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ORIGINAL PAPER

Assessment of pollution sources in the southeastern of the Riyadh and its impact on the population/Saudi Arabia

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Abstract The rapid growth of Riyadh—capital of Saudi Arabia—is pushing the area to more pollution and incentive for reorganization. The aim of this research is to assess air pollutants in southeast of Riyadh and detect opinion of the population about their environment. The assessment was done by analyzing 405 questionnaires, evaluating thermal band of Landsat 8, and spatial analyzing of particular matter and chemicals in 19 air samples by geostatistical tool in the ArcMap. Most of the inhabitants stated that they are suffering from bad odor, sewage leakage, and dust mainly from a cement factory. The thermal band of Landsat clarified the location of the pollution sources mainly the 1st industrial city, Yammama Cement Factory, and power plant in Farouq area. The ordinary kriging maps showed that the highest concentration of PM_{10} (>403 μg/m^3) lied to the northern and western side of the study area and caused a health issue to most inhabitants.

Keywords Pollution · Riyadh · Yammama Cement Factory · Geostatistic

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Introduction

The environment of Saudi Arabia faces very difficult challenges due to rapid economic development and welfare state, as a result consequences harmful air emission affecting negatively on humanity and environment. Oil industry, desalination, industrial activities, and automobiles increased in the level of the air, water, and plant and soil contamination.

Air pollution increased climate change especially greenhouse gases (Ramanathan and Feng 2009) influenced on public health (Al-Ahmadi and Al-Zahrani 2013), changed the concentration of elements within the plant tissue (Al-Muwayhi 2012; Baker et al. 1994; Salama et al. 2011), and create unsuitable environment for human life.

In addition, particulate matter (PM) with a diameter of less than 10 μm that could be dispersed to a long distance is the main atmospheric pollutant that emitted from industrial factories such as cement factory (Blezard 1998). The particular matters are affect human health by causing respiratory diseases such as wheezing, dry cough, and phlegm (Kakooei et al. 2012) and may reduce the lung capacity in humans (Ghose et al. 2005). Moreover, dust is known to be responsible for vegetation injury and crop yield loss (Iqbal and Shafig 2001; Salama et al. 2011).

In addition, Urban Heat Island (UHI) can cause air pollution (Youssef et al. 2011; Yin and Xu 2007; Li et al. 2014) where it is growing up as a result of heat emission of many sources such as urbanization, asphalt and concrete (Oke 1987; Lo and JC 1997; Owen et al. 1998; Voogt and Oke 2003), and vegetation cover. Urbanization expansion can undergo profound change in a thermal environment (Xu et al. 2014).

Pollution is a critical challenge in Saudi Arabia. The Presidency of Meteorology and Environment Protection (PME) in Riyadh stated that the fuel combustion of the vehicles (almost two thirds of carbon monoxide and 50 % of hydrocarbons and nitrogen oxides) is the main source of pollution, followed by industrial cities and small industries within the populous mass (Presidency of Meteorology and Environment Protection, PME 2012). Moreover, drought and dust storm increased pressure of air pollution.

The inhabited area in Riyadh (Capital of Saudi Arabia) is a dynamic city characterized by extremely rapid growth over the past quarter of a century (Struyk 2005). The population number of Riyadh is increasing rapidly mainly in the southern and central part of the capital (CDSI 2004) as shown in Fig. 1 where the services are more available and land prices are more suitable. Consequently, cement factor, power plant, and industrial city were built, and the urban growth has become crowded around the industrial area.

