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Article

Health Impact Assessment Associated with Exposure to PM10 and Dust Storms in Kuwait

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Academic Editor: name
Received: date; Accepted: date; Published: date

Abstract: Little information is available on the assessment of health impact concerning the Middle Eastern dust storms and PM10 concentration levels despite the aridity of the region and frequent dust storms occurring in this part of the world. A prospective study was conducted to determine the association between dust particles and morbidity and mortality rates in Kuwait. Generalized additive Poisson models with parametric and nonparametric correlations were used to identify such association. Results revealed a strong Spearman's rank correlation between dust storms, suspended dust and rising dust ($p < .01$). The PM10 concentrations were highly correlated with bronchial asthma at the 0.05 level (Pearson $r = 0.292$, Sig = .036) and significantly correlated ($p < .01$) with both acute lower respiratory tract infection and acute upper respiratory tract infection ($r = 0.232$, Sig = .097; $r = 0.255$, Sig = .068), respectively. Respiratory and cardiovascular mortality rates were both equal to 0.62 per 10,000 persons, each corresponding to 8.7% proportionate mortality rate. This study provides a good evidence of the consistent relationship between dust storm events, PM10 concentration levels and respiratory groups of diseases.

Keywords: Dust storms; PM10; Respiratory; Cardiovascular; Morbidity; Mortality; Health impact

1. Introduction

Dust storms are natural phenomena, most of which originate in desert or semi-desert drylands, in which dust particles are transported away from the main source, sometimes over thousands of kilometers. The northern region of the Arabian region is characterized by complex dust storm trajectories where they pass through the western desert of Syria and Iraq toward the Mesopotamian flood plain reaching the northeastern region of the peninsula into Kuwait at dust fallout rate of 5.07 tons/km^2/month (61.4 tons/km^2/year) where fallen dust compromises 37% of sand particles [1,2]. A particular feature of dust blown is its extreme particulate matter intensity that increases the ambient air dust concentrations for several days. Dust particles, according to their aerodynamic diameter constitute of both fine particles ($PM_{2.5}$) which have an aerodynamic diameter smaller than 2.5 μm and coarse particles (PM_{10}) that include both the course (particle size between 2.5 and 10 μm) and the fine (particles less than 2.5 μm). A large number of desert dust contains particles with much higher concentrations than those established by the World Health Organization guidelines for PM_{10} (20 μg/m^3 annual mean; 50 μg/m^3 24-hour mean) [3]. Atmospheric concentrations in individual dust events have recorded PM_{10} levels of 1000 μg/m^3, with extreme values exceeding 10,000 μg/m^3 [4]. PM_{10} levels over 200 μg/m^3 were suggested for small to medium scale dust events, while a higher cutoff point of 400 μg/m^3 were used to define severe dust events [5,6]. Other studies have used much lower PM_{10} levels to identify dust storm days [7–10].

Because of most air quality monitoring stations record data based on the PM_{10} measurements as opposed to other particulate matter size, the majority of epidemiological studies use PM_{10} level as the exposure indicator. The World Health Organization air quality guidelines have provided a basis for characterizing human health effects of major air pollutants including PM_{10} [3]. The assessment of personal exposure to air pollution is a critical component of epidemiological studies in the evaluation of health effects from airborne particulate matter (PM). Although fine particles below $PM_{2.5}$ comprise the greatest health concern since they are more likely to penetrate deep into the alveoli sacs of the lungs, the PM_{10} course particles represent the predominant part of dust in dust storms and cover most of the respiratory health issues as large particles become trapped in the nasal passages, nose hair follicles and upper respiratory tract [11]; in contrast, fine particles decline due to high wind speed and long travel distances of dust storms [12,13].

