.087		0.25	0.175	0.17	0.231	0.207	
Reference Laboratory	0.184	0.126	0.09	0.173	0.143		0.319	0.229	0.202	0.28	0.257	
Office of Chemists	0.251	0.172	0.126	0.216	0.191		0.331	0.257	0.244	0.303	0.284	

* **Egyptian acceptable limit** (29)

Table (2): Seasonal and annual mean concentration levels of PAHs in SPM in Abu-Rawash WWTP

MW	PAHs compounds (ng/m^3)		Autumn	Winter	Spring	Summer	Annual
LMW	Naphthalene	NAP - 2	28	33	42	11	29
MMW	Acenaphthylene	ACY - 3	185	297	370	38	223
	Acenaphthene	ACE - 3	58	192	103	18	93
	Phenanthrene	PHE - 3	237	85	61	18	100
	Fluorine	FLU - 3	68	73	64	17	56
	Anthracene	ANT - 3	45	76	50	13	46
	Fluoranthene	FLT - 4	42	64	38	8	38
	Pyrene	PYR - 4	161	68	45	7	70
	Benzo(a)anthracene	BAA - 4	19	44	40	7	28
	Chrysene	CRY - 4	176	133	62	7	95
HMW	Benzo(b)fluoranthene	BBF - 5	56	248	40	8	88
	Benzo(k)fluoranthene	BKF - 5	16	24	24	4	17
	Benzo(a)pyrene	BAP - 5	29	39	40	7	29
	Dibenzo(a,h)anthracene	DBA - 5	22	29	33	5	22
	Indeno(1,2,3-c,d)pyrene	IND - 6	12	31	34	4	20
	Benzo(ghi)perylene	BGP - 6	60	69	69	12	53
∑PAHs			**1215**	**1504**	**1115**	**183**	**1004**
OSHA (PEL)		0.2 mg/m^3 = 200000 ng (8,17)					
NIOSH (PEL)		0.1 mg/m^3 = 100000 ng/m^3(8,17)					
ACGIH (TLV)		0.2 mg/m^3 = 200000 ng/m^3 (17)					

LMW: *low molecular weight;* ***MMW:*** *moderate molecular weight;* ***HMM:*** *high molecular weight;* ***OSHA:*** *Occupational Safety and Health Administration,* ***NIOSH:*** *National Institute for Occupational Safety and Health,* ***ACGIH:*** *American Conference of Governmental Industrial Hygienists;* ***PEL:*** *permissible exposure limit;* ***TLV:*** *Threshold limit value.*

Table (3) Distribution of ECG abnormalities among WWTP workers in different departments

	Administrators (13)		**Operators (96)**		**Laboratories (33)**	
	No.	**%**	**No.**	**%**	**No.**	**%**
Examination						
Hypertension	3	23.1	35	36.5	6	18.2
Pulse rate	1	7.7	17	17.7	3	9.1
ECG abnormalities						
Bundle branch block (No. 2)	0	0	2	2.1	0	0
Atrial fibrillation (No. 3)	0	0	3	3.1	0	0
Bradycardia (No. 2)	0	0	2	2.1	0	0
Depressed ST segment (No. 3)	0	0	2	2.1	1	3
Elevated ST segment (No. 4)	0	0	3	3.1	1	3
Inverted T wave (No. 2)	0	0	2	2.1	0	0
Irregular rhythm (No. 4)	0	0	3	3.1	1	3.0
Left ventricular enlargement (No. 9)	1	7.7	8	8.3	0	0
Tachycardia (No. 3)	0	0	3	3.1	0	0
Tall T wave (No. 6)	0	0	6	6.3	0	0
ventricular extra systole (No. 14)	1	7.7	11	11.5	2	6.1

Table (4) Laboratory investigations of WWTP workers according to their occupation

