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Evaluation Of Dust/Particle Fallout Content Within Cairo Central Railway Station, Egypt

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ABSTRACT

In this study, the dust/particle fallout rate within the cairo central railway station was investigated during the period from december 2003 till november 2004. Results obtained indicated that the average particle fall-out rate within the main station building was less than 10g/m^2/month, with its soluble portion exceeding its insoluble portion. Identification of the main organic functional groups within the soluble portion of the collected dust was conducted using FTIR technique. As well, selected metal ion content (Ca^{2+}, Cu^{2+}, Cr^{3+}, Fe^{3+}, Mg^{+2}, Mn^{+2}, Pb^{+2}, Se^{+2}, Ag^{+}, V^{+5} and Zn^{+2}) within the insoluble portions was analytically determined. The data revealed that while the intensity of activities within the station building had a notable impact on the recorded particle rate and its content, the effect of outside activities(heavy traffic and construction work) was considerable noting the ambient and regional wind conditions. Multivariate cluster analysis of the measured parameter values showed a strong dependency of both the soluble and insoluble components on the extent of diesel fuel emissions therein. As well, it helped in the identification of sources contributing to the measured metal ion content of the insoluble portion of dust.

KEYWORDS

Dust;
Cairo railway station;
Diesel locomotives.

INTRODUCTION

Egypt has the first railway network in the African continent that was commissioned in 1851 to link Alexandria and Cairo overland by 1856[1,2]. Basically, the Egyptian railway network was constructed along the nile valley and the delta passing through the capital with extensions to the east and the west to connect it with major cities and main locations[2]. The original length of this network was 3600km, however, in 2002/03, it measured around 5000 km[1] (Figure 1[3]). Evidently, the Egyptian national railways (ENR) is a vital commercial sector that serves from 1.4 to 2.28 million passengers per day, 89% of whom are students and civil servants[4]. As well, this sector employs 25% of the ministry of transport's (MOT) working force[5]. In addition to that, it conveys an estimated 12,000 tons of goods per year[1,4].

Capacity wise, ENR has a passenger fleet of around 3100 plain and air-conditioned coaches that make up an equivalent of 1210-1315 train assemblies and provide for a daily seat capacity of around 630,000[1]. Trip-wise, this amounts to 460 million trips and 800 million passenger miles annually(1480 million passenger km)[1,6]. Additionally, the ENR has a cargo fleet of 10,600 carriages that provides space for 40,000 tons of goods to be transported per year[1,4]. Moreover, ENR has over 761 locomotives all of which were built abroad and all of which are above 40 years old[1]. This number includes 671 diesel-electric locomotives and several turbine-powered bi-directional train sets operating in 12 regions[6]. However, in 2007, the minister of transport declared that only 300 locomotives of the 700 available were operational because of the deficiency in the maintenance infrastructure at the railways authority[5].

Historically, trains and railroad travel has long been an object of fascination since their early days of introduction into the modern world[7]. In view of that, train emissions were not considered to have any impact on either human health or the environment. However, recent studies have concluded that locomotives were amongst the most dangerous air polluting mobile sources that pose not only a serious impact on human health but also the environment[7,8,9,10,11]. This is mainly because these engines

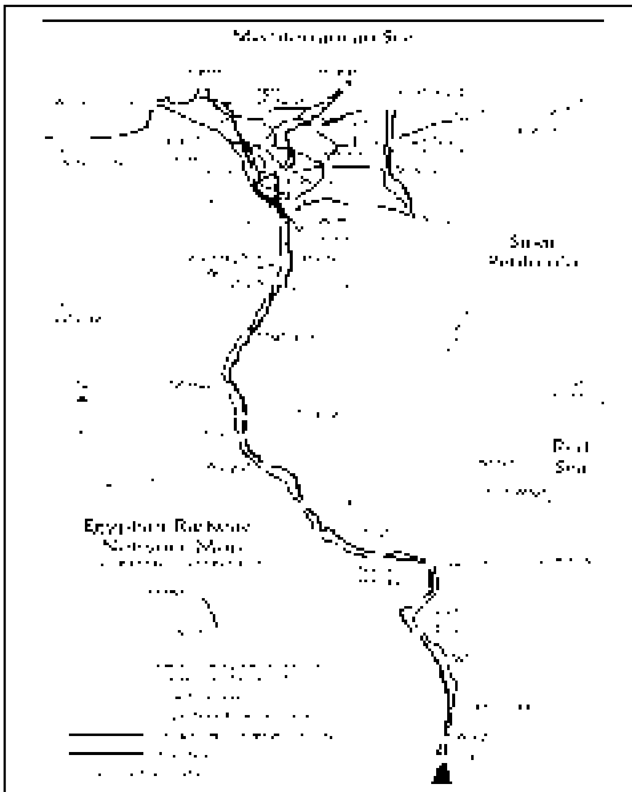

Figure 1: The egyptian railways network map[3]

run on diesel fuel or petrol diesel, a mixture of the middle distillates or gas oils and residual oils[8,12]. Upon combustion, diesel exhaust contributes a significant amount of particulate matter, polycyclic aromatic hydrocarbons(PAH), smog-forming nitrogen oxides, sulfur dioxide, and global warming gases to the ambient levels[12,13,14,15,16,17,18].

Furthermore, recent studies evaluating the health impacts from exposure to this PM-rich exhaust concluded that human exposure to such a mixture was responsible for high rates of mortality both at the work place and outside it[11,19,20,21]. Moreover, this mixture was found to contain a variety of PAH and nitro-PAH adsorbed to its particulates, the majority of which are considered potentially carcinogenic for humans[11]. Emission-wise, a diesel engine contributes 20-100 times more PM and NOx to the environment than a gasoline-powered engine per km traveled[8,14,22]. Furthermore, the combustion of diesel fuel was reported to contribute significantly to the ambient fine inhalable soot or particulate matter(PM) both outdoors and indoors[23,24]. Subsequently, as the momentum of studies exploring the impacts of diesel exhaust on human health was growing, environmental agencies in countries such as the US, Canada, Europe and Japan were urged to set forth more stringent standards requiring the reduction of PM emissions from locomotives by 90%[9,18,25]. An additional obligation set within these standards was to reduce the burden of the NOx emissions resulting from diesel powered locomotives by 60% as it was implicated in the formation of secondary PM[13].

From a technical perspective, the impact of diesel exhaust was found not to depend only upon the quality of the fuel used but also upon the degree of utilization, the load and speed of engine[8,14,15,19,22,26,27]. Moreover, these impacts tend to be amplified the longer diesel engines remain idle during their operation time[8,14,18,19,28] In specific terms, it was reported that a locomotive that remains idle 75% of its operation time consumes 27% of its fuel and produces 25% more of emissions[28].