Dust storm events have been strongly associated with mortality and morbidity rates with broad range of health effects, but predominantly to the respiratory and cardiovascular systems. Several studies from various countries have examined the effects of dust storms and particulate matter on morbidity and mortality rates, and hospital admissions for various ill-health effects. During Saharan dust days, a daily increase of 10 μg/m^3 of PM_{10} increased daily mortality by 8.4% in Barcelona (Spain) [14]. A 10 μg/m^3 change in daily PM_{10} was associated with an approximately 1% increase in cardiovascular and respiratory mortality in the Coachella Valley, California [15]. Dust storms in Taiwan had a 7.66% increase in the risk for respiratory diseases [16], congestive heart failure [8] and daily pneumonia hospital admissions [9]. Asian dust storms had a 4.1% increase in the rate of deaths from cardiovascular and respiratory causes in Seoul, South Korea [17] and significant increase in respiratory hospitalizations in China [18,19]. Dust blown from the Sahara to the Eastern Mediterranean resulted in increase in all-cause hospital admissions including respiratory and cardiovascular diseases in Nicosia, Cyprus [7]. An Australian dust storm which lasted for only one day had a 39% increase in hospital emergency admissions [20]. Increased asthma emergency admissions were associated with Saharan dust in the Caribbean island of Trinidad [21] and with Asian dust in Toyama, Japan [22].

Little information is available on the assessment of health impact in relation to dust storms and PM_{10} concentration levels in the Middle Eastern district despite the facts that the region constitute frequent dust storms [23] and it is considered a major source of global dust [2,4,24]. Many studies from Iran have demonstrated positive association between dust particles and total mortality including cardiovascular and respiratory mortalities [25–30] and hospital admissions for cardiovascular and respiratory diseases [31,32]. Only three studies were conducted in Kuwait to determine the health impact of dust storms on morbidity and mortality rates. A study conducted by Thalib and Al-Taiar [23] concluded that dust storms had a significant impact on asthma and respiratory hospital admissions. Al-Rifaia et al. [33] and Al-Taiar and Thalib [5] showed that dust storms had little impact on short-term respiratory, cardiovascular or all-cause mortality.

The primary objective of this study was to assess the environmental burden of outdoor air, specifically dust storms and PM_{10} airborne concentration on the health impacts in Kuwait in terms of morbidity and mortality rates.

2. Materials and Methods

A prospective time-series study of daily PM_{10} concentrations and daily morbidity and mortality through hospital admissions were evaluated in a single district in Kuwait, Ali Sabah Al-Salem (ASA) during 2012. The effect of changes in daily levels of PM_{10} hospitalization for respiratory, non-respiratory, cardiovascular and all-cause diseases was investigated using the generalized additive Poisson model; the type of research analysis that avoids incompleteness of retrospective data. Daily and weekly attendance rates of air pollution-related group of diseases in ASA primary health care center were evaluated. Data collection included daily PM_{10} concentration levels, PM_{10} related morbidity and mortality rates, and length of hospital stay for PM_{10} related morbidities. The daily data of both PM_{10} and air pollution related diseases allowed for the investigation of the pattern of association between air pollution and morbidity by correlating visits to public health centers for air pollution related diseases and the daily measurements of PM_{10} pollutant level during 2012. Dust storms, rising dust and suspended dust were collected from Kuwait international airport station for the last 53 years (1962-2015). PM10 pollutant levels were obtained from Kuwait Environment Public Authority (KEPA) for the year 2012.

2.1 Health Classification

The International Statistical Classification System of Diseases and Related Health Problems from the World Health Organization ICD-10 was used for health classifications in the study [34]. ICD-10 was endorsed in May 1990 by the Forty-third World Health Assembly. It is cited in more than 20,000 scientific articles and used by more than 100 countries around the world. ICD is the foundation for the identification of health trends and statistics globally, and the international standard for reporting diseases and health conditions [34]. The list of group of diseases related to air pollution was used to determine the selected diagnosis. Each group of diseases was classified under a heading following the ICD. A person may have one disease or more per year and coded as a case for each one, thus the number of cases and the attributed estimate rates may exceed the total population in some incidents. Respiratory diseases were identified by the ICD-10 codes J00-J99 and contain acute upper respiratory infection (J00-J06), influenza and pneumonia (J09-J18), other acute lower respiratory infection such as acute bronchitis (J20-J22), other diseases of upper respiratory tract such as chronic rhinitis (J30J39), chronic lower respiratory diseases such as emphysema (J40-J47), bronchial asthma (J45-J46), and lung diseases due to external agents (J60-J70).