	Administrator (13)	**Operators (96)**	**Laboratory (33)**	**P-value**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	
Lpα (mg/dl)	68.43±18.41	107.87 ± 23.85	68.77 ± 7.30	0.24
APO-A (mg/dl)	76.8 ± 11.8	89 ± 13.8	74.2 ±5.04	0.64
APO-B (mg/dl)	106.8 ± 16.14	192.3 ± 33.78$^{(a,b)}$	116.6 ± 8.46	0.02
APO-E (µg/ml)	30.1±12.4	26.8 ± 14.3$^{(a,b)}$	51.8±11.6	0.01
APO-B/APOA ratio	1.39±0.45	2.16±0.91$^{(a,b)}$	1.57±0.50	0.02

LSD: a: significant difference between operator workers and administrators

b: significant difference between operator and laboratory workers

In the current study, PM_1 concentrations (40-121 µg/m^3) in selected WWTP couldn`t compared with the Egyptian limit, as PM_1 is not mentioned in the Egyptian law, but, were higher than that measured in WWTP at Taiwan (0.53–1.67 µg/m^3) (19). $PM_{2.5}$ concentrations (69-191 µg/m^3) were lower than the Egyptian limit, but, higher than the average concentrations ambient air of Greater Cairo (85 µg/m^3), (20, 21), and in the industrial areas at China (47.0-72.2 µg/m^3), at Middle East (27 µg/m^3), at North-Western Europe (13 µg/m^3), and at low- and middle-income countries (16 µg/m^3), as well as at high-income countries (12 µg/m^3), (22). It was also higher than the WHO Air quality guidelines (AQG) (10 µg/m^3) (23), and California air quality standards/Environmental protection agency (Cal EPA) limit (12 µg/m^3) (24).

Hamanaka and Mutlu (25) found that exposure to PMs is associated with heart arrhythmias, changes in heart rate variability, myocardial infarction, arterial vasoconstriction, increasing blood coagulability, atherosclerosis, heart failure, and stroke. Jaganathan et al. (26), added that industrial rising areas; such as India, China, and Africa, showed positive correlations between $PM_{2.5}$ concentrations and the occurrences of CVDs.

In the current study, one third of the WWTP workers were hypertensive; the highest percent was among operators, followed by administrators and laboratories. This could be attributed to their exposure to high PM_1 and $PM_{2.5}$ concentrations compared to the administrators and the laboratories. Rajagopalan et al. (27) found that over several years prolonged exposure to PM_1 and $PM_{2.5}$ increases the incidence of hypertension. Fahmy et al. (28) found also that 50% of the ewage workers were hypertensive, but, with significant decrease in their heart rate compared to controls, which is contrary to the current results, that detected irregular pulse rate in 14.8% of the examined workers, the highest percent was among the operators, followed by the laboratories then the administrators.

High $PM_{2.5}$ concentrations in the current study could explain the high percentages of ECG abnormalities and complaints of dyspnea. The majority of the ECG abnormalities were found among the operators; mainly ventricular extra systole and left ventricular hypertrophy, that could be due to high concentrations of PMs in the operator departments compared to the other departments. Fahmy et al. (28), found similar results, that was 27% of the WWTP workers were complaining of dyspnea and 18% of left ventricular hypertrophy. The current results were also with the results in previous studies, that detected positive relationship between CVDs and long-term exposures to $PM_{2.5}$ or PM_{10} (29), as well as with short-term exposures (27).

Agency for Toxic Substances and Disease Registry's (ATSDR) reported that ambient PAHs levels were found to be 0.02–1.2 ng/m^3 in rural areas and 0.15–19.3 ng/m^3 in urban areas worldwide (18). But, there is no standard limit for PAHs in the Egyptian environmental law; except for naphthalene (52 mg/m^3), but it was mentioned that workers must minimize their exposure to the following PAHs: benzo(a)anthracene, benzo(a)pyrene, chrysene and benzo(b)fluoranthene due to their hazardous health effects according to the Egyptian regulation mentioned in the Law 4 (Law of the Environmental Protection for the year 1994) (8, 30).