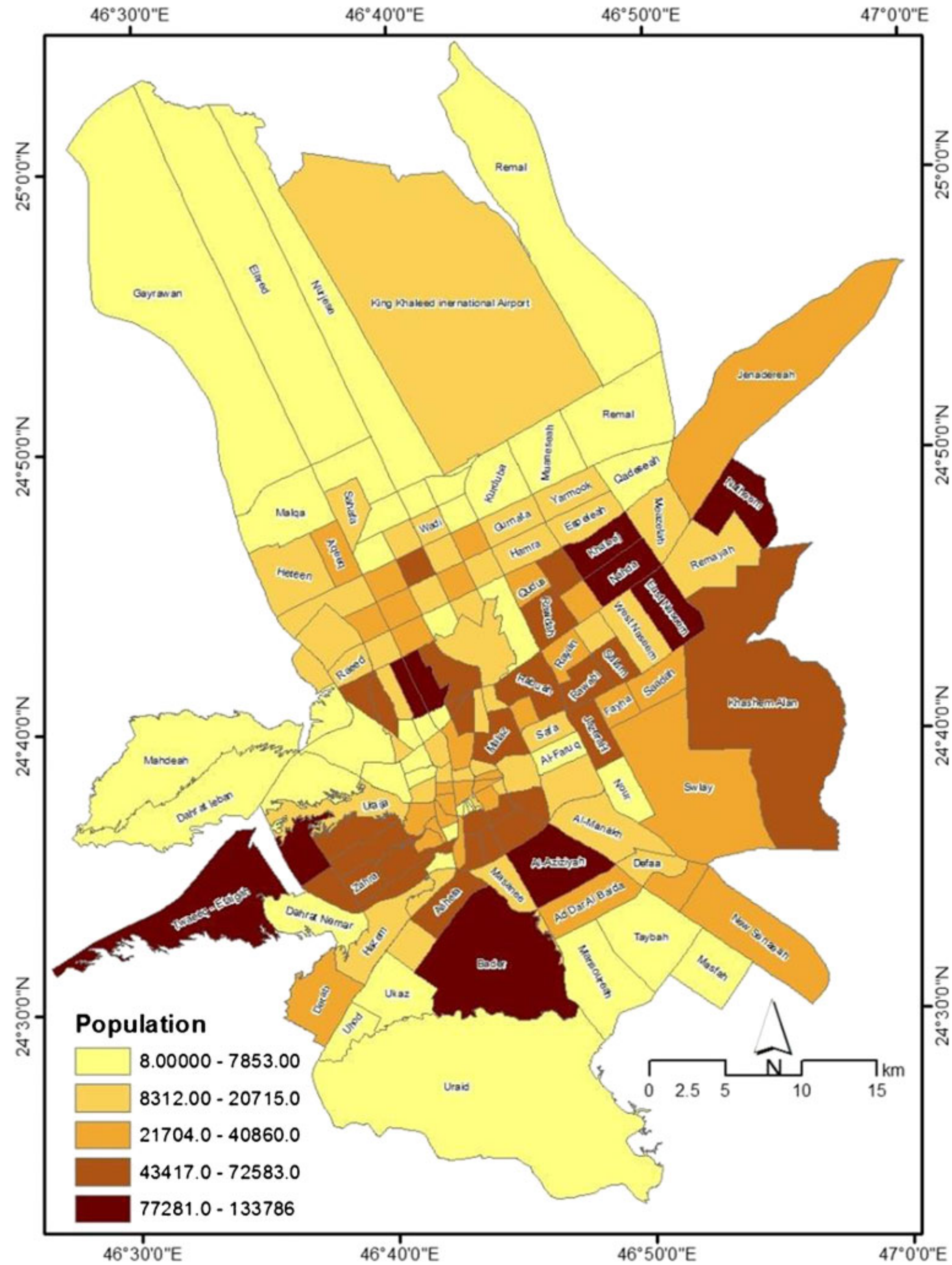


Fig. 1 Population number in Riyadh

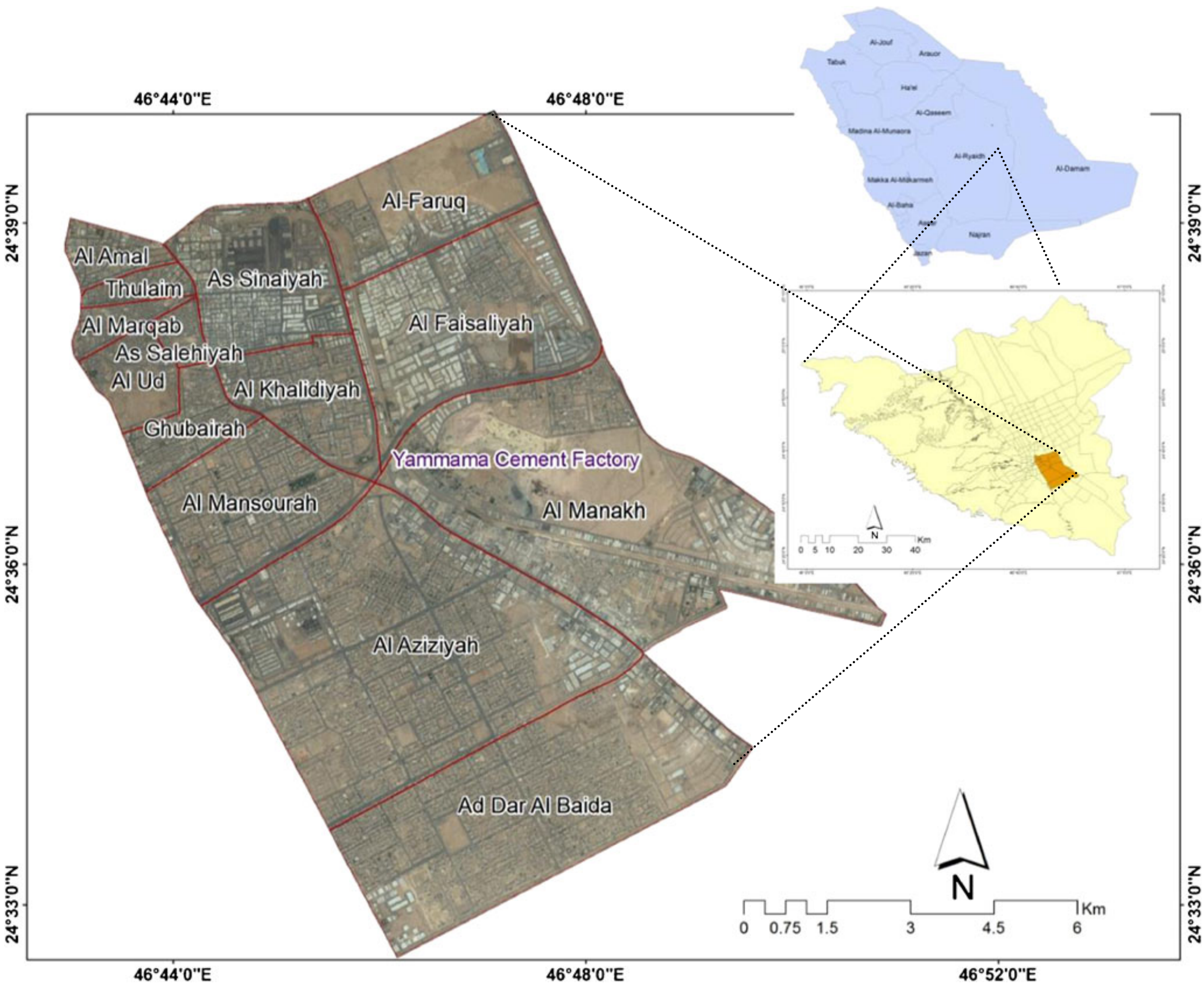


Fig. 2 Study area in the southeastern of Riyadh

The aim of this research is to assess the status of urban pollution in the southeastern of Riyadh and to evaluate its impact on human health. The assessment of pollution was deliberated according to three viewpoints: population view (Questionnaire), air analysis view, and thermal Landsat view. These are the critical axes considered to evaluate and protect environment of Riyadh.

Study area

The study area is the southeast of Riyadh enclosed between 24° 40 N 46° 42 5 E and 24° 32 25 N 46° 51 50 E covering about 99 km^2 as shown in Fig. 2. It is a dry and hot area; the temperature typically varies from 8 to 43 °C and is rarely below 3 °C or above 45 °C (Weatherspark 2014). The fall season is mostly between January and May.

The study area is of high population (Fig. 1), and the industrial facilities are numerous in the eastern and southeastern side as shown in Fig. 3. Yammama Cement Factory is the most remarkable factory in the study area, and the main source of pollution in Riyadh that was established in 1961 by Prince Mohammed Bin Saud Al-Kabeer with production power 1553 thousand tons Clinker per a day (Yammama Cement 2010). Yammama Cement Factory was constructed in an exposed area, far away from housing; however, the urban sprawl forced the factory to be in the central urbanized area.

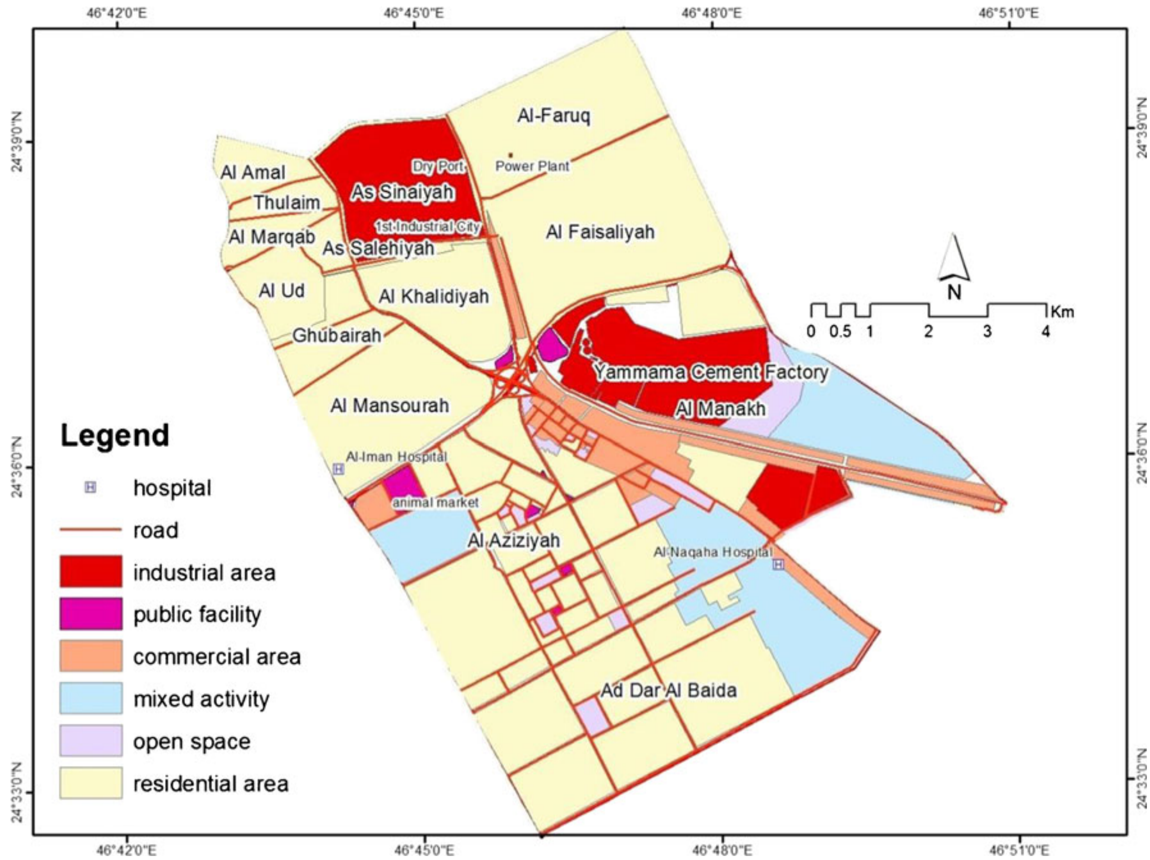


Fig. 3 Landuse of the study area

Table 1 Distribution of questionnaires in the study area

	District	Number of inhabitants[a]	Ratio	Sub-sample
1	Al Amal	17,884	0.030054516	12
2	As Sinaiyah	9290	0.015612081	6
3	Al Faruq	4737	0.007960649	3
4	Al Marqab	24,579	0.041305634	17
5	Al Ud	40,480	0.068027668	28
6	As Salehiyah	18,672	0.03137877	13
7	Manfouhah Al Jadidah	66,958	0.11252462	46
8	Ghubairah	46,931	0.078868738	32
9	Al Khalidiyah	47,241	0.0793897	32
10	Al Faisaliyah	19,668	0.033052574	13
11	Yamama	48,920	0.082211303	33
12	Manfouhah	49,432	0.083071732	34
13	Al Mansourah	48,283	0.081140808	33
14	Al Aziziyah	78,062	0.131185174	53
15	Ad Dar Al Baida	28,780	0.048365521	19
16	Al Misfat	3961	0.006656561	3
17	Al Manakh	15,207	0.02555575	10
18	Thulaim	25,967	0.043638203	18
	Total	595,052	1	405

[a] According to the census of 2004 of CDSI

The 1st industrial city (As Sinaiyah) in the northern side of the study area was established in 1973. It manufactured plastic, wood, electrical, building, and metal products from more than 50 factories (Moden 2014). Most of these products are transported in dry port by the Riyadh Railway.