2.2 Quality Control

Certain quality control measures were incorporated throughout the study period. Health records of Kuwaiti citizens residing in ASA and meteorological records of the same district were investigated prospectively during the same period. Primary health care morbidity data and length of hospital stay were obtained from the information technology electronic database of the Ministry of Health of Kuwait. A case with multiple admissions for different morbidities was counted as multiple cases. Records of cases registered in Kuwait health information electronic file as suffering or dying from a pre-selected list of air pollution related releases were selected. A record of any case present in the selected health establishment but residing in another area was excluded from data analysis. Digital raw data about particulate air pollution was obtained from the database of Kuwait Environment Public Authority (KEPA) fixed station located in the selected district. Only 11 days ($<$ 3%) had missing values from KEPA meteorological station (n = 354 days recorded out of 365 days/yr).

2.3 Statistical Analysis

Descriptive statistics, parametric and non-parametric correlations were used in the study. Descriptive statistics were utilized to determine frequency distributions, measures of central tendencies (mean, medians) and measures of variability from data related to dusts, PM_{10} and hospital visits for respiratory diseases. Pearson product-moment correlation, a parametric statistical test was used to determine the degree of association between PM_{10} concentration and morbidity health rates. Spearman's rho rank correlation was utilized to investigate the monotonic association between dust storms, rising dusts and suspended dust.

3. Results

3.1 Sand and Dust Storms and PM10 Concentration Levels

Figure 1 shows the total number of dust storms (DS), rising dust (RD) and suspended dust (SD) collected from Kuwait meteorological stations for the last 53 years (1962-2015). A DS was defined as the result of surface winds exceeding 33 km/h raising large quantities of dust into the air and reducing visibility to less than 1000 m [35,36]. A RD was defined as an elevated dust occurring when winds are moderately active at a speed of 15-40 km/h and visibility is 1000 m or more. A DS occurs with calm wind speed of 6-26 km/h and horizontal visibility in the range of 1-5 km. A total of 859 SD occurred between 1962 and 2015 with an average of 15 SD per year. It is apparent that both RD and SD are significantly higher than DS throughout the period. The total number of RD is roughly equal to SD during the same period (3380 total RD vs. 3128 total SD) with an average of 62 vs. 58 dusts per year, respectively. A similar trend of DS, RD and SD occurs throughout the studied period except for a low episode between years 1990 and 1998 in large part due to missing or incomplete data record during and after the Gulf War in 1990. Figure 2 presents monthly records of dusts at ASA area for the year 2012. It is apparent that all three dust types follow a similar pattern with significantly higher number of dust storms, rising dust and suspended dust events during the summer season (June, July, September, August) and lower events during the remaining seasons. This phenomenon may be attributed to several factors including higher temperature and lower precipitation; daily average temperature recorded during the four summer months equaled to 38.3 ^{0}C with zero daily precipitation. Table 1 shows non-parametric Spearman's rank correlation between all three dust types. A highly significant correlation is shown between dust storms, rising dust and suspended dust ($p < .01$).