Evaluation of dust fall and its content was recently applied as a key parameter to evaluate the impact of emissions on both commuters and workers in railway stations[29,30]. With the above in mind, the aim of this study was to investigate the particle fallout rate and its content within the cairo central railway station(CCRS)-central cairo-during the period from december 2003 till november 2004 and on a monthly basis. Dust samples were collected from within the station and the major contents of the soluble and the insoluble components were analyzed accordingly. Analysis included the determination of some selected metal ion contents and the identification of the major functional organic groups present within. Throughout the period of study, observations concerning the intensity and types of activities within and outside the station premises were recorded. Meteorological data(Temperature, relative humidity%, wind speed and direction) within the capital region were also recorded for the entire monitoring period and the findings were incorporated in the results interpretation and evaluation thereafter.

EXPERIMENTAL

The study area:cairo central railway station

The study area, the cairo central railway station (CCRS), is the largest passenger station in Egypt and the center of the ENR network[2] (Figure 2). Originally built in 1856, it was reconstructed in 1892 to incorporate architectural elements of the traditional arabic style[31]. However, the building façade was re-

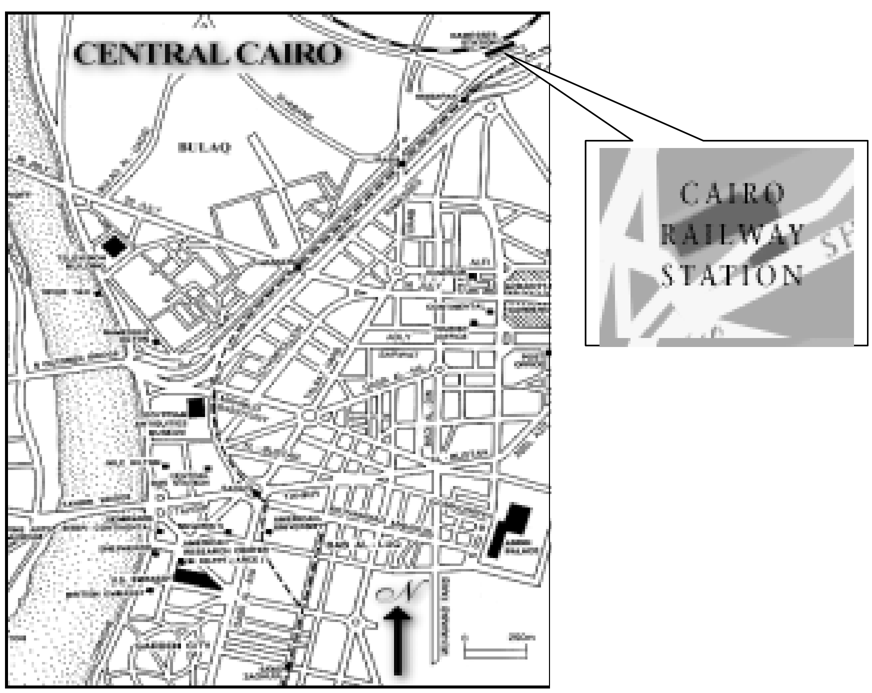

Figure 2: A map of central cairo indicating the coordinates of cairo central railway station (Aka ramesses station) and the network of main streets in its immediate surroundings(Inset the station building)

modeled in the same style later in 1955. Cairo's main station is also known as ramses station after the relocation of ramses II statue in the square adjacent to it in 1954[32].

Initially, the station was built with nine platforms and a total length of 2,180 yards(About 2000m) and was designed to handle over 10,000 passengers and 160 trains daily[2]. Today, it has 21 platforms and handles both passengers and goods traveling along this network daily. Activity-wise, indoors platforms/ tracks 1 to 5 handle the fast and slow traffic west of the nile delta and further west. Tracks 6-13, north of the old station building, receive incoming and departing trains from upper egypt to Alexandria and vice versa as they pass through the capital uninterrupted. Platforms numbers 18-21 are called the east line and are located south east of platforms(1-5) at the extension of platform 1. These platforms receive traffic daily from the eastern part of the nile delta and the canal region.

District-wise, the station is located in central cairo, the heart of the transportation center of the capital(Regional buses, microbuses and taxis). The station is contoured from the east and south by the high bridge of 6^{th} of october that links the greater cairo region suburbs in the west with downtown cairo and giza city in the east. This bridge also connects these western suburbs to the mehwar-26^{th} july street route, which ultimately links them to the cairo-alexandria desert road, and the south and west bound freeways. To its immediate southeast lies a high-rise of Egypt post administration and services(Central postal customs depot) and the national postal museum. In front of its main entrance to the west lies a bridge treaded by heavy traffic(Public buses and microbuses) traveling to and from the northern districts of shoubra and shoubra el-khiema. This road ultimately connects to the Cairo-Alexandria agricultural road, the western gateway to the main cities within the nile delta. In addition to that, this station lies on top of one of the 4 busy underground metro stations intersecting the greater cairo metro lines.

In august 2002, the financial services annex building of the cairo main station(South) was demolished in preparation for the construction of a multi level-parking garage to serve the area[33]. Although there was a prolonged debate about the objective of the project, construction on the 8-level parking garage commenced in 2003 and ended in 2005. Ironically and after its completion, the egyptian railways Authority announced that the new building had to be removed because of safety reasons and the 6^{th} of october high bridge. Consequently, the entire building was demolished by the end of 2006 and in 4 months only.

Sampling period and procedure

The investigations within the cairo central railway station(CCRS) were carried out during the period from december 2003 till november 2004. Prior to the installation of sampling apparatus, a pre-selection survey of the inside of the station was undertaken. Sampler setting points were identified as the midway point along the 120-m long train platforms for tracks 1-4 in the main station building. These platforms receive a high turnover of passengers daily from alexandria and the west of nile delta. As a precaution, the selected location had to be from 10-12m above the ground and away from the public station entrances. Such a placement ensured that the sampling apparatuses did not receive dispersed dust from the station floors as well as they were not subject to tampering during the 12-month study period plus being accessible for regular checkups and replacements.

Dust-particle fallout measurement[34,35]

Cylindrical glass containers with a circular opening of 7.5cm diameter and a length two or three times this diameter were utilized for dust sampling. In order to avoid particle blowout and subsequent removal by the wind, each container was filled with 500mL of distilled water before setting it in the selected site. After a period of 30 days, the container was removed and replaced by a new water-filled container. Dust fallout content was determined gravimetrically and its amount was reported in the units of t/km^2/month(or g/m^2/month). The content of the collecting container and its washing were then analyzed according to the scheme shown in figure 3[35].