Methodology

Questionnaire

The study area is divided into 18 districts. Stratified random sampling was chosen to distribute the questionnaire according to the number of inhabitants (Table 1). The samples were chosen randomly in one district. The information collected about the respondents' health and source of pollution in the study revealed that most of the respondents were employees and residents in the study area for more than 10 years.

The questionnaire consisted of three parts including occupation conditions, recognizing pollution, and its impact on the environment and general health such as

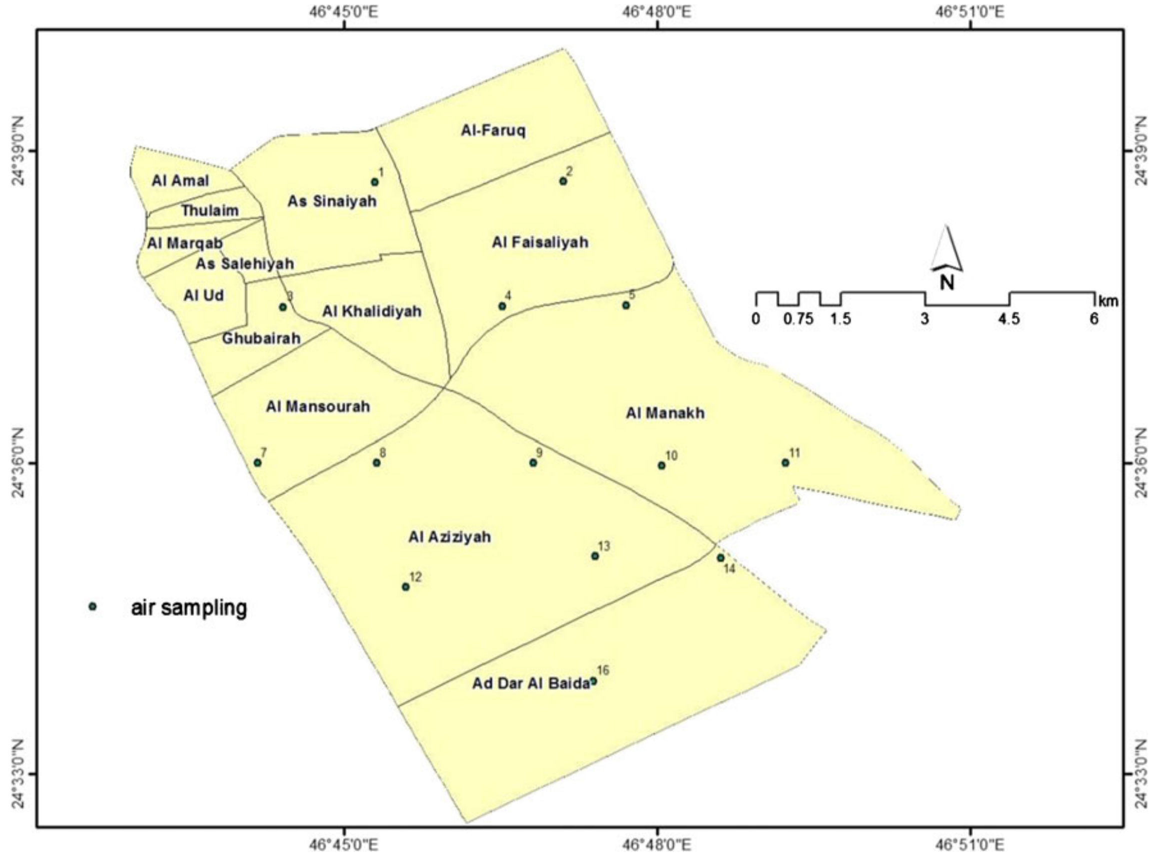


Fig. 4 Air samples in the study area

incidence of eye problems, acute and chronic respiratory diseases, and skin diseases.

Number of sample was determined according to Eq. (1) (Cochran 1977). Four hundred and eighty seven questionnaires were distributed among various age, gender, and ethnic backgrounds. Incomplete questionnares were removed. Finally, 405 questionnaires were completed and analyzed statistically by the Statistical Package for the Social Sciences (SPSS) software version 21.

$$n = \frac{pqz^2}{d^2(1\text{-}r)} \qquad (1)$$

Table 2 Methods and instruments used in air sampling

	Method	Instrument
NO_2 (mg/m^3)	US EPA method 7E	Multi RAE Quick Start Guide
SO_2 (mg/m^3)	US EPA method 6C	Multi RAE Quick Start Guide
CO	US EPA method 10	Multi RAE Quick Start Guide
$PM_{2.5}$ and PM_{10}	____________	TSI Dust Trak II
O_3	____________	AeroQUAL 500

Where n is the sample size = 405, and z is the abscissa of the normal curve that cuts off an area α at the tails $(1 - \alpha)$ equals the desired confidence level (95 %). In the statistical table, z = 1.96. d is the desired level of precision = 5 %, p is the estimated proportion of an attribute that is present in the population = 0.5 (maximum variability)

$$q = 1\text{–}p$$

Where r is the non-response rate (appreciate his 0.05).

The chi-square test and Cramer V were used to compare between variables and measure of association between two nominal variables, respectively. A p value less than 0.05 was considered statistically significant.

Thermal analysis

UHI where temperatures are higher in built-up areas compared to natural landscapes in their surroundings (Dobrovolný 2013) are increased as a result of the urban and industrial developments. Thermal infrared satellite sensor images are widely used for assessing (UHI) in highly urbanized areas (Kaya et al. 2012). Landsat

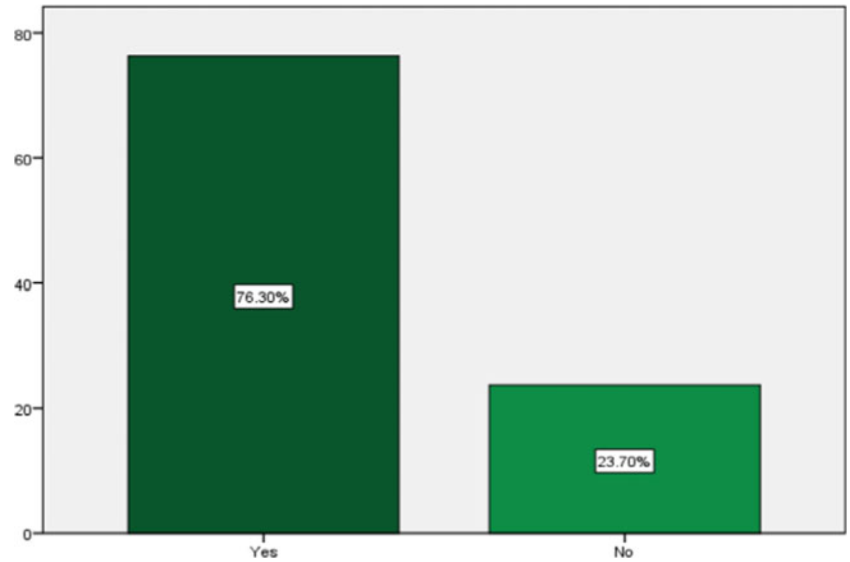


Fig. 5 Is Yammama Cement Factory the main source of pollution?