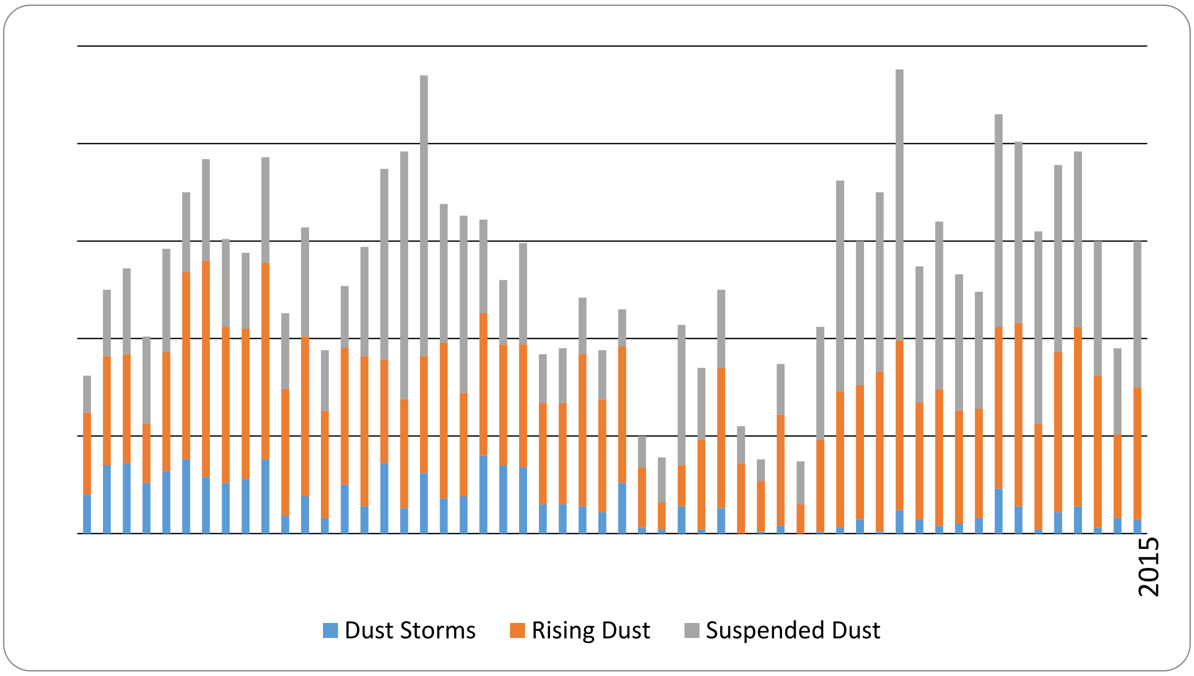

Figure 1. Total number of dust storms (DS), rising dust (RD) and suspended dust (SD) in Kuwait, 1962-2015

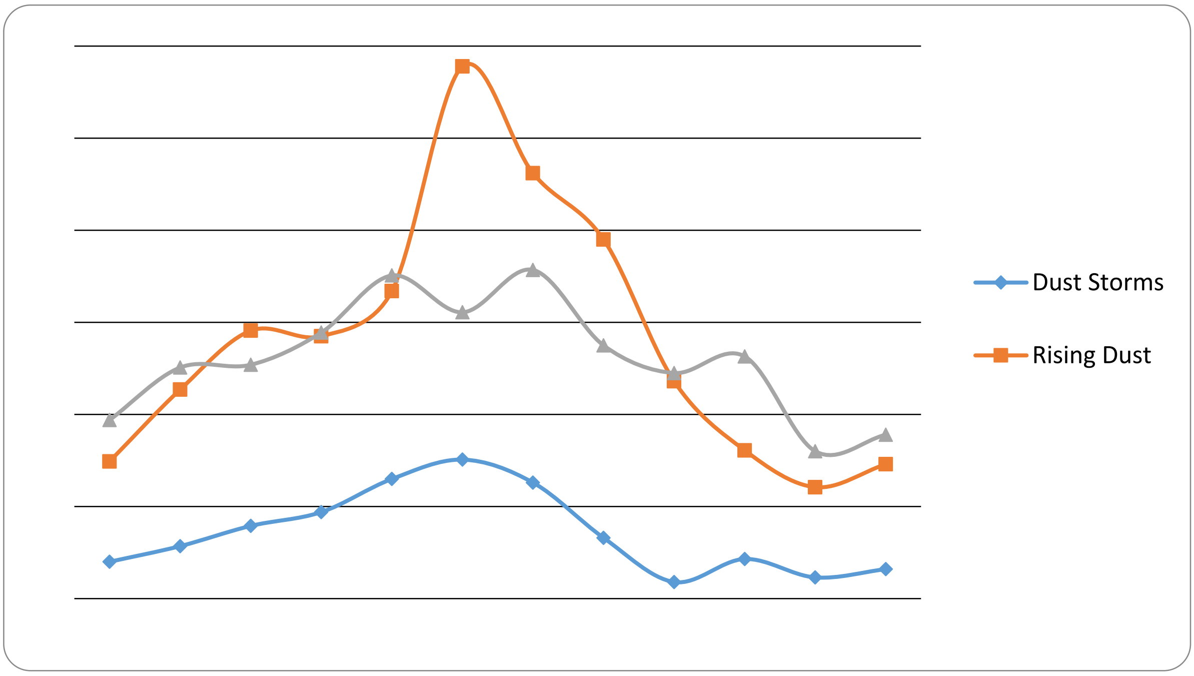

Figure 2. Number of recorded dust storms (DS), rising dust (RD) and suspended dust (SD) by month (in ASA), 2012