Methods

Analytical procedures adopted therein for deter-

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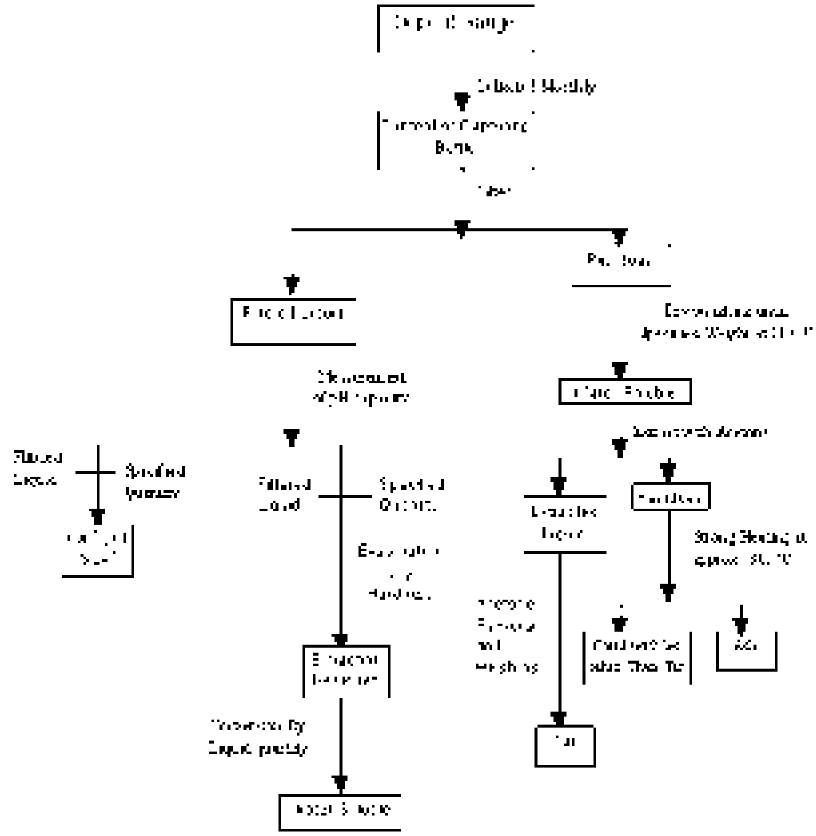

Figure 3: Schematic diagram for the analysis of dustfall content[35]

mination of the soluble and insoluble dust fallout components were: gravimetric method, tarry matter, extraction with carbon disulfide; ash and combustible matter, gravimetrically evaporation of filtrate after tarry matter extraction[35]. Selected APHA[36] analytical methods were utilized for the determination of nitrates: UV spectrophotometric screening method, sulfates: barium sulfate turbidimetric method, chlorides: argenometric turbidimetric method, selected metal ions(Ca, Cu, Cr, Fe, Pb, Mg, Mn, Ni, Se, Ag, V, Zn): atomic absorption spectroscopy. Ammonium content in dust was determined using nessler's reagent and potassium mercuric iodide reaction[37]. FTIR technique was used to determine the main functional organic groups present in the soluble portion of the collected dust.

Statistical analysis and data manipulation

Multivariate statistical analysis(Cluster analysis) of the obtained data was calculated using 'statistiXL' version 1.6 incorporated within microsoft excel (Microsoft® windows98) software program. Cluster analysis was performed using the ward's method for minimum variance(centroid) and the similarity coefficient used was the square euclidean distance function. Hierarchal clustering of the measured variables of sulfates, nitrates, chlorides ammonium, tar, ash and combustible matter was performed as well as for the obtained monthly metal ions content values. Dendograms obtained from the analyses revealed the degree of similarity between measured values and parameters as well as groups of parameters and the significance of the correlation.

RESULTS

TABLE 1(Figure 4) presents the mean monthly data for pH, soluble and insoluble contents and total particle fallout rate of samples collected within the cairo central railway station(CCRS) during the period of study from december 2003 till november 2004. In general, the total particle fallout rate ranged between 2.12-6.55g/m^2/month, with higher rates recorded during the months from february till july

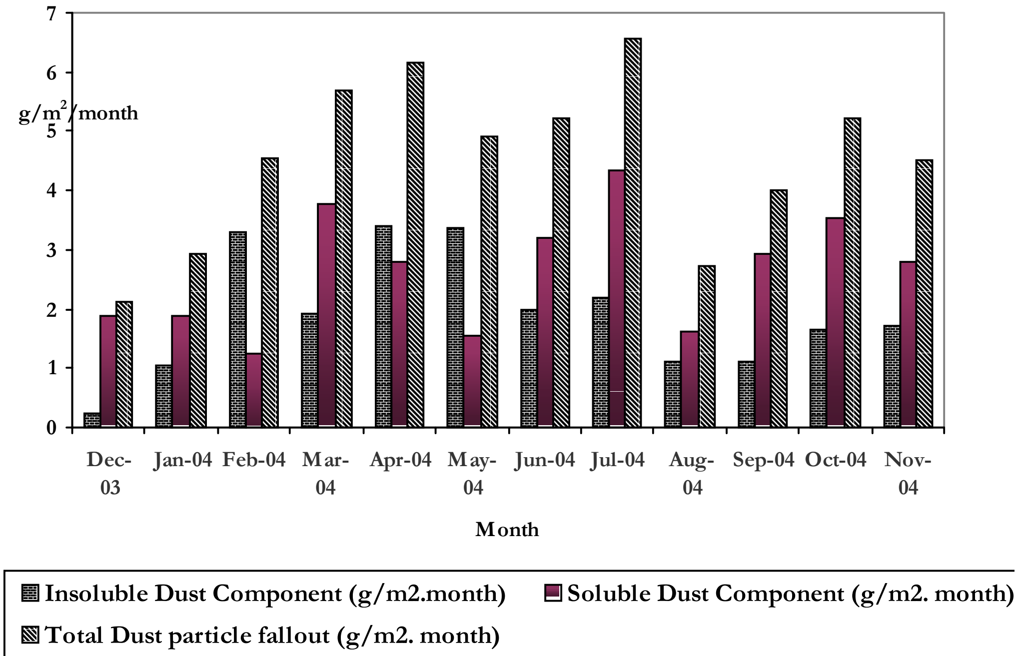

Figure 4: Mean monthly values for total dust fallout particle and its soluble and insoluble components(g/m2.month)-cairo central railway station(Dec 2003-nov 2004)

TABLE 1: Average monthly pH and soluble content, insoluble content and total particle fallout(g/m^2/month) of collected dust-cairo central railway station(dec 03-nov 04)

Month	pH	Soluble content	Insoluble content	Total particle fallout
December 03	6.23	1.9	0.22	2.12
January 04	6.36	1.9	1.04	2.94
February 04	6.6	1.23	3.3	4.53
March 04	6.7	3.78	1.92	5.7
April 04	7.0	2.79	3.41	6.17
May 04	6.9	1.55	3.35	4.9
June 04	6.15	3.21	2.0	5.21
July 04	6.17	4.35	2.2	6.55
August 04	6.27	1.63	1.1	2.73
September 04	6.51	2.92	1.1	4.0
October 04	6.46	3.55	1.65	5.2
November 04	6.92	2.78	1.72	4.50

2004. The soluble and insoluble portions of the sampled dust ranged from 1.55-4.35g/m^2/month and 0.22-3.41g/m^2/month, respectively. The recorded pH ranged between 6.15-7.0, with the slight acidic values obtained during the months of dec 03-january 04 and june 04 till october 04. A summary of the average monthly meteorological data(Temperature, %of wind speed and direction, maximum temperatures, precipitation, and relative humidity %) compiled for the capital region during the period of study is reported in TABLE 2.