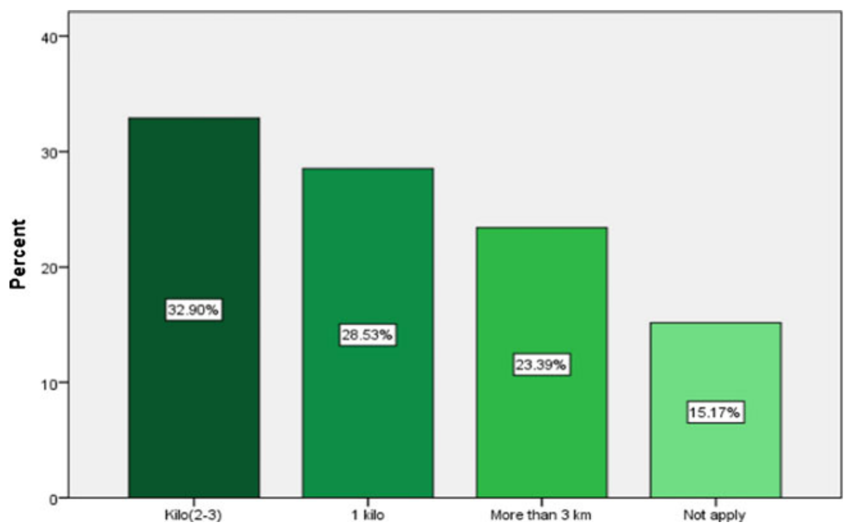


Fig. 6 Extension of the hazy cloud around cement factory

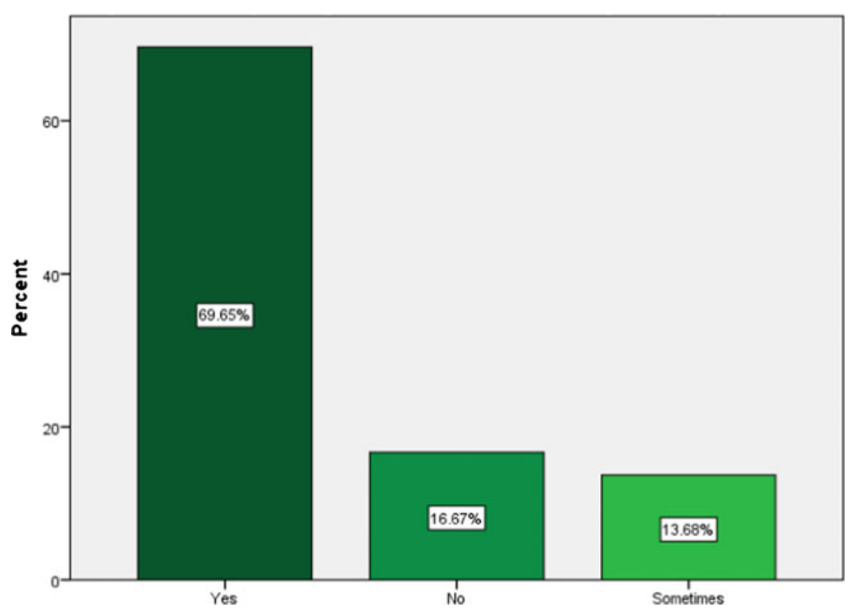


Fig. 7 Yellowish and dusty leaf in the study area

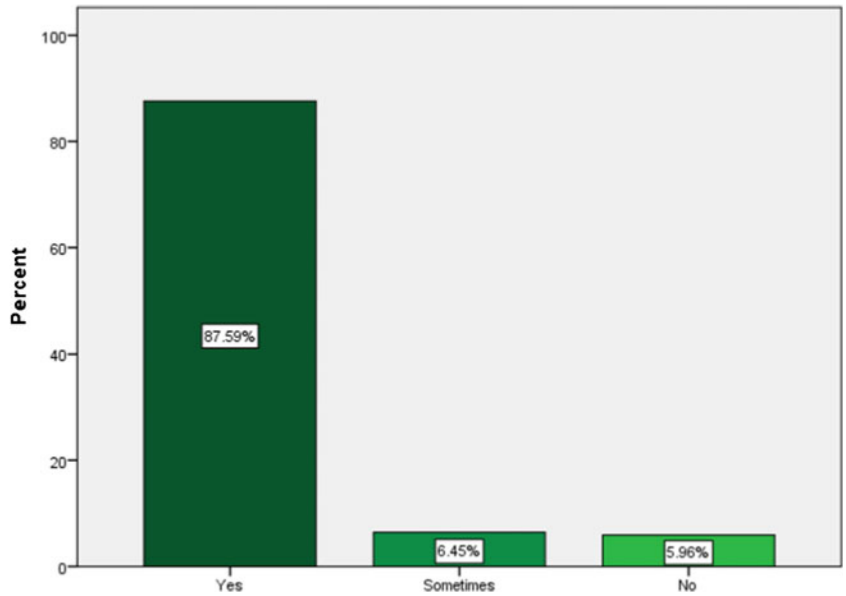


Fig. 8 Dirty rooftops

thermal images provided spatially consistent and detailed information on land surface temperature variation (Dobrovolný 2013; Weng 2009). The standard Landsat 8 products provided by the USGS EROS Center consist of quantized and calibrated scaled Digital Numbers (DN) representing multispectral image data acquired by both the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (USGS 2013).

In this study, Landsat 8 satellite sensor image was taken on 2013-09-07 at time 07:19:29 with a ground resolution of 100 m. It was a clear day and the temperature was 30 C. A thermal infrared sensor (TIRS) detects long wavelengths (bands 10 (10.6–11.2 μm) and 11 (11.5–12.5 μm)) that depend on the surface temperature.

Air sampling

A total of 19 air samples were measured in the study area and around (Fig. 4) using portable instruments during 25–28 May 2014 by the Geotechnical and Environmental Company (GECO). Five parameters were measured, particularly matter (PM_{10} and $PM_{2.5}$), NO_2, SO_2, CO, and O_3. The sampling