Table 1. Non-parametric correlation matrix between dust storms, rising dust and suspended dust in ASA, Kuwait

	Dust Storm	**Rising Dust**	**Suspended Dust**
Dust Storm	1		
Rising Dust	.746**	1	
Suspended Dust	.722**	.709**	1

** correlation is significant at the 0.01 level; *p*-value ≤ 0.01

Figure 3 shows that the mean daily air concentration of PM10 for year 2012 was 361 μg/m^3, which was 6.2 times higher than the 50 μg/m^3 specified by the World Health Organization (WHO) air quality guidelines [3]. The highest monthly average concentration of PM10 was recorded in June (611 μg/m^3) with a maximum concentration value of 3369 μg/m^3, which was much higher than Kuwait EPA maximum 24-hour concentration level of 350 μg/m^3 [37] (table 2). A total of 104 days exceeded the maximum daily concentration level set by KEPA. The most probable explanation for the high PM10 concentrations in June is due to sand and dust storms (SDS) events during the summer seasons in Kuwait. As shown at the bottom of figure 3 a total of 14 SDS events were recorded by Kuwait meteorological stations during 2012 of which 60% (8 SDS events) occurred during the four months of the summer season (May, June, July, and August). The month of January recorded the lowest monthly average concentration level of PM10 (141 μg/m^3) with a minimum daily value of 45 μg/m^3, a good justification for such low PM10 levels was related to lower SDS events in the winter season in Kuwait [23].

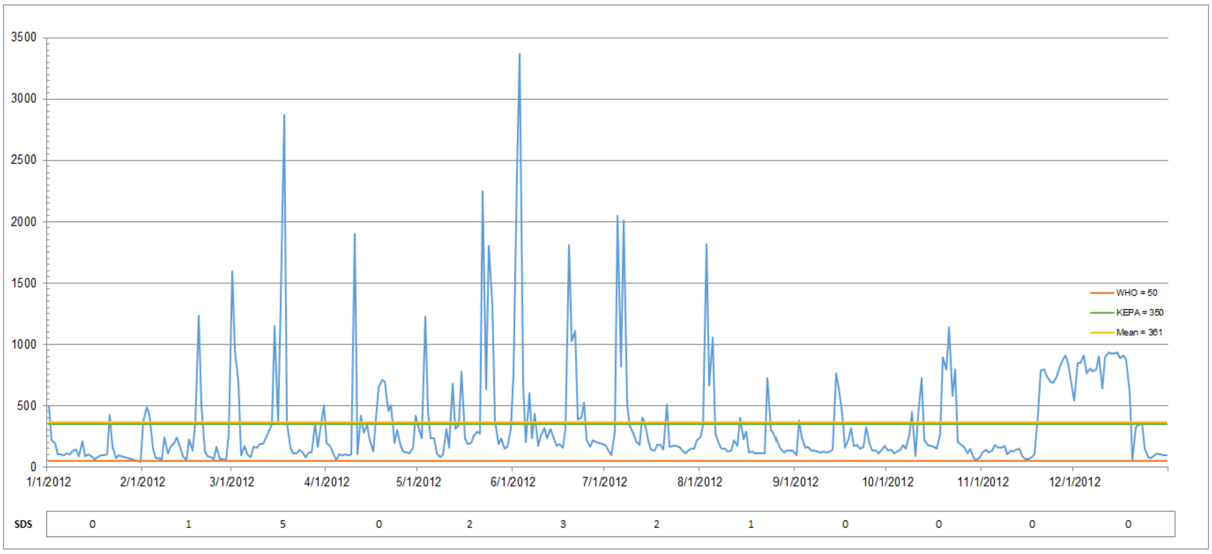

Figure 3. Daily Pattern of PM10 concentration (in ASA) and number of sand and dust storms in Kuwait, 2012