The mean monthly values for the soluble dust contents of Cl^-, NH_4^+, SO_4^{2-} and NO_3^- are shown in TABLE 3(Figure 5). Results reveal that the chlorides, sulfates and nitrates concentrations determined ranged from 52-2095$\mu g/m^3$, 2100-9850$\mu g/m^3$ 2100-9850$\mu g/m^3$ and 1433-9329$\mu g/m^3$, respectively. Values for the ammonium content ranged between 4.0-4010$\mu g/m^3$, with a very significant increase of the content recorded during the month of july 04. Results for the FTIR analysis of the soluble component of the sampled dust are presented in TABLE 4. The data show the main organic functional groups identified in the tested fractions and their infrared absorption wavelength ranges and their respective peak heights. Monthly values for tar, ash and combustible matter content of the insoluble dust portion are shown and illustrated in TABLE 5 and figure 6, respectively. Analytical results for the mean monthly metal ion concentrations within the sampled

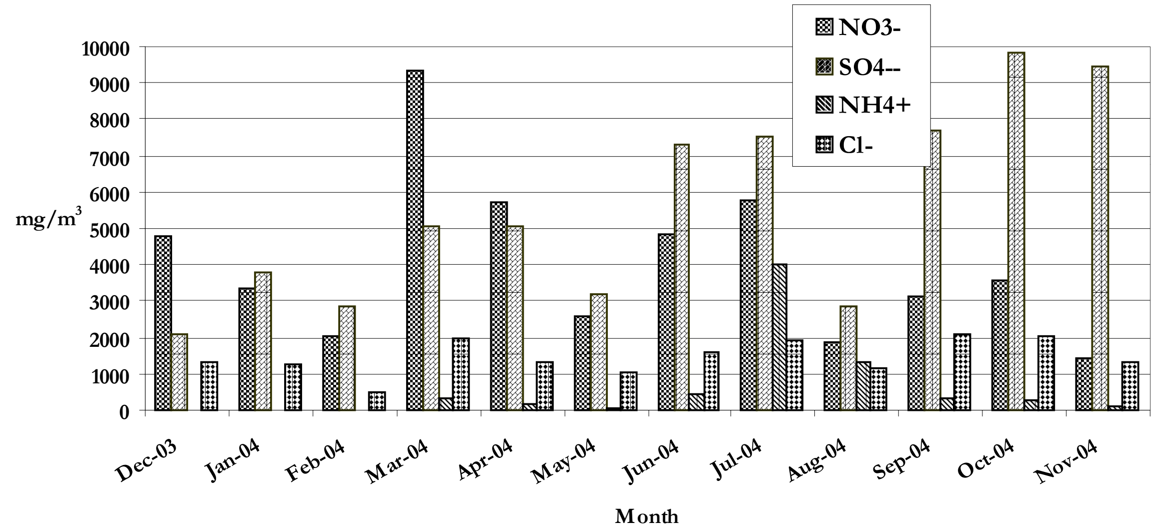

Figure 5: Monthly average chlorides, nitrates, sulfates, and ammonium contents ($\mu g/m^3$) within the sampled dust–cairo central railway station(Dec 03-nov 04)

TABLE 2: A summary of meteorological data recorded for the capital region during the study period (December 03-november 04)

Meteorological elements	Month	Dec 03	Jan 04	Feb 04	Mar 04	April 04	May 04	June 04	July 04	Aug 04	Sept 04	Oct 04	Nov 04
Percentage of wind and Direction (Km/h *10 $^{-3}$)	N	3	5	--	19	--	14	23	14	12	12	12	--
	NNE	--	--	--	--	11	9	20	11	--	--	11	--
	NE	5	--	--	14	15	--	--	--	8	--	14	8
	ENE	--	--	--	--	--	19	--	--	--	--	--	--
	E	--	--	8	--	--	--	--	--	--	--	--	5
	SSE	--	--	8	--	--	--	--	--	--	--	--	--
	S	--	8	--	--	--	--	--	--	--	--	--	--
	SSW	23	28	27	--	--	--	--	--	--	--	--	--
	SW	--	14	19	--	--	--	23	--	--	--	--	--
	W	--	--	--	--	21	--	14	--	--	--	--	--
	WNW	--	--	--	--	--	--	--	10	--	12	--	7
	NW	--	--	23	--	--	--	--	--	--	--	--	--
	NNW	--	--	--	18	--	16	--	12	14	10	--	19
Average of Max temperature °C		20.6	20	19.6	23.1	26.6	29.6	33.8	35	35	34	29.5	20.4
Average of Visibility (Km)		9.99	8.6	9.25	7.9	8.9	9.9	9.99	9.325	8.32	9.325	9.325	9.19
Average of relative humidity (RH%)		67	51.8	53.6	58	57.8	60	42.5	57	55.5	68.6	62.6	70.4
Average of dew point (°)		7.6	5.1	5.5	10.5	10	13.4	14.3	19.3	19	18.1	16.6	8.8

dust(Ca, Cu, Cr, Fe, Ni, Mg, Mn, Pb, Se, Ag, V and Zn) are shown in TABLE 6.

Figure 7 depicts the dendogram obtained for the hierarchal cluster analysis of the measured monthly variables for the main soluble and insoluble contents(Cl^-, NH_4^+, SO_4^{2-}, NO_3^-, tar, ash and combustible matter) of the sampled dust. The dendogram indicates the presence of 7 clusters that were arranged into two major groups based upon the degree of similarity. The results for the hierarchal clustering of the monthly metal concentrations(Ca, Cu, Cr, Fe, Ni, Mg, Mn, Pb, Se, Ag, V and Zn) is provided in the dendogram figure 8, which indicates the presence of 14 clusters grouped into two major factions.

DISCUSSION

Essentially, the main contributors towards the measured particle fallout rate in this station are diesel locomotives as they traverse the tracks and remain idle during the loading and unloading of passengers between trips. Before departure, another locomotive is brought to the rear of the train assembly and the relieved locomotive retreats from the platform to a nearby shed for a checkup in preparation to switch roles with another incoming engine. Until the mid of 2004, regular line haul engines were used as switcher engines bringing in and driving out train carriages from these platforms. However, after that, smaller switcher engines were brought into service to handle such operations throughout the station.