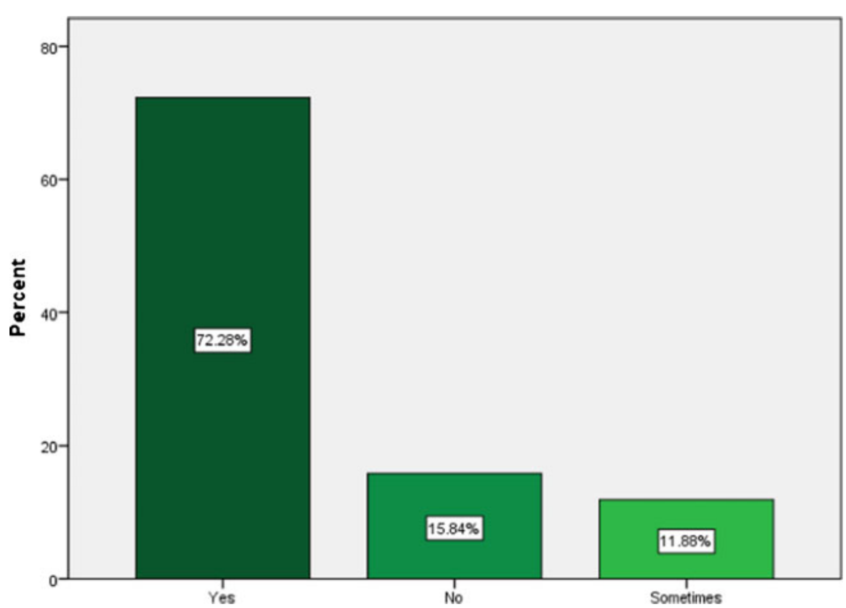


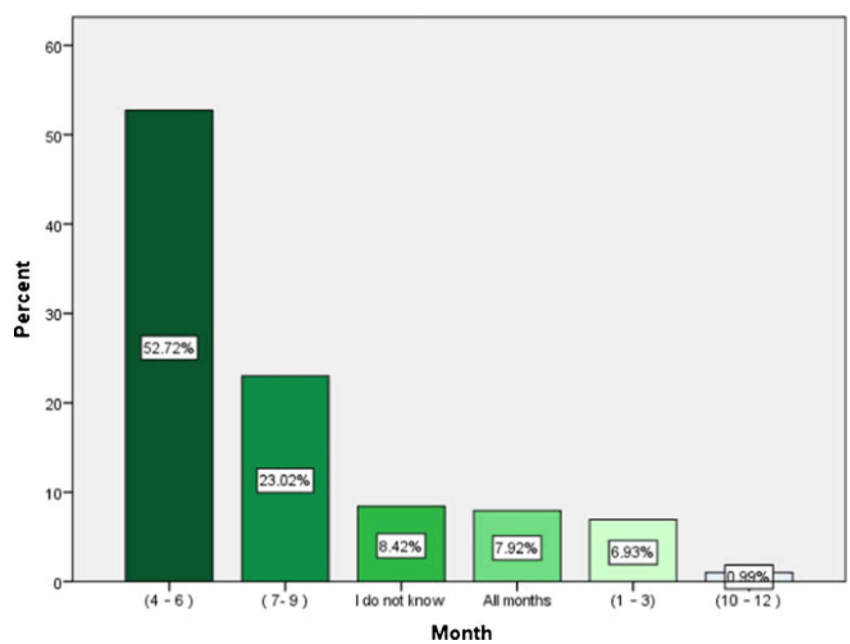
Fig. 9 Increasing of temperature

Table 3 Relationship between districts and impact of pollution

District	Yellowish and dusty plants			Hazy cloud			Dirty rooftop			Hearing explosion		
	Yes	No	S.t.	Yes	No	S.t.	Yes	No	S.t.	Yes	No	S.t.
Al Amal	2.7	0.0	0.2	1.5	0.2	1.2	2.7	0.0	0.2	0.5	2.5	0.0
As Sinaiyah	0.2	0.2	1.0	0.5	0.0	1.0	0.7	0.5	0.2	0.0	1.5	0.0
Al Faruq	0.5	0.2	0.0	0.5	0.2	0.0	0.7	0.0	0.0	0.0	0.7	0.0
Al Marqab	2.7	0.5	0.5	2.5	0.5	1.2	4.0	0.0	0.2	1.7	2.2	0.2
Al Ud	3.5	1.7	1.7	4.7	1.0	1.2	6.5	0.2	0.2	0.7	6.2	0.0
As Salehiyah	2.0	0.7	0.5	2.2	0.2	0.7	3.0	0.2	0.0	0.2	3.0	0.0
Manfouhah Al Jadidah	7.5	2.5	1.5	4.7	2.0	4.7	10.7	0.7	0.0	0.7	10.7	0.0
Ghubairah	5.7	1.7	0.5	3.7	3.2	0.7	6.0	1.7	0.2	0.7	6.5	0.5
Al Khalidiyah	4.7	1.2	2.0	5.0	0.0	3.0	6.9	0.2	0.5	2.2	4.7	1.0
Al Faisaliyah	2.5	0.0	0.7	1.2	0.2	1.7	2.7	0.0	0.5	0.0	3.2	0.0
Yamama	5.5	1.5	1.2	3.0	1.7	3.2	7.4	0.0	0.7	0.7	6.9	0.5
Manfouhah	4.2	3.5	0.7	4.5	2.2	1.7	6.7	1.0	0.7	0.0	7.9	0.5
Al Mansourah	7.5	0.2	0.5	5.5	0.2	2.2	7.2	0.0	1.0	2.5	3.7	2.0
Al Aziziyah	10.9	1.0	1.2	9.2	0.7	3.2	12.7	0.0	0.5	3.7	8.4	1.0
Ad Dar Al Baida	3.7	0.0	0.7	2.2	0.5	1.7	3.7	0.0	0.7	0.2	3.5	0.7
Al Misfat	0.5	0.2	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.7	0.0
Al Manakh	2.2	0.0	0.2	2.2	0.0	0.2	2.5	0.0	0.0	1.2	1.0	0.2
Thulaim	3.0	1.2	0.2	1.7	1.2	1.5	3.0	1.0	0.5	0.7	3.7	0.0
Total	69.7	16.7	13.7	55.6	14.7	29.7	87.6	6.0	6.5	16.1	77.2	6.7
Chi-square	69.862			71.700			65.918			86.999		
Sig	0.000			0.000			0.001			0.000		
Cramer's V=	0.292			0.299			0.28			0.33		
Decision	There is a statistically significant relationship			There is a statistically significant relationship			There is a statistically significant relationship			There is a statistically significant relationship		

S.t. sometimes

Fig. 10 Impact of pollution throughout the year



points that were selected to cover the whole of the study are with successive distances about 2–3 km to include diversity landuses. The samples were measured according to PME standards as in Table 2.

Geostatistical analyses were performed to determine the spatial extent of the air quality in the study area. All the geostatistical analyses were performed using the ArcGIS Geostatistical Analyst (ESRI_ version 10.1) software. The variables were subjected to three stages of analysis; the first is univariate analysis for numerical variables including measures of central tendency (e.g., mean and median), measures of dispersion (e.g., standard deviation and variance), and shape (skewness and kurtosis) for determining the type of distribution by using the Moran I test histogram views and Voronoi maps.

The second stage of analysis is fitting the best representative semivariogram model according to the following formula:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[\left(Z(x) - Z(x+h) \right) \right]^2 \tag{2}$$

Where $\gamma(h)$ is the semi-variance, $Z(x)$ is the value of initial potential at site x, $Z(x + h)$ is the value of potential at site (h) distance apart from (x), and N is the number of sample pairs (Bachmaier and Backes 2008).

Finally, the third stage is constructing the spatial distribution maps based on kriging interpolation techniques. This technique was first published in Krige (1951), and developed by French mathematician G. Matheron and established the whole field of linear geostatistics (Cressie 1990; Webster and Oliver 2001). Since then, many techniques have been discovered using various approaches (Venables and Ripley 2002).

The Ordinary Kriging (OK) method is a standard approach of kriging that assumes a constant unknown meaning, where the value at the unsampled point can be predicted by a linear weighing of the variation between the surrounding points derived from variogram analyses (Eq. 3a and b)

$$Z(X_0) = \mu + \varepsilon(X_0) \tag{3a}$$

$$Z(X_0) = \sum \lambda_i \ \gamma(x_i), \quad \sum \lambda_i = 1 \tag{3b}$$

Where μ is an unknown constant, and $\varepsilon(X_0)$ is the error associated with an unknown location X_0; $Z(X_0)$ is the estimated value of Z at Xo, and λ_i is the weight that gives the best possible estimation from the surrounding points.

Results and discussion

Questionnaire

More than three quarters of the respondents in the study area believed that the cement factory is the main source of pollution as shown in Fig. 5, and they demand to move it outside the boundary of the region. However, there are many sources of pollution such as traffic vehicle, stone factories in Al-Manakh, power plant in Farouq, animal market in the Al-Aziziyah, and the 1st industry city in As Siniyah.

According to the questionnaire, the study area is suffering from pollution in several aspects such as a hazy cloud around their area that extends at least 1 km

Table 4 Speed of the extreme wind (knots/degrees) in the Riyadh new station (Presidency of Meteorology and Environment Protection, PME 2011)

	2007	2008	2009	2010	2011	Average
January	22	25	18	28	23	23.2
February	24	23	28	32	40	29.4
March	25	24	33	30	29	28.2
April	50	28	33	36	31	35.6
May	41	25	24	33	37	32
June	23	30	35	29	30	29.4
July	24	24	24	31	32	27
August	23	24	25	30	31	26.6
September	21	25	24	26	27	24.6
October	15	20	30	23	20	21.6
November	21	15	24	18	26	20.8
December	21	17	22	30	17	21.4

Table 5 Enumeration of dust storm in the Riyadh new station (Presidency of Meteorology and Environment Protection, PME 2011)

	2007	2008	2009	2010	2011	average
January	0	3	3	2	3	2.2
February	1	6	6	4	5	4.4
March	8	3	8	3	6	5.6
April	9	9	9	14	9	10
May	5	7	7	5	7	6.2
June	7	16	11	2	6	8.4
July	5	7	4	2	8	5.2
August	0	4	0	4	3	2.2
September	2	1	1	2	0	1.2
October	0	0	3	0	0	0.6
November	2	0	0	0	7	1.8
December	2	0	2	1	0	1