Table 2. Descriptive statistics related to PM10 for ASA, Kuwait

	N	Min	Max	Mean	SD	DES	KEPA 24-h mean	WHO 24-h mean	WHO annual mean
PM10	354	45.18	3369.33	361.69	431.20	104	350	50	20

SD: Standard Deviation

DES days: Days Exceeding Kuwait EPA maximum 24-hour concentration level

KEPA: Kuwait Environment Public Authority

3.2 Morbidity Indicators

3.2.1 Adjusted Health Visits for Respiratory Diseases

Figure 4 shows the annual adjusted health visits per 1000 person of air-pollution related respiratory and non-respiratory group of diseases in ASA health center during 2012. For respiratory group of diseases the highest annual attendance rate was observed for acute upper respiratory tract infection (AURTI) (91,490 visits), which was followed by bronchial asthma (BA) (8075 visits), acute lower respiratory tract infection (ALRTI) (2499 visits), and other diseases of upper respiratory tract infection (other URTI) (1473 visits). However, lower attendance rates were observed for chronic lower respiratory diseases (CLRD) (20 visits), and influenza and pneumonia (IP) (14 visits). Table 3 presents the adjusted attendance rates (visits per week) to ASA health center during 2012. It clearly shows that patients with AURTI diseases constitute the highest number with an average of 1,711 visits per week, followed by bronchial asthma (148 visits per week) and ALRTI (47 visits per week).

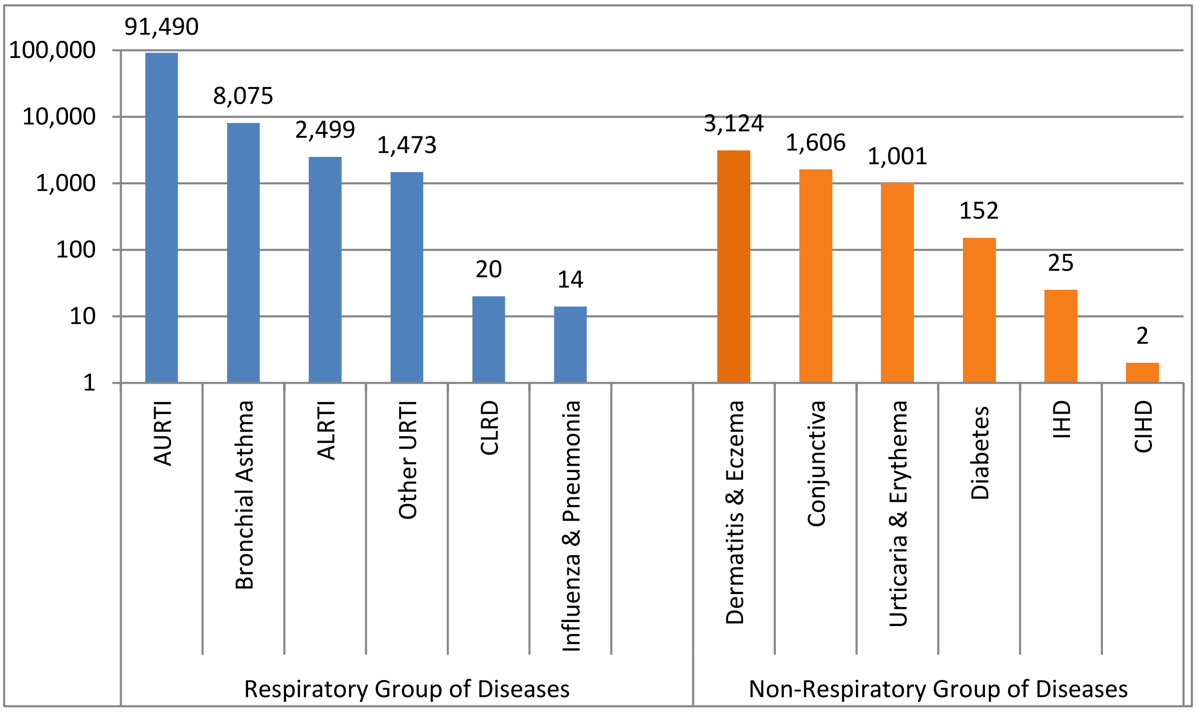

Figure 4. Annual adjusted health visits per 1000 person of air-pollution related respiratory and non-respiratory diseases in Kuwait