TABLE 3: Mean monthly values for Cl^-, NH_4^+, SO_4^{2-} and NO_3^- contents(μg/m³) in sampled dust-cairo central railway station-(Dec 03-nov 04)

Month	Cl^-	NH_4^+	SO_4^{2-}	NO_3^-
December 03	1320	20.0	2100	4771
January 04	1269	4.0	3807	3336
February 04	521	4.0	2883	2034
March 04	1968	320	5062	9329
April 04	1330	148	5071	5730
May 04	1037	72	3162	2570
June 04	1608	455	7292	4814
July 04	1906	4010	7538	5757
August 04	1180	1293	2884	1859
September 04	2095	309	7674	3110
October 04	2016	278	9850	3546
November 04	1317	111	9433	1433

In order to account for the variations in the measured particle fallout rate(TABLE 1), observations concerning the travel pattern and number of train trips per month or season as well as other ongoing activities in and around the station during the study period were recorded. These observations indicated that during the entire study restorations to the interior and the exterior of the station was undertaken in preparation for the 150th anniversary celebrations. Concerning the regular train travel pattern, observations indicated that during the day there were two

TABLE 4: Results of FTIR analysis of the soluble dust component indicating the main organic functional groups detected, their relevant wave numbers ranges(cm^{-1}) and peak height(P.H.=I^0-I) for each determined group per month and season-cairo central railway station-(Dec 03-nov 04)

Wave number range (cm^{-1})	Organic functional group	Peak height (P.H.= I^0- I)											
		Winter season (03-04)			Spring (04)			Summer (04)			Fall (04)		
		Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
4000-3700	OH $_{water}$	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	1.7	0.0	0.0	0.0
3700-3200	OH $_{phenols\ and\ alcohols}$	3.9	2.9	2.0	3.2	0.7	2.0	2.5	2.7	2.4	2.2	1.2	3.6
3000-2850	C-H and C ≥16	1.2	1.5	1.4	0.9	0.6	1.2	1.2	1.6	2.0	1.6	1.4	0.5
2800-2400	NO and –N-	0.0	0.4	0.4	0.0	0.0	0.9	0.0	0.3	0.4	0.0	0.3	0.0
1850-1700	C=O $_{acids\ and\ esters}$	1.6	0.0	0.5	0.0	0.2	1.0	1.2	0.5	0.6	0.4	0.4	0.2
1630-1600	Aromatic rings	2.8	0.0	1.6	3.6	3.2	2.0	0.4	0.0	0.0	0.0	0.0	4.2
1580-1500	Ca organometallic	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
1480-1460	$-CH_2$	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
1450-1390	CO_3	3.0	0.0	5.0	2.1	3.1	3.1	2.1	4.7	4.0	4.6	4.6	4.3
1380-1360	$-CH_3$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1320-1100	Esters & alcohols	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6
1100-990	PO_4 and SO_4	0.0	6.6	4.9	6.0	4.1	2.7	6.3	7.5	7.3	6.8	7.2	7.5
900-750	-C=C-	1.8	1.3	1.3	1.4	1.9	0.7	0.8	1.1	1.2	0.9	2.7	0.7
730-710	R-C and C ≥ 4	0.0	0.9	0.7	0.0	0.8	2.9	0.4	0.6	1.0	0.6	0.7	0.7
690-680	Cl	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.6	1.2	0.0	0.0	0.0
640-550	R-X (halogens)	2.0	0.0	0.9	0.4	1.0	0.8	0.0	0.5	0.0	0.0	0.7	5.5
500-400	-S-	0.4	1.2	2.0	1.8	2.3	2.0	2.8	3.3	1.2	2.5	2.6	3.4

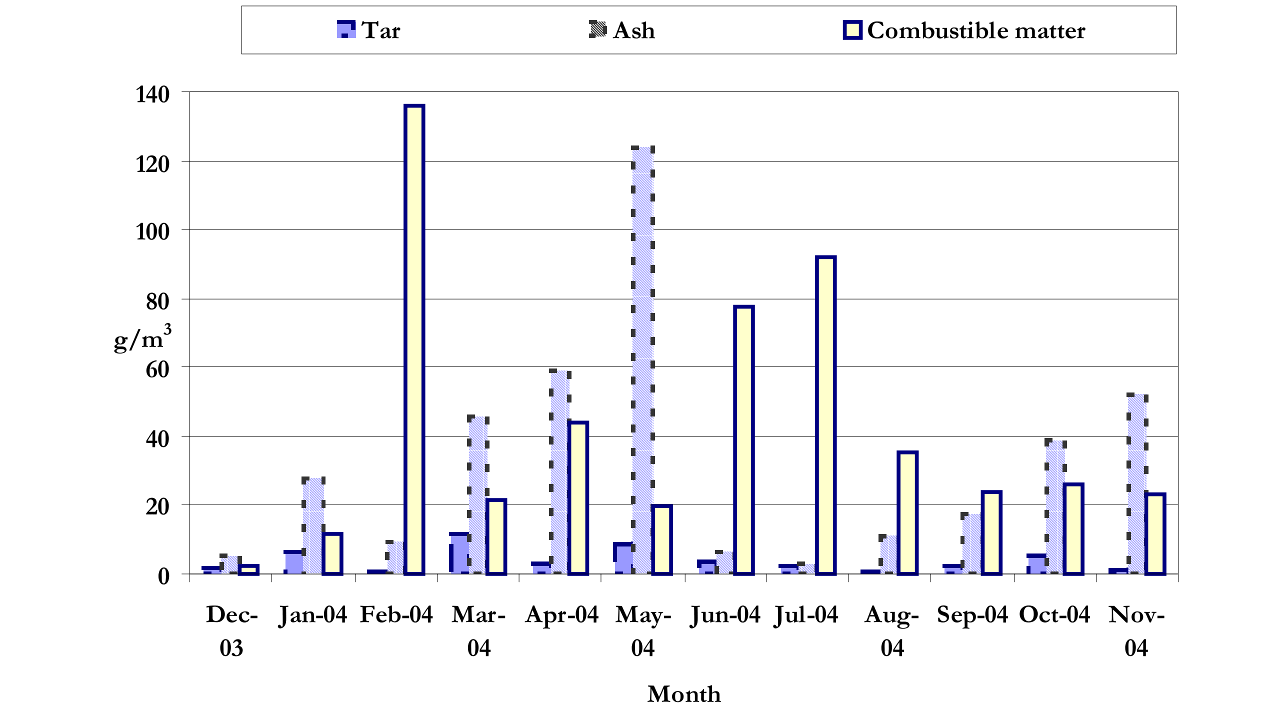

Figure 6: Mean monthly tar, ash and combustible matter content(Insoluble component)(g/m³) of the sampled dust-cairo central railway station(Dec 03-nov 04)