In the current study, the EPA 16 PAHs were detected in all the collected air samples from the included WWTP. Benzo(a)pyrene (BAP) is one of the priority pollutant of the individual PAHs listed by the U.S. Environmental Protection Agency (EPA) (24). It is used as an indication of the presence of PAHs in air, where PAHs usually occur as complex mixtures, not as single compounds (18). There is no Egyptian acceptable limit for BAP (30). In the present study, the concentration levels of BAP (29 ng/m^3) were lower than that found at industrial areas in China (91 ng/m^3) (31), but higher than that found at industrial areas in Germany (2.88 – 4.19 ng/m^3), and in United Kingdom (10 ng/m^3) (32), and higher than the European limit (1 ng/m^3) (33). Meanwhile, the sum of PAHs concentrations in the current study (1004 ng/m^3) were lower than that found at industrial areas in China (2020.4 ng/m^3) (31).

Therefore, the annual ∑PAHs in the current study were lower than the safe levels mentioned by the Occupational Safety and Health Administration (OSHA) (18), the National Institute for Occupational Safety and Health (NIOSH) (8, 18) and the American Conference of Governmental Industrial Hygienists (ACGIH) (18), and were within the concentrations ranged from ∑PAH 373.3 ± 27.3 to 12959.5 ± 685.9 ng/m^3 in the air around WWTP using coke as a fuel in China (34).

In the present study, low molecular weight PAHs (LMW: 2 – 3 ring PAHs) were the most predominant PAHs in the air samples the included WWTP, while, the high molecular weights PAHs (HMW: 4, 5 – 6 ring PAHs) were the less predominant. The molecular diagnostic ratios of the measured PAHs were used for identification of possible sources of the PAHs polluting the work environment in the included WWTP in this study. If the ratios of ANT/ (ANT + PHE) > 0.1, FLU/ (FLU + PYR) = 0.4 – 0.5, BAA/(BAA + CRY) = 0.2 – 0.35, IND/(IND + BGP) = 0.2 – 0.5 indicate that the main sources of PAHs were fuel combustion (15). In the current study these ratios values were 0.3, 0.4, 0.2, 0.3 respectively. If FLU/PYR < 1.0 and LMW/HMW > 1.0 indicate that the main sources of PAHs are petrogenic (15). In the present study the ratios were 0.8 and 1.2.

Meanwhile, high molecular weights PAHs (HMW-PAHs) are usually released from pyrogenic sources including coal combustion and vehicular emissions (35). The results of the present study were in agreement with Nitsche et al. (36), which indicated that LMW-PAHs were mostly originated from low-temperature combustion processes, while, HMW-PAHs were mostly originated from high-temperature combustion processes in the industrial activities.

Mallah et al. (37) denoted that the underlying mechanisms for development of CVDs due to exposure to high concentrations of PAHs could be attributed to induction of systemic inflammation and oxidative stress, that led to endothelial dysfunction, loss in smooth muscle cell, and thickening of the intima media of the carotid artery. Though endothelial dysfunction may contribute to development of blood vessel inflammation, remodeling of blood vessels, and aggravation of plaque development in atherosclerosis (37), and increases the risk of ischemic heart development.

The link between inflammatory cytokines and Lpα was proved. Lpα could entail platelet aggregation, promote endothelial dysfunction, inflammation and calcification in vasculature (38). This may shed light on how Lpα functions in thrombogenesis and as a pro-inflammatory factor, and it may also implement in connection between elevated Lpα levels and atherosclerotic CVDs (39). Therefore, higher concentrations of Lpα is a predictor risk for the occurrence of atherosclerotic heart disease. But, Lpα was not identified as an independent risk factor for CVDs (40, 41).

In the present study, the mean levels of Lpα of the workers in the three departments were high than that level, and the highest levels were among the operators, but, without significant difference between each other groups. Therefore, analysis of apolipoproteins could have a significant predictor role for CVDs among the exposed WWTP workers in the present study.