Table 3. Hospital visits for respiratory diseases (visits/week) in ASA, Kuwait

	Mean	SD
AURTI	1711	813.14
Bronchial Asthma	148	62.28
ALRTI	47	26.43

AURTI – Acute Upper Respiratory Tract Infection

ALRTI – Acute Lower Respiratory Tract Infection

3.2.2 Adjusted Health Visits for Non-respiratory Diseases

The highest annual adjusted attendance visits per 1000 person for non-respiratory group of diseases were recorded for dermatitis and eczema (DE) (3124 visits), which was followed by disorders of conjunctiva (1606 visits), urticaria and erythema (1001 visits), and diabetes mellitus (152 visits), However, ischemic heart diseases (IHD) and chronic ischemic heart diseases (CIHD) had the lowest annual attendance rates (25 and 2 visits, respectively) (figure 4).

3.2.2 Correlation between PM10 and morbidity

A correlation matrix is presented in table 4 which provides the Pearson product-moment correlation between morbidity hospital visits due to respiratory diseases to ASA public health center and the PM10 concentration levels during 2012. The table shows that PM10 concentrations are significantly correlated with bronchial asthma at the 0.05 level ($r = 0.292$, Sig = .036). The PM10 concentration is also highly correlated at the 0.1 level with both AURTI and ALRTI ($r = 0.232$, Sig = .097; $r = 0.255$, Sig = .068), respectively. The table also shows that all three morbidity diseases (bronchial asthma, AURTI, ALRTI) were highly correlated among each other at the 99% significant level ($p < .01$).

Table 4. Pearson correlation matrix between PM10 concentration and respiratory diseases in ASA, Kuwait

	PM10	Bronchial Asthma	AURTI	ALRTI
PM10	1			
Bronchial Asthma	.292*	1		
AURTI	.232	.839**	1	
ALRTI	.255	.737**	.827**	1

* correlation is significant at the 0.05 level; *p*-value ≤ 0.05;

** correlation is significant at the 0.01 level; *p*-value ≤ 0.01

3.3 Mortality Indicators

Table 5 demonstrates air pollution related proportionate and cause-specific mortality rates in ASA during 2012. The burden of congenital anomalies and prerinatal disease represent the primary causes of mortality with proportionate mortality rates of 26.1% and 17.4% respectively, and cause specific mortality rates of 1.86 and 1.55 per 10,000 persons, respectively. Congenital anomalies also known as birth defects are structural or functional metabolic disorders that occur during pregnancy and constitute a large mortality rate or long-term disability worldwide [38]. The most common, severe congenital anomalies are heart defects, neural tube defects and Down syndrome. Table 5 also shows that both respiratory and cardiovascular diseases have similar mortality rates, equal to 0.62 per 10,000 persons, each corresponding to 8.7% proportionate mortality rate.

Table 5. Proportionate and cause-specific mortality rates in ASA, Kuwait

Cause of Mortality	Number of Deaths	Proportionate Mortality Rate %	Cause Specific Mortality Rate
Congenital Anomalies	6	26.1	1.86
Prerinatal Disease	5	17.4	1.55
Respiratory Diseases	2	8.7	0.62
Cardiovascular Diseases	2	8.7	0.62
Non-Respiratory Diseases	1	4.3	0.31
Diabetes Mellitus	1	4.3	0.31