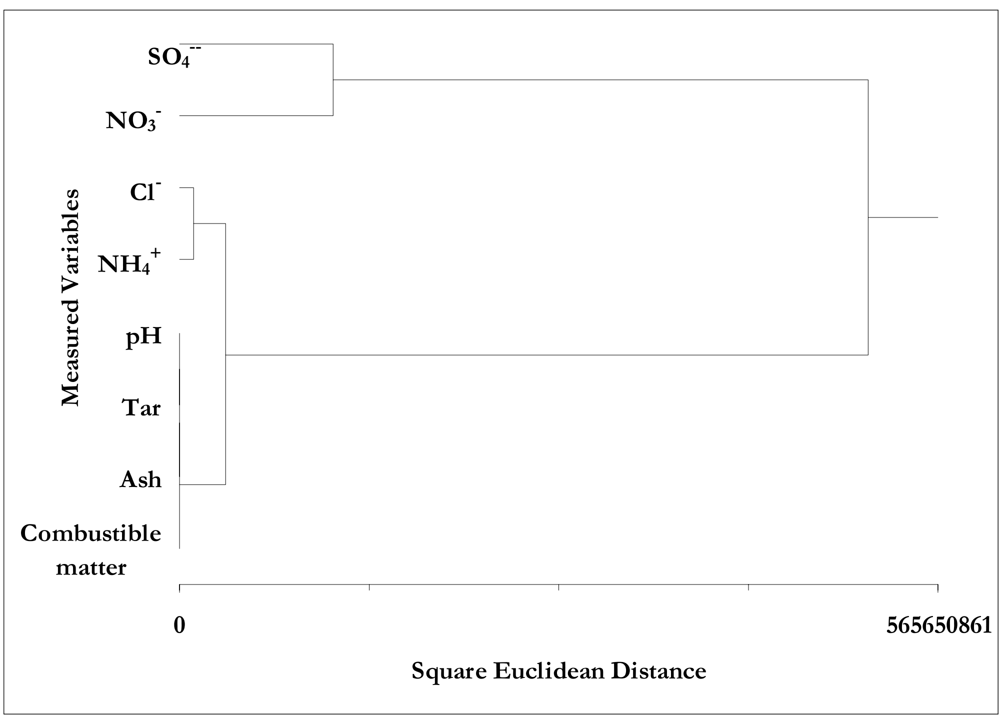

Figure 7: Dendogram for hierarchal clustering of the soluble(chlorides, sulfates, nitrates and ammonium) and insoluble(tar, ash and combustible matter) portion contents of sampled dust using Ward's method for minimum variance(Dec 03-nov 04)

peak travel periods in which the number of incoming and departing trains increased. These two periods coincided with the beginning of the workday and its end. Schedule-wise, the end of december and beginning of january generally mark the end of first schooling term, which is followed by a two weeks recess ending the first week of february. During march 04, a one-week holiday was observed because of Eid El-Adha festivities. In this period, the number of train trips increased to and from the capital as the majority of cariennes traveled outside the city to visit with families and/or to vacation destinations.

The regular train schedule was restored during the months of april and may 04; however, there were intermittent increases in travel frequency during this period because of religious and official holidays (Eastern christian easter, sham el-nessim and other lunar calendar events). Nonetheless, the end of may and the beginning of june mark the end of the academic schooling year and the second term final exams period. A subsequent increase in train trips was recorded during the months of july and august as they signify the peak holiday season. However, with the beginning of the schooling year in the mid of september, the regular travel schedule was restored as students traveled towards their institutions within the capital region. Finally, the fasting month of ramadan was observed during the months of october and november 04. This period was generally characterized by a reduced daily working hours schedule as well as a decrease in train travel after sunset. Eventually, this month ended by a 3-4 day holiday period of Eid El-Fitr festivities that was observed in mid november 04.

Generally, there are a number of factors that influence the indoor concentrations of air pollutants[38]. In addition to indoor sources, these include outdoor pollutant levels, the rate of exchange between the indoor and outdoor air, and the geographical and seasonal and diurnal variations. Concerning the indoor sources, the impact of the increase in travel

TABLE 5: Mean monthly tar, ash and combustible matter(Insoluble component) (g/m^3)-cairo central railway station-(Dec 03-nov 04)

Month	Tar	Ash	Combustible Matter
December 03	1.9	5.2	2.6
January 04	6.3	27.8	11.6
February 04	0.46	9.2	135.9
March 04	11.3	45.7	21.3
April 04	2.8	58.8	43.8
May 04	8.8	123.8	19.8
June 04	3.2	6.1	77.4
July 04	2.5	3.0	91.8
August 04	0.5	11.0	35.2
September 04	2.6	17.2	24
October 04	5.0	38.6	26
November 04	1.1	52.1	23

TABLE 6: Mean monthly metal ions concentrations(Ca, Cu, Pb, Fe, Ag, Ni, Mg, Mn, Zn, Cr, Se, and V) ($\mu g/m^3$) determined in dust samples-cairo central railway station-(Dec 03-nov 04)

Month	Metal ions concentration ($\mu g/m^3$)										
	Ca	Cu	Cr	Fe	Ni	Mg	Mn	Pb	Se	Ag	V	Zn
Dec 03	12500	1187	11.0	375	0.0	23545	0.0	1850	41.5	130	0.0	2385
Jan 04	12500	1417	14.5	875	0.0	38300	0.0	2620	50.5	10.0	0.0	550
Feb 04	9700	831	7.0	1130	0.0	7600	0.0	600	86.5	5.0	0.0	610
Mar 04	3335	80	2.0	4385	0.0	1345	0.0	2485	495	30.0	0.0	343.5
Apr 04	2655	85	2.0	6335	0.0	1085	0.0	1960	415	4.0	0.0	387.5
May 04	10060	195	1.0	15170	0.0	2760	0.0	450	1070	0.0	0.0	48.0
Jun 04	3985	75	0.0	2325	50.0	917.5	5	2820	470	261.5	0.0	674
July 04	2505	46	0.0	1715	75.0	805	10	6290	555	263	0.0	320
Aug 04	12320	437	0.0	3910	700	3017.5	30	3550	205	120	0.0	1586
Sept 04	1125	49	0.0	1095	6441.5	675	0.0	3060	0.0	51	0.0	330
Oct 04	2100	80.5	0.0	1850	1307	895	0.0	3330	0.0	9.5	0.0	225
Nov 04	13545	392.5	0.0	4225	198	3200	80	6450	0.0	0.0	24.0	830

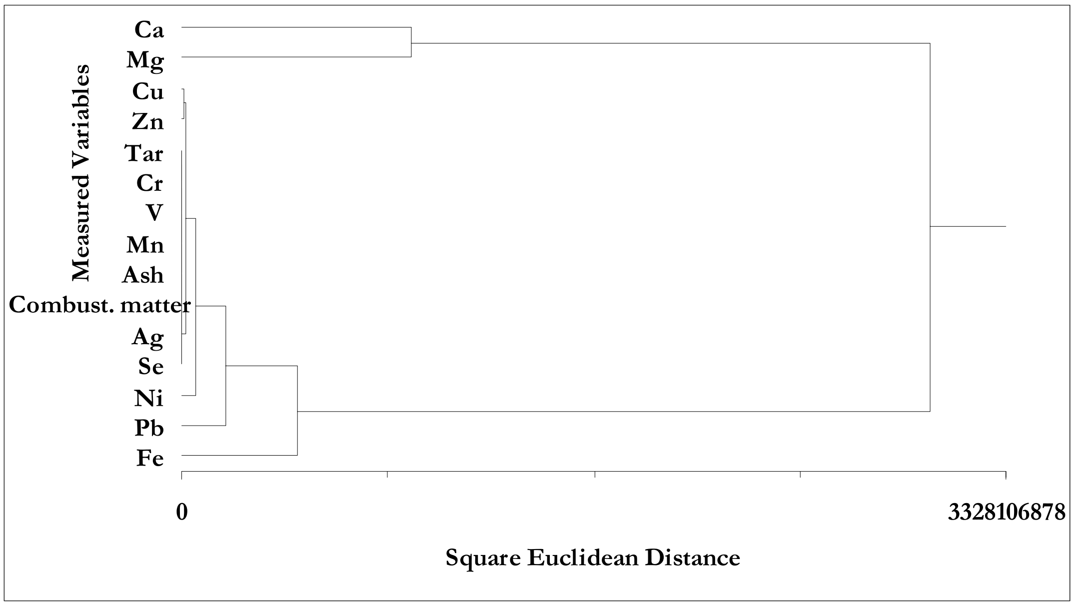

Figure 8: Dendogram for the measured selected metal ions content and the insoluble component of dust(tar, ash and combustibles) using Ward's method for minimum variance-CCRS-(Dec 03-nov 04)