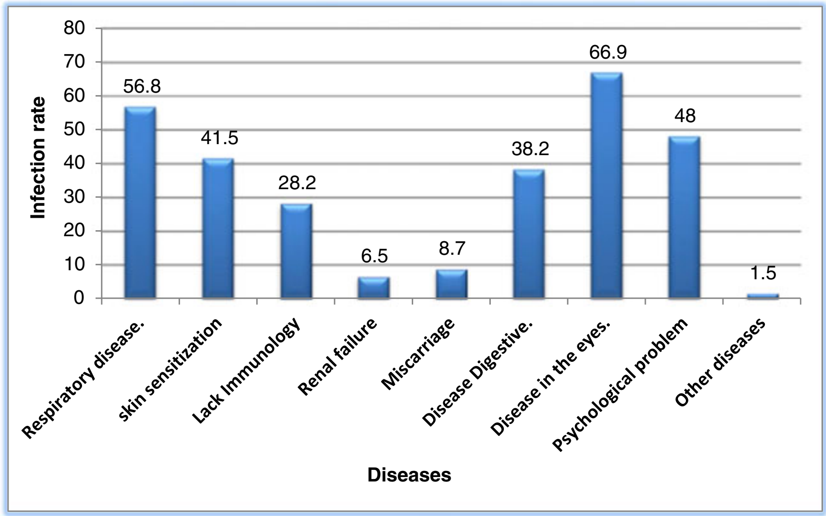


Fig. 11 Various diseases in respondents

(Fig. 6), yellowish and dusty plants (Fig. 7), dusty of rooftops (Fig. 8), and increasing air temperature more than that of the neighborhood (Fig. 9), mainly in Aziziyah as shown in Table 3. Moreover, most of the study area is suffering from leakage of the sewage and bad odor from factories and landfill in the eastern side.

Based on the opinion of the population, the temporal effect of pollution increased in April–June as shown in Fig. 10. The rapid increase of this effect can be due to the exposal of the region to extreme weather phenomena such as dust storms and extreme wind speed as shown in Tables 4 and 5.

Information was collected from respondents about their health issue such as eye, respiratory, and skin diseases. In many cases, incidence of multiple diseases in a single respondent was reported. Figure 11 presents an account of occurrence of various diseases in respondents interviewed at the different study locations. In addition, about 80 % of respondents believed that their health issue is caused by pollution as in Fig. 12.

Thermal analysis

The unitless digital number of the thermal band in Landsat image provides spatially information on land surface temperature variation in the study area as shown in Fig. 13.

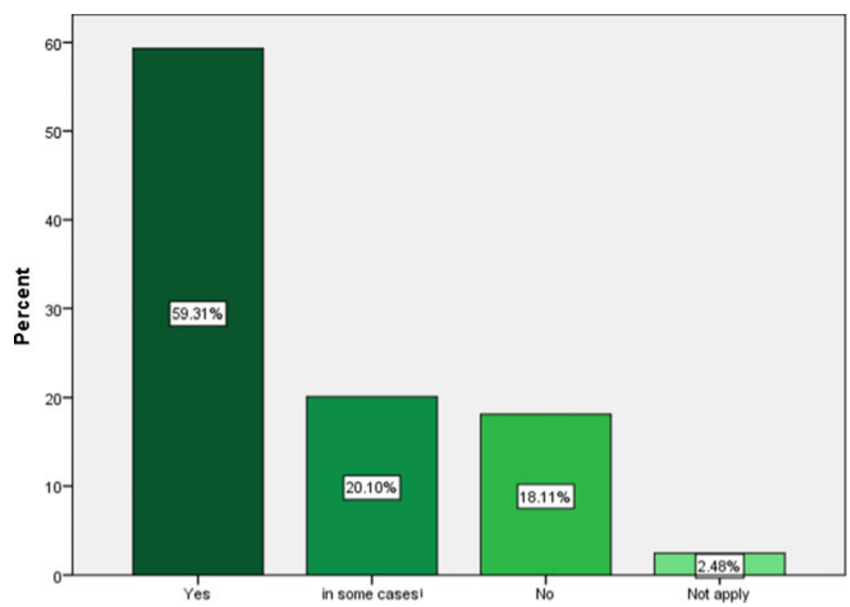


Fig. 12 Is your condition related to pollution?

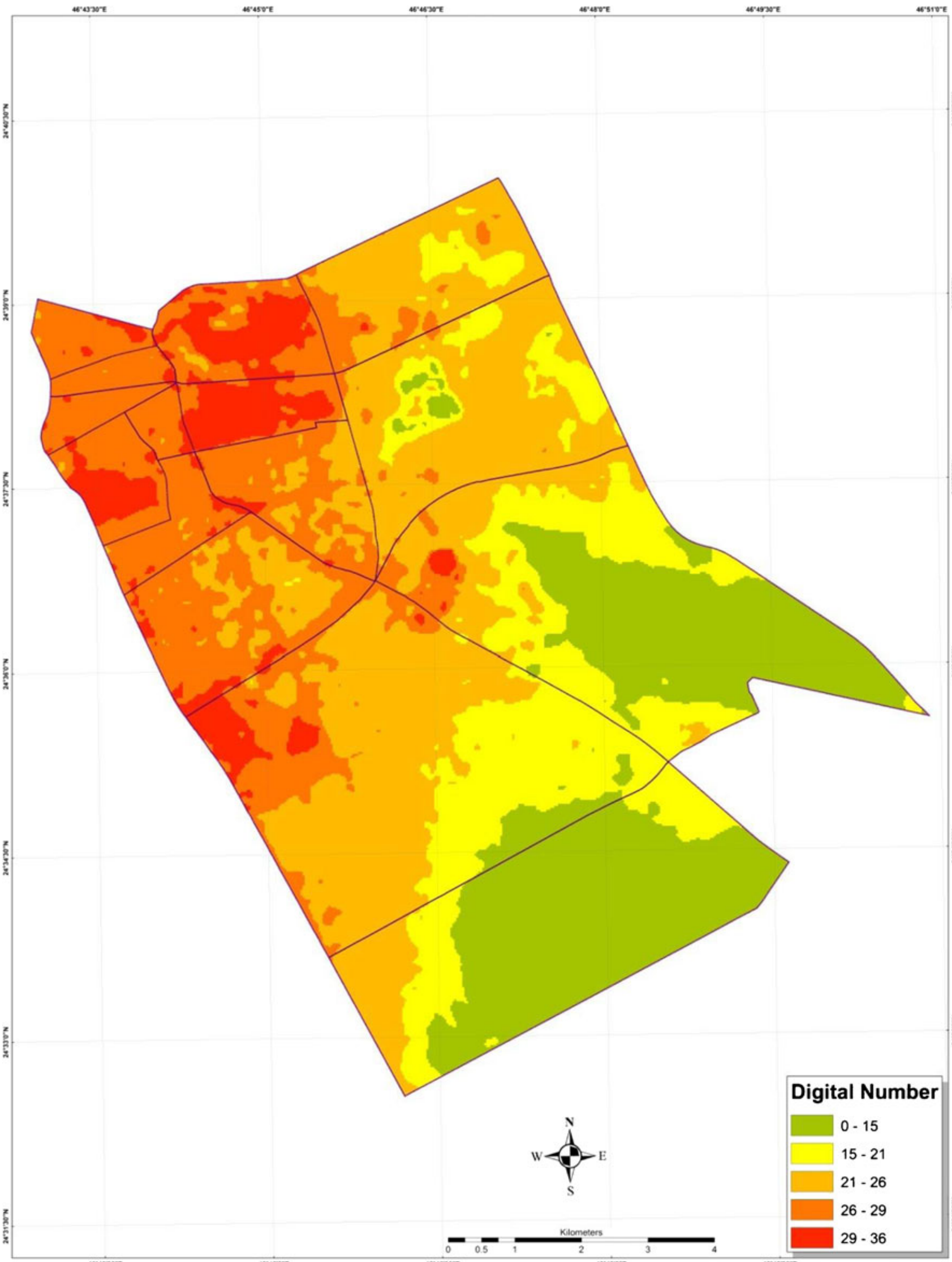


Fig. 13 Thermal band of Landsat

Generally, high surface temperature dominated in the southwestern side and the center of the study area due to urbanization while the barren land had the lowest temperature. The urban area emitted more heat than the non-urban area due to urban materials, asphalt, and concrete those absorb and release more

Table 6 Statistical analysis of the air sampling

Parameter	Min.	Max.	Mean	NAAQS	Distribution	Skewness	Kurtosis	Model	St.dev.	Direction	Major range	Minor range	Partial sill	Nugget
PM_{10} μg/m^3	78	485	269.6	150	N	0.034	1.509	Stable	129.7	30	0.144	0.083	0.5	0.0005
$PM_{2.5}$ μg/m^3	28	273	184	35	L	0.566	3.26	Stable	0.884	45	0.065	0.042	0.7	0.0007
CO ppm	2	16	6	35	L	0.394	1.726	Stable	0.744	24	0.14	0.079	0.8	0.06
NO_2 μg/m^3	19	91	46	100	L	0.347	1.544	Stable	0.56	19	0,14	0,06	0.4	0.12
SO_2 μg/m^3	218	890	438	1300	L	0.414	1.768	Stable	0.48	31	0.14	0.078	0.4	0.02
O_3 ppm	0.01	0.02	0.015	0.075	N	−0.105	1.011	Stable	0.005	161	0.057	0.04	3.3	0

St.dev. standard deviation, *NAAQS* National Ambient Air Quality Standards, *L* lognormal, *N* normal

heat from the sun. The surface heat intensity was varied due to land cover and loss of agricultural lands. The industrial and commercial areas such as the Yammama Cement Factory, power plant, dry port, 1st industrial city, and animal market were demonstrated with very high surface temperature. Consequently, 72 % of the respondents in the questionnaire stated that the temperature in the industrial area is higher than the surrounding area as shown in Fig. 9.