4. Discussion

The health impact of dust storms and PM10 concentrations have been thoroughly studied in North America, Europe and East Asia and to a lesser extent in Iran; however, only three studies have explored the association between dust particulates and health morbidity or mortality in Kuwait, of which two of the studies were done by the same authors [5,23]. Moreover, all regional Iranian studies have used the AirQ software to model the health impact of short-term exposure to PM10; this software was developed by the WHO to model European morbidity and mortality rates and may overestimate the relative risk and increase prediction error if used by non-European countries because of the obvious higher dust storms events and elevated levels of PM10 concentrations, especially in the Arabian region. This study used actual cases for morbidity and mortality and concluded that dust particulates were strongly correlated with acute lower/upper respiratory disorders and asthma. This study also revealed that dust storms, suspended dust, rising dust and PM10 followed a similar pattern throughout the studied period with high peaks during summer months, specifically in June, and lower during winter months; this finding confirms the robust link between dust storm events and ambient air PM10 levels and is in agreement with other studies in similar arid conditions [6,28,39,40]. Increased PM10 concentrations during the summer can be associated with the Middle Eastern dust storms from the arid lands of Iraq, Jordan, and Saudi Arabia which are the particular sources of dust events coming to Kuwait from the Northwest [1,28,41].

This study concluded that dust particulates were strongly correlated with acute lower/upper respiratory disorders and asthma. Thalib and Al-Taiar [23] showed that Kuwaiti children with asthma are particularly vulnerable to dust storm events. Other studies showed that respiratory admissions to hospitals were attributable to PM10 concentrations above 20 μg/m^3 [42] An estimated effect of 3% decline in daily respiratory FEV1 change was observed for every 10 μg/m^3 increase in ambient PM10 level [44]. Other studies showed strong association between dust events and asthma admissions in Japan [22], Trinidad [21], Taiwan [44], South Korea [45, 46] and southern Europe [47].

This study identified that cause-specific respiratory and cardiovascular mortality rates for all pollutants including PM10 ranked third after congenital anomalies and prerinatal diseases. Studies of 29 European cities [48] showed increase in daily mortality with an increase in PM10 concentrations. The impact of particulate matter on daily mortality has been shown by similar studies [49,50]; other studies demonstrated that short-term impacts of PM10 on mortality were exceeded even at concentrations complying with the European air ambient monitoring regulation [51].

Some limitations of this study is the unknown composition of the chemical and biological dust particles, future research should provide analysis of total dust and PM10 compositions and study the link between the individual components and the health impact. Another limitation of this study is that it did not consider intra- individually susceptibility to health disorders, particularly the impact of dust storms on asthma patients, further epidemiological studies are needed.

5. Conclusion

The impact of dust storms on human health has drawn great interest of research from various regions, especially in the western and east Asian countries; very little research was conducted to study the association of Arabian Peninsula dust storms or PM10 levels and associated health impact. The evidence on airborne particulates and its impact on morbidity and mortality is consistent in showing adverse health effects in both developed and developing countries. Dust storm events and PM10 concentration levels may vary across different regions in Kuwait, but only to a limited degree because of the very small geographic area (17,000 km^2) and similar climatic conditions across the country. It is assumed that dust concentration variation may not be very significantly different across multiple cities and individuals are most likely to be exposed to the same level of exposure. All population is affected, but susceptibility to the pollution may vary with health or age. Findings of this study suggest that there is a strong association between dust storms and PM10 and morbidity rates of asthma, acute upper and lower tract infections. The risk for various outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated [3]. However, it may be worthwhile to further investigate the health impact of dust storm events across Kuwait and such further evaluation can improve our understanding of the health impact of dust storms and PM10 pollutants.

Acknowledgments: The research study was initially triggered by the Kuwait Ministry of Health to assess the health impact of Ali Sabah Al-Salem area in Kuwait; the study started in year 2000 and was completed in year 2005. A recent project (2017) has been carried out at the Kuwait Institute for Scientific Research (KISR) and was funded by the Kuwait Environment Public Authority (KEPA) (KISR no. EC109K), through a task entitled 'risk assessment study for dust storms'.

Author Contributions: Dr. Ali Al-Hemoud developed the research methodology, analyzed the data using SPSS and finished writing the manuscript; Dr. Ali Al-Dousari provided significant details on dust fallout characteristics and sand storm trajectories and revised the manuscript; Dr. Ahmed Al-Shatti defined the health characteristics of morbidity and mortality and defined the research theme; Ahmed Al-Khayat carried out the statistical analysis using SPSS; Weam Behbehani analyzed the data and performed all figures, graphs, and tables; Mariam Malalk collected the meteorological data and presented the time-series analysis of PM_{10} pollutants.

Conflicts of Interest: The authors declare no conflict of interest.

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