frequency to and from the station was reflected by the acidic pH associated with the dust collected during the months of december 03-january 04 and june 04 till october 04(TABLE 1). Obtaining slightly acidic pH values(6.15-6.17) within main locations/cities in Egypt was attributed to the increase in diesel or fossil fuel consumption[39,40]. On the other hand, variations in the measured pH and particle fallout rates during the period from february to may 04 was attributed to the prevailing khamasin sand storms, which is accompanied by winds blowing from the west and south direction[41]. During this period, near neutral pH recorded was attributed to the neutralizing capacity of the alkaline component of the dispersed suspended particulate matter from soils[39]. In effect, these winds traversing cairo city were considered an important factor in increasing the ambient airborne suspended particles[40]. Conclusively, such a natural incidence besides human related activities around the country were responsible for increasing of the natural PM_{10} background value within Egypt to around the national air quality limits of 70$\mu g/m^3$ per day.

Moreover, wind and its directions were reported to play a key role in the dispersal of air pollutants, with the concentration of pollutant dispersed being inversely related to the wind speed for ground level sources[39]. In addition to that, turbulence around and within buildings was considered an important factor in controlling the extent pollutants' dispersion. In this effect, the impact of other activities within and without the station building upon the sampled content cannot be overlooked given the monthly wind conditions, as this area is covered by a hanging wedge-shaped metal ceiling. Essentially, the motion of vehicles within the city streets was reported to have a direct impact on the resuspension of particles and dust therein[40]. Subsequently, contributions from the heavy traffic commuting along the 6^{th} of october high bridge may be anticipated as the bridge crosses over the tracks twice towards the east then closely contours the building from the south and southwest (Figure 2). Such an impact may become significant as the percentage of northeasterly winds(N, NE, NNE, ENE) increased during the period of study(TABLE 2). In addition, site observations indicated that some street sweepers on this bridge section resorted to the disposing of gathered dust either by feeding it into the gaps between the bridge connecting joints or by throwing some of it over the tracks. This ultimately may increase the amount of airborne suspended particles(fine dust) around the eastern entrance of the station.

Alternatively, as the percentage of westerly winds(W, NNW and WNW) increased during the months of april and june 04(21% and 22%, respectively(TABLE 2)), the amount of total dust collected significantly increased(6.17 and 6.55g/m^2/month, respectively). This may be attributed to the wind aided dispersal of particulate matter resulting from activities outside the building towards the west and southwest directions and its subsequent infiltration through the ceiling structure. Such activities included apart from the heavy traffic on the bridge west of the station, the construction of a lane extension for the eastbound section of the high bridge (west) and the mixing of construction materials at the garage site(south-west).

Interestingly, the natural dust deposition rate for locations remote from air pollution sources in Egypt was reported to be 0.1-0.25kg/m^2/year(≈8-20.8g/m^2/month)[41]. As well, the background fallout rate for the central cairo area was determined to be between 13.7-55.8g/m^2/month[42]. In this study, the total particle collected within the station averaged 4.54g/m^2/month, which is considerably less than the reported values. This and in western countries, an area was considered clean if a dust rate of less than 10g/m^2/month(or 30days) was measured[40]. On the other hand, a recent study at the Rome and London underground stations indicated that the dust collected underground was higher than that collected from above[29,30]. In these cases, contributions of dust from the above ground activity was considered significant, a fact that may require more investigations at the underground metro station.

Evaluating the data obtained for the soluble and insoluble components of the collected dust(TABLE 1 and figure 4), the results revealed that the range for the soluble portion was slightly higher than that for the insoluble portion(1.55-4.35g/m^2/month and 0.22-3.41g/m^2/month, respectively). As well, the increase in the soluble portion content was more pronounced during the months of march-april, june-july, and September to november 04, accordingly. As for the measured monthly chloride content, the results revealed that it averaged 1464μg/m^3 with significant increases in this content recorded during the months of march, june-july, september and october 04, respectively(TABLE 3). Essentially, the main sources of chlorides in the ambient atmosphere were identified to be gasoline and diesel exhaust[43]. The presence of trace amounts of organic halides(both chlorides and bromides) in diesel fuel was reported to an inherent characteristic(i.e. natural constituent) of the original crude utilized[8,12,43]. Such an incident was confirmed by the FTIR analysis data obtained during this study(TABLE 4). With the information that oil consumption contributes 0.2-0.5% of fuel consumption within diesel engines[15,44], the increase in chlorides exhaust emissions may be attributed to the use of chlorinated waxes in diesel lube oils both as pour point depressant(0.1-0.5%) and extreme pressure additives(2-5%)[45]. A more serious health impact of the presence of trace amounts of chlorides in diesel fuel(≈0.9ppm) was reported because of its potential role in the formation of dioxins in the exhaust in the presence of copper organometallic smoke suppressant additives[12].

Generally, particulates emitted by diesel engines consist of a mixture of soot, smoke and tiny particles from sulfur dioxide(SO_2), nitrogen oxides(NOx) and ammonia(NH_3)[46]. Significantly, the annual sulfates of the sampled dust average exceeded that of the nitrates content(5563 to 4024μg/m^3, respectively) (TABLE 3) with peak concentrations obtained during the months of march-april 04, june-july, and september-november 04, which corresponded to the increase in train travel. As well, the average ammonium content was 585.3μg/m^3, with higher values reported during the summer, an observation which in accordance with previous studies[39]. Generally, in Egypt, diesel fuel has an average 1.2% sulfur content[41]. Nonetheless, the amount the diesel sulfate particulate and SOx emitted with the exhaust was reported to be directly proportional to the fuel's sulfur content[12,14,16]. As well, the inhalable PM_{10} and $PM_{2.5}$ portion within the diesel exhaust was linked to the increase in sulfate particulate emissions. In addition, the use of smoke suppressing additives with the diesel fuel tends to increase the particulate sulfate emitted with the exhaust[12,16], a fact that was affirmed by FTIR data(TABLE 4).