Air sampling

Means, maximum values, and minimum values of the particular matter and chemicals in 19 samples were calculated as shown in Table 6. The maximum values were below the National Ambient Air Quality Standards (NAAQS) except in PM_{10} and $PM_{2.5}$.

The 1st industrial city and Yammama Cement Factory are the main sources of air pollution in the study area. The wind direction during air sampling was north to northwest (Fig. 14) mainly toward neighborhoods.

Air data were statistically analyzed, and the semivariance models were built according to the histogram distribution as shown in Table 6 and Fig. 15.

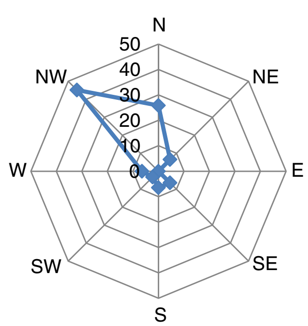


Fig. 14 Wind rose for a week during air sampling

Based on the semivariance modeling, air chemical parameters and particular matter are spatially anisotropic. The trended models of their spatial distributions are to the northeast except in the ozone to the northwest. This means that the same factor is affecting the spatial distribution suggesting a non-point source of pollution.

OK maps were built depending on the semivariance modeling as shown in Fig. 16. They indicate that maximum of particular matter, nitrate, sulfate and monoxide carbon are almost identical in their locations suggesting that they originated mainly from combustion of fossil fuels and have similar sources. Maximum contents are encountered in the northwestern side of the study area downwind of the city and toward the neighborhood.

The PM_{10} and $PM_{2.5}$ exceed the air quality standard of NAAQS in almost all areas. The highest concentration of PM_{10} and $PM_{2.5}$ (485 and 273 μg/m^3, respectively) lies to the northern and western side of the study area mainly around the cement factory where fuel preparation, clinker burning, and extraction of raw material are the major source of particular matter.

The maximum PM_{10} exceeds the NAAQS limit for more than 3 times and dispersed to about 1 km from the cement factory downwind, while maximum $PM_{2.5}$ exceeds the NAAQS limit for more 7 times and dispersed to about 3 km from the cement factory upwind.

The concentration of PM_{10} and $PM_{2.5}$ were gradually decreased upwind toward southeast until they reached 78 and 273 μg/m^3, respectively, where industrial and urban areas are less.

Carbon monoxide (CO) ranged between 2 and 16 μg/m^3. The maximum concentration is in a small area along the western side of the study area (Al Mansourah), and it does not exceed the NAAQS limit.

Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were concentrated in the north and northwestern side

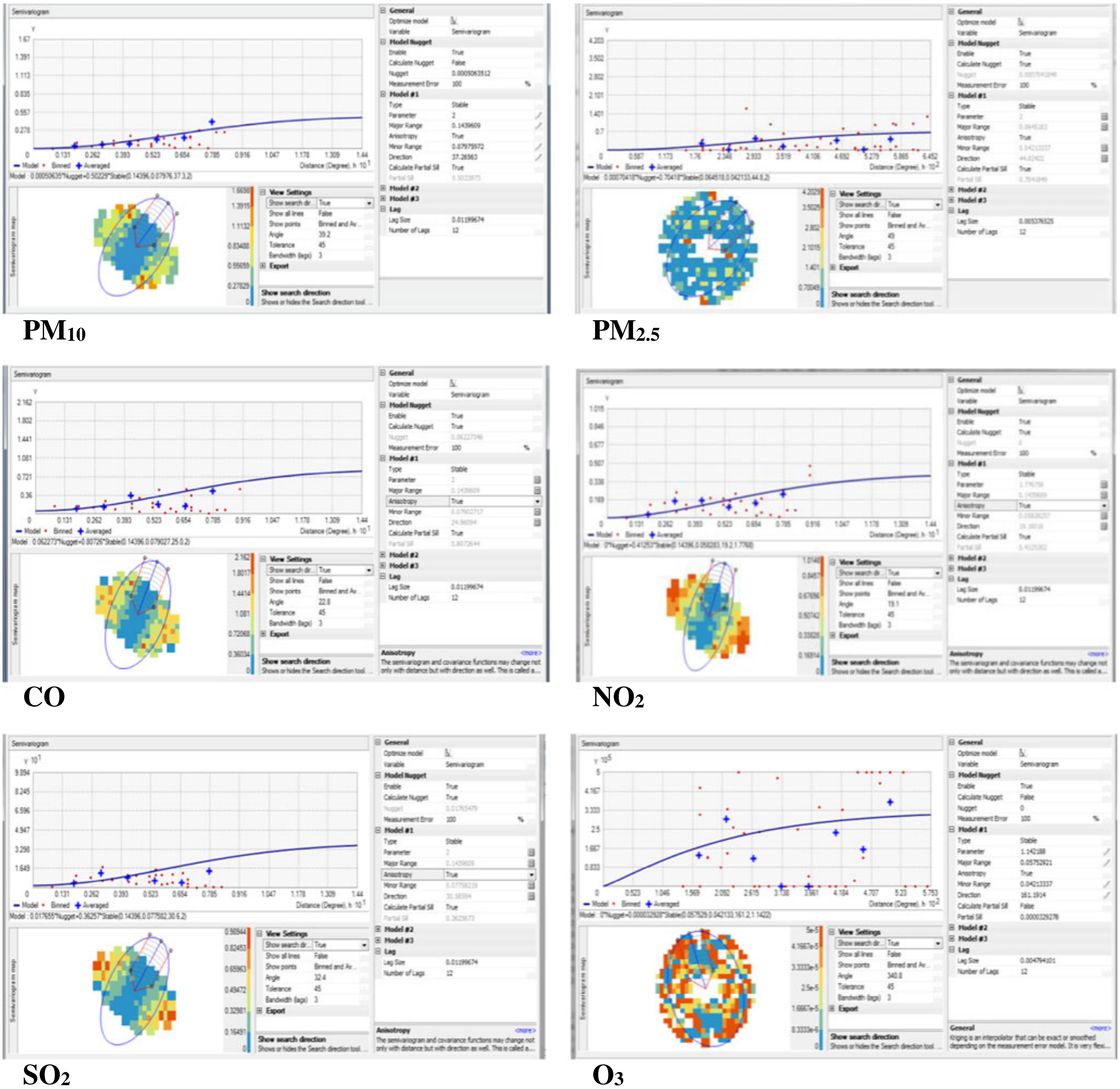


Fig. 15 Semivariance models for air sampling

of the study area. The maximum concentration of NO_2 and SO_2 were 91 and 890 μg/m^3, respectively. Both concentrations are critical although they did not exceed the standard limit (100 and 1300 μg/m^3, respectively). The main sources of NO_3 and SO_2 are traffic emissions and industrial activities. Power plant in the Faruq area (4th station) plays a significant role in NO_2 concentration where it operates on diesel and exceeds the standard PME limits in 2013 to about 268 % in two units (Saudi Electricity Company 2013). The rotary kiln system in the cement industry is the main source of SO_2 and may affect human health.

