Geographic Information Systems for Appraisal of Spatial Disparities of Air Pollution in Karachi

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Abstract:
Air pollution is a major environmental health problem affecting the developed as well as developing countries around the world. Continuous growth of human induced unchecked sources of pollution is the pivotal point of this burgeoning problem.

GIS has largely been employed for environmental inquiries in the developed world. In Pakistan, these technologies are in their introductory phases. However, it is a pioneering attempt of using Geographic Information Systems to evaluate the spatial variations of air pollution. The study area is Karachi metropolis, the largest city in Pakistan.

Traffic and industrial activity have been identified as the major sources of pollution in Karachi. The ultimate Risk Zone map is clearly demonstrating the spatial patterns of air pollution in Karachi. The built-up localities of old city area, Landhi Korangi industrial/residential area, and SITE Industrial region are under high risks on an aggregate level.

1. INTRODUCTION

Karachi since 1947, from the birth of Pakistan has changed gradually from a fishing village in nineteenth century. It has now become one of the fastest growing metropolis of the world. Rapid population growth and urbanization have created severe environmental hazards for the city life [1]. Air pollution is a serious concern worldwide, especially in a developing country like Pakistan. Regular growth in the industrial sectors, and in the wastage from an ever-increasing number of sources, together with the need to preserve nature, have found worldwide attention focused on the burgeoning problems of air pollution [2].

Therefore, there is an urgent need for the monitoring of the adverse affects caused by pollution in such a manner that an affective monitoring and controlling technique could be developed. Because of the injurious effects of air pollution on human beings, it is appropriate to have scientific mechanisms to handle this environmental problem, which is one of the major causes of respiratory diseases in Pakistan.

Although few organizations have been working on the subject of air pollution but spatial dimensions within metropolis have been largely ignored mainly due to less comprehension and under estimation of spatial techniques as well as the difficulty in collecting, processing, and analyzing the data at micro geographic scales.

This research is focused on the development of a system on experimental level that could monitor the sources, concentration patterns and risk-zones distribution of air pollution all over the metropolis. The formulated system is a prototype that could be further utilized on countrywide environmental monitoring of air pollution.

2. MATERIAL AND METHODS

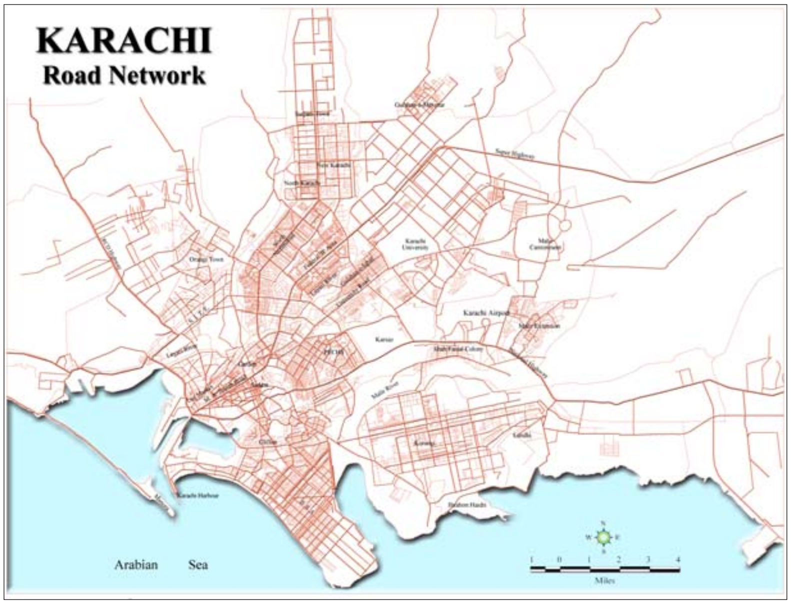
2.1 Digital Mapping

SPOT, a French satellite provides image of global coverage for down-to-earth projects such as cartographic mapping, land-cover inventories, natural resource mapping, water quality assessment, and flood control etc. [3]. In this study, SPOT Panchromatic data have been used to map the road network of Karachi as shown in Figure 1 [4]. The quality of the image was found satisfactory however; *rectification, corrections* and *enhancement* were conducted according to advanced image processing techniques.

2.2 Air Pollution Statistics

Space and Upper Atmosphere Research Commission (SUPARCO), a governmental organization, had been interested in the instrumental monitoring of air pollution for different cities of the country. However, in a developing country it is quite difficult to update monitoring statistics rapidly. Therefore, the last publication “Assessment of air quality in the metropolitan Karachi” [4], a collaborative project of SUPARCO and Karachi Electric Supply Corporation (KESC) is the major source of air pollution statistics for this study. These air quality measurements were taken at different sites of the city (Table 1), which are mapped in Figure 2.

Total Suspended Particulates (TSP), Nitrogen Oxides (NOx), Sulphur dioxide (SO_2), Carbon monoxide (CO) and Surface Ozone (O_3) were collected according to their specifically designed criteria through samplers and analyzers [5].



Source: [4] Figure 1

2.3 GIS Modeling

The term 'model' entered the lexicon in the 1960s when the idea of symbolically representing complex systems suddenly came of age [6]. As computers have pervaded every corner of our world, the idea of a model no longer has the drawing power it once did. There are a number of spatial modelling methods available with respect to application by virtue of efficacious computer tools [7]. The main purpose of building a spatial model here is to demarcate the locational distribution of air pollution.