APO-A is one of the main component of high-density lipoprotein (HDL), which transports abnormally deposited cholesterol from peripheral tissue cells to the liver for excretion, in addition to the anti-inflammatory, antithrombotic, and anti-oxidative properties of HDL (42). While, APO-B form around 90% of the protein in the low density lipoprotein (LDL), which serves as the main functional protein for delivering cholesterol to peripheral cells, and APO-B measurement offers precise data on the quantity of circulating atherogenic particles (43). It's significant to denote that APO-E stimulates liver-to-peripheral tissue reverse cholesterol transfer, to stop the development of atherogenesis, and have anti-atherogenic effect; through the anti-inflammatory, anti-oxidative, anti-thrombotic, and endothelium repair actions (44).

In the current study, there was no significant difference between the three working groups regarding APO-A serum levels. Maiseyeu et al. (45) found that PMs exposure did not lead to HDL dysfunction. However, Mathew et al. (46) found that exposure to even low levels of $PM_{2.5}$ for short-term were linked to HDL dysfunction, and Ramanathan et al. (47) found that exposures to $PM_{2.5}$ (0.15 mg/m^3) lead to negative effects on the anti-oxidative properties of HDL.

APO-B has a higher sensitivity and specificity than total cholesterol or LDL-cholesterol in predicting CVDs (9). While, APO-E appears to have anti-inflammatory, anti-oxidative, and anti-thrombotic actions, as well as associated abilities to re-endothelialize and stabilize plaques (48). APO-B/APO-A ratio is considered to be superior than lipids, lipoproteins, and standard lipid ratios in identifying predictor of CVDs risk (43), as this ratio representing the balance of cholesterol between the potentially atherogenic and anti-atherogenic lipoprotein particles. Its high score would denote an elevated propensity for cholesterol deposition, endothelial dysfunction, and increased risk of CVDs. The higher the ratio, the more cholesterol is transported through the bloodstream and deposited in the artery wall.

In the present study, APO-B and APO-B/APO-A ratio were significantly higher and APO -E was significantly lower among the operators compared to the other groups. These significant findings are with the high percent of ECG abnormalities among the operators compared to the other groups.

Conclusion:

The study concluded that the surrounding areas were contributed mainly for the elevation of $PM_{2.5}$, PM_1 and PAHs concentrations in the WWTP, and the main sources of PAHs were petrogenic. These exposures were associated with potential risk of developing CVDs, especially among the operator workers. Operators were the riskiest group for development of CVDs among the different tasks in the WWTP, and that combination of APO-B, APO-E and APO-B/APO-A ratio were excellent non-invasive predictor for the CVDs development.

Declarations

Funding

This work was funded by Academy of Scientific Research and Technology (ASRT) (2017–2020), the funded project (ID:1475) was with title “Improving environmental and health conditions for workers in Abu-Rawash wastewater treatment plant and remediation of pollution resources at El-Rahawy Drain”.

Author contributions

AS-H was the principle investigator of the funded project, she did the statistical analysis and tabulations, and shared in writing the manuscript. **SB** did the blood laboratory investigations and shared in writing the manuscript. **WS** measured blood pressure and pulse of the workers and shared in EGC and in writing the manuscript. **IS** collected air samples and monitoring of the PMs levels in the workplaces, and revised the air results. **SH** shared in EGC and collection of the references. **AM** collected SPMs, monitored of PAHs with the analysis of the individual PAHs compounds, and used the wind rose plots for meteorological data to study the wind directions. **AM** also wrote the air results explanations and comparisons with the Egyptian and the world standard limits of the air pollutants.

Consent to participate

Consents were obtained from all subjects before onset of work.

Consent to publish

Not applicable

Ethical Approval

Approval of the Ethical committee of the National Research Centre was taken prior to the study (Registration number 17085).

Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and material

The original data is available.

Competing of interests

The authors declare that they have no conflict of interest.

Consent to Publish

All the authors revised the manuscript and accepted publishing it.

Acknowledgement

The authors express their sincere thanks to Academy of Scientific Research and Technology (ASRT). As this work was funded by Academy of Scientific Research and Technology (ASRT) (2017–2020), and to the mangers of Abu-Rawash WWTP and the workers in it for their cooperation to finish this work.

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