Pearson product matrix for the particular matter and gases show strong to moderate positive correlation except in ozone as shown in Table 7 as a result of ozone depletion due to chemical reactions.

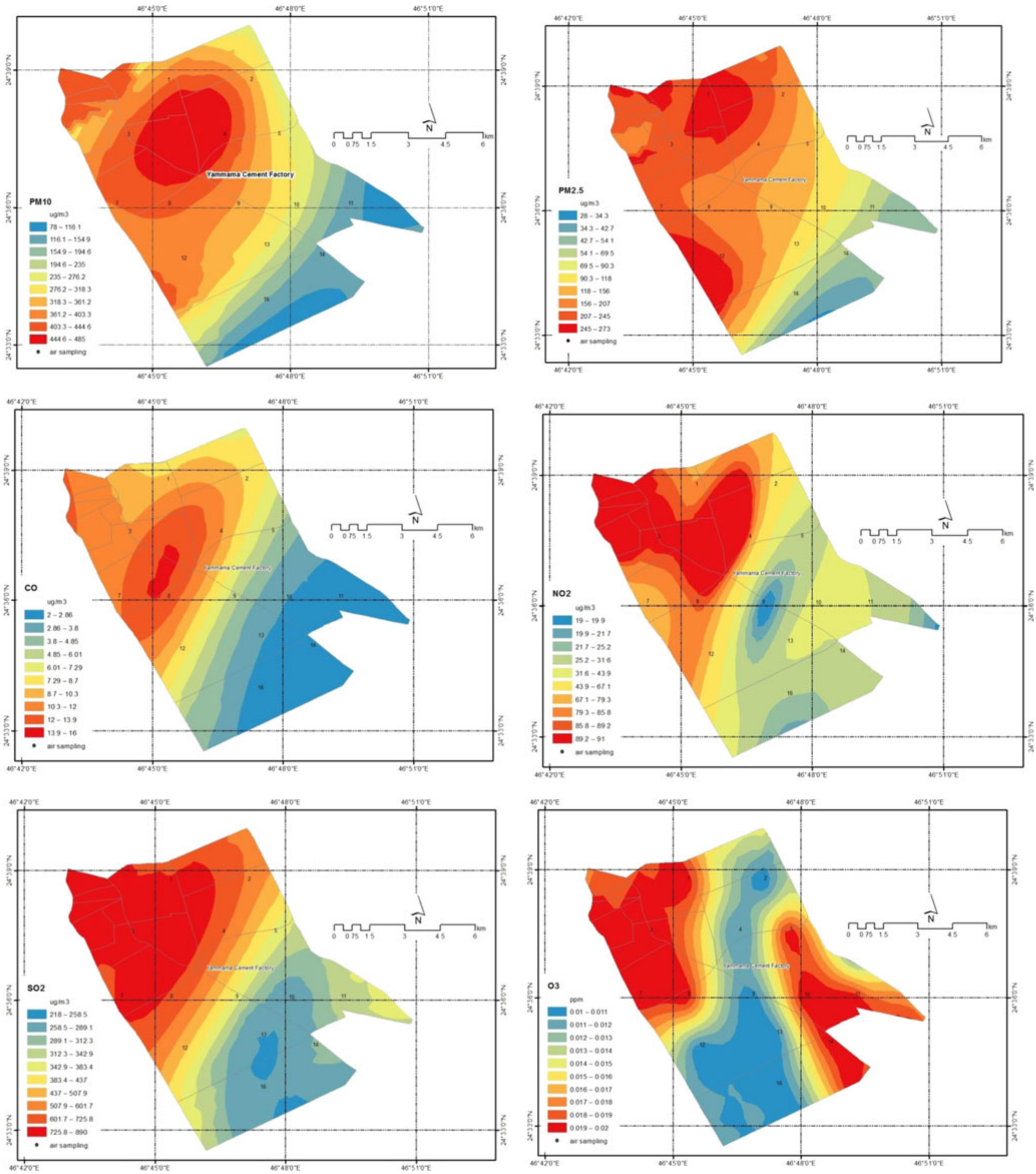


Fig. 16 Ordinary kriging maps of particular matter and chemical elements of the air sampling

The high concentration of all these gases and particular matter is evident that the industrial city, power plant, and cement factory were responsible for this. The distance between the cement factory and the

Table 7 Psearson product (correlation coefficients) matrix for the particular matter and gases in the study area at 95 % confidence level

	PM_{10}	$PM_{2.5}$	CO	NO_2	SO_2	O_3
PM_{10}	1					
$PM_{2.5}$	0.941353	1				
CO	0.848096	0.809493	1			
NO_2	0.840876	0.876045	0.921862	1		
SO_2	0.815974	0.817013	0.923114	0.963121	1	
O_3	0.031082	0.040468	0.046295	0.188166	0.264485	1

residential area should be at least 4 km upwind and more than 6 km downwind. In the other hand, High Commission for the Development of Riyadh decided to remove the cement factory away from residential area in 2012, but the decision has not yet been implemented.

Finally, according to the questionnaire, thermal analysis, and air sampling, the study areas were suffering from different sources of pollution as shown in Fig. 17, and all of them influence effectively in air pollution and human health. Particular matters are the main pollutants which came from cement factory and stone factories where they dispersed to long distances and exceed the standard limit. Most people in the study area are suffering from bad odor caused by landfill and animal markets, harmful chemical gases ascended from cement's factory chimneys, 1st industrial city, and power plant. In addition, the emission caused by vehicles in the whole study area creates pollution problem, at least as important as the combustion-related pollution.

Conclusions

1. Southeastern side of the Riyadh is densely populated and factories.
2. Most of population in the southeastern side of the Riyadh are suffering from health issues due to particular matter and pollutants in the air.
3. The 1st industrial city, Farouq Power Plant, and Yammama Cement Factory are the main air and thermal pollutants in the southeastern side of the Riyadh.

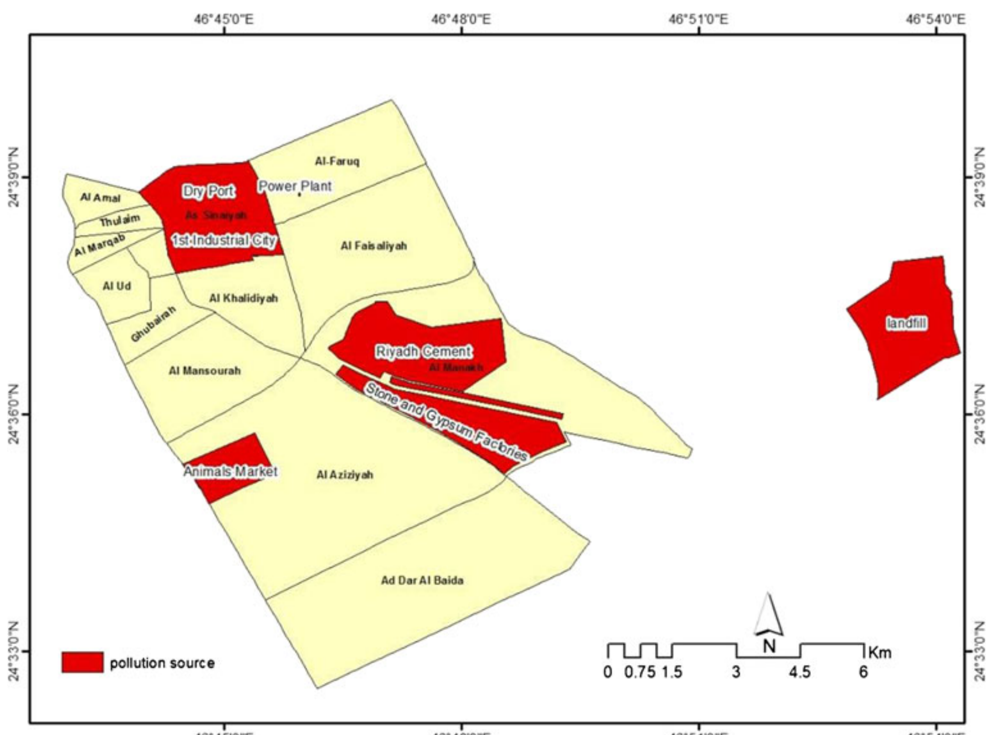


Fig. 17 Sources of the pollution in the study area

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