Apart from being an end product of the combustion of diesel fuel, the presence of nitrates and organic nitrates in the exhaust may be attributed to the use alkyl or organic nitrates as cetane enhancers[8,11,12,14,16]. These compounds are used to improve the self-ignition quality of diesel fuel on cold starting and hence reduce the combustion noise and gaseous emissions. Such an additive was also reported to help reduce the exhaust NOx content and the PM associated with it[12]. In addition to that, amines and other organic nitrogen compounds were added to diesel fuel as detergents, anti corrosion agents, and anti oxidants in order to improve the engine performance as well as biocides to control micro-organism growth during storage[8]. On the other hand, contributions to the exhaust ammonium content may be linked to the use of quaternary ammonium or amine salts as dehazers additives with the fuel[8,12].

With respect to the insoluble portion contents, results revealed that the inherent tar content averaged 3.87g/m^3; ash was 33.2g/m^3 and combustible matter 42g/m^3(TABLE 5). Evidently, the hierarchal clustering of the measured soluble and insoluble portion contents versus pH(Figure 7) indicated the presence of seven clusters that were grouped into two main fractions(Group A and B) according to the similarities in source. Group A comprised of two minor clusters that revealed a strong dependency of pH on tar, ash and combustible matter as well as a strong dependency between chloride and ammonium contents, both of which were significantly related. Group B revealed an overall strong dependency between the measured sulfates and nitrates content that was characterized by an overall dependency on the clustered parameters in group A. Significantly, diesel particulate matter is the residue of fuel combustion with elements from unburned fuel, lubricating oil and pyrosynthesis during fuel combustion adsorbed onto its surface area[8,11,47]. The incomplete combustion of diesel fuel was reported to result in the emissions of volatile hydrocarbons and low molecular hydrocarbons(PAH) and their derivatives with the exhaust[11]. Tar emissions associated with the diesel PM was reported to be dependent on the coking tendency of the fuel[12]. As well, introduction of lubricating oil into the exhaust comes from the ability of fuel to dissolve and then volatilize the thin film on the cylinder walls[12]. Partially burned lubricating oil ash was reported to contribute around 40% to the final diesel PM emissions[44]. One indicator related to such an occurrence was reported to be the presence of calcium organometallic compounds in the emitted ash[12], a detail affirmed by the FTIR data(TABLE 4). In fact, the presence of such a functional group was indicative of the use of calcium sulfonate(2500ppm) as a detergent with lube oil to suppress the formation of carbonaceous diesel particles[12,44]. With respect to the study data, FTIR analysis indicates a sudden increase in the calcium organometallic functional group during the month of june 04. This may be attributed to the addition of smoke suppressors and combustion enhancers to reduce the formation of carbonaceous soot at the onset of the hot summer season(Personal communication).

Generally, the performance of a diesel engine requires the use of a number of additives to improve its operation and reduce the resulting emissions accordingly[8,12,14]. From the FTIR analysis data(TABLE 4), the results indicated the presence of phenolic and alcoholic OH groups, which may be attributed to the use of hindered phenols as anti-oxidant additive in fuel and as pour point depressant in engine oil[8,12,14]. As well, the detection of alcoholic OH functional group may be attributed to the use of polyethylene glycol di-nitrate as cetane number improver[8]. Generally, the presence of aromatic rings fraction in the exhaust is considered an indication of the aromatic hydrocarbon content of the diesel fuel used and its cetane rating[12]. Fuels with cetane rating between 40 and 45 were found to have high aromatic hydrocarbon content and a poor self-ignition quality[12]. In this case, the national production standards require the cetane rating for the diesel fuel to be between 45-46(Personal communication).

Other functional groups detected were esters, which are compounds used as fuel anti-corrosion chemicals, flow improver and cloud point depressors[8,12]. The presence of organic NO and -N-functional groups is indicative of the use of amines, amides and imidazolines as anti oxidants, dehazers, detergents and anti corrosion chemicals and as fuel stabilizers and biocides[8,12]. The use of organic sulfates and phosphates compounds as detergents lube additives and anti rust additives in diesel engines was also being reported[45]. As well, phosphorous may be used as an anti-wear additive with engine oils[48]. Furthermore, the presence of water in fuel may be regarded as a minor contaminant that result from production operations or storage conditions[12,49]. However, high water content in exhaust may be result of coolant leak, prolonged idling of engine or its operation at low temperatures[48]. On the other hand, it was reported that diesel fuel emulsions with water produced less NOx emissions by means of lowering the combustion temperature[49], such an incident may be affirmed by the reduction of nitrate content (TABLE 2) as well as the presence of water OH functional groups in the sampled particles during the summer season(TABLE 4).

Regarding the metal content of the sampled dust, the results in TABLE 6 indicated that the all through the study period both the calcium and magnesium contents averages were significantly in excess of all the other measured ion contents(7419.2 and 7012$\mu g/m^3$, respectively). This may be attributed mainly to the restoration works done throughout the building, which involved the scarping of the stucco of the walls inside and outside of the station. Such an occurrence was affirmed by a strong dependency between these two concentrations and their grouping into one main cluster in figure 8. The use of metallic additives containing calcium, magnesium, iron, nickel, manganese, zinc and copper as metal deactivators and catalyst reaction to control fuel instability may contribute to the presence of these metal ions in the exhaust and the resulting PM[8,12,44].

Individually, iron in exhaust is associated with soot particles and was related to the rust formation within the engine system[48]. Zinc was reported to be used as an additive in lube oil[44]. As well, lead was used as an additive in gear oil[48]. Vanadium and nickel were present in heavy fuel as trace elements or contaminants and chromium is used as a coolant additive[48]. The presence of silver, nickel, and manganese may indicate wear metals from engine units[48]. These metals in addition to selenium may originate from the hazardous air pollutant content associated with the base oil formulation of lube oil[50]. Finally, the hierarchal clustering of these determined metal values relative to the insoluble particle content revealed a strong dependency of tar on the chromium, vanadium, manganese, ash, combustible matter and silver and selenium contents(Group 2), correspondingly (Figure 8). Another dependency revealed within this cluster was for these contents on the measured nickel, lead and iron content, which affirms the conclusion that these elements were derived from one source mainly engine operation and not the renovation work carried out, as was apparent in the case of Ca and Mg ion contents.

CONCLUSION

In conclusion, this study provided an insight as to the 'indoor' air quality within one of the busiest transportation centers in Egypt and in Africa, the cairo central railway station. The data obtained in this evaluation revealed that passengers, commuters, and workers in this station might be subject to a variety of pollutants emitted from the diesel locomotives. Activities around the station building from mobile and stationary sources did have a notable impact on the particle rate measured within the station and its inherent content. These contributions were dependent not only upon the intensity of activities within and without the building but also upon the prevailing weather and wind conditions within the city. While within the context of this study a preliminary evaluation of the air quality conditions within the station building was being assessed, it is recommended that the study should extend to include the underground sections of the metro lines, as their tracks and lines are closely intermingled.

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