Spatial interpolation is a pervasive operation. This technique of simulation has successfully been used in many areas and applications such as to estimate the rainfall, temperatures, elevation and ground water extent etc. e.g. [8]; [9]; [10] and [11].

Interpolation can be performed through many statistical techniques. Inverse Distance Interpolation (IDW) is commonly used in environmental GIS modeling to create raster / grid overlays from point data [12] and [13]. Inverse distance weighted interpolation determines cell values using a linearly weighted combination of a set of sample points [14]. The weight is a function of inverse distance. The surface being calculated is a locationally dependent variable. IDW allows controlling the significance of known points, upon the interpolated values, based upon their distance from the output point. This method provides accurate weighted interpolated surface grid as well as isolines.

$$Ze = \sum_{i=1}^{i=n} Z_i \times W_i \times R_i \qquad \text{(i)}$$

where:

Z_i = the sample value at point X_i
R_i = the distance X_e - X_i within defined radius
X_e= the estimated point (x_e , y_e) with estimated value Z_e
n = the number of data samples in defined radius
W = weight function

$$W_i = \frac{P^{1/R_i}}{\sum_{i=1}^{i=n} P^{1/R_i}} \qquad \text{(ii)}$$

Where:

P = the power of exponentiation
Source: [15]

2.4 Cumulative Risk Evaluation

Through advanced techniques of virtual realities in the form of GIS functions and outputs, handling of maps, measurement and calculation even up to more than 10^{th} digit of decimal precision value is possible [16]. Map algebra provides a way to create mathematical and statistical operations that compare grid themes. In this regard collected data have been converted into interpolated grids for carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO_2), surface ozone (O_3) and total

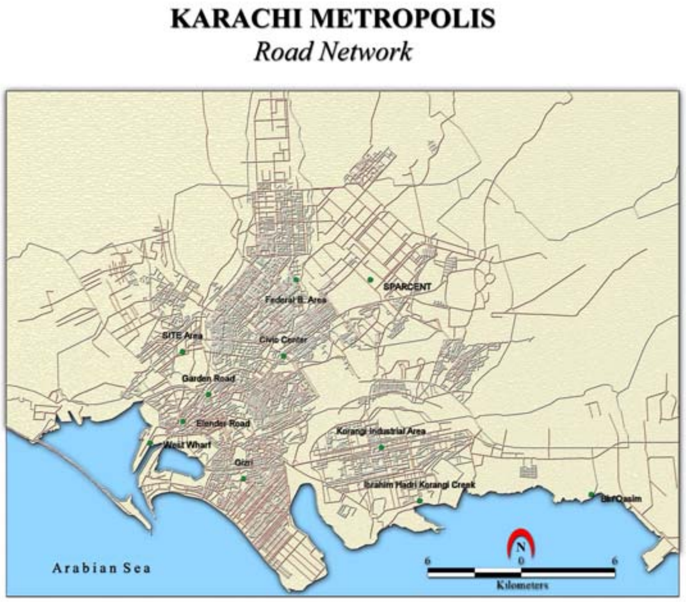


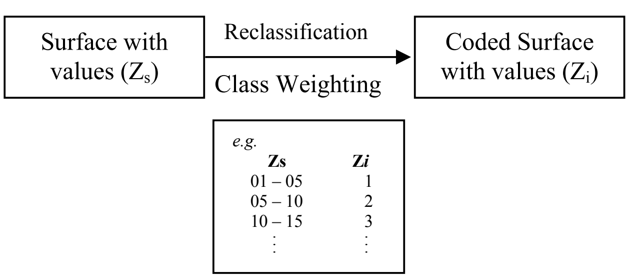
Figure 2

Table 1: Air Pollution Assessment in the Karachi Metropolis (1999)

Site	SO_2 (ppb)		NOx (ppb)		O_3 (ppb)		CO (ppm)		TSP ($\mu g/m^3$)	Fine < 10 µm ($\mu g/m^3$)
	Max	Mean	Max	Mean	Max	Mean	Max	Mean		
Civic Center	1.7	1.3	36	17.0	13	10.6	6.9	6.5	233	195
Garden Road	1.3	1.3	25	16.0	14	12.0	7	6.8	254	200
Elender Road	1.5	1.3	37	22.5	17	13.6	7.5	7.0	263	193
West Wharf	1.4	1.3	14	10.7	18	12.5	7.0	6.8	238	216
SITE	2.6	1.6	37	26.5	14	12.3	7.2	7.0	222	205
Korangi Industrial Area	1.5	1.3	44	22.6	15	13.4	7.1	6.7	318	238
Ibrahim Hadri Korangi Creek	1.3	1.2	12	09.5	16	12.8	7.1	7.0	261	238
Gizri	1.2	1.2	19	14.0	15	12.4	6.8	6.5	214	179
F. B. Area	1.2	1.1	18	14.5	16.5	13.0	7.1	6.5	290	248
Bin Qasim	8.0	5.0	23	15.0	-	-	-	-	307	-
SPARCENT	1.0	1.0	12	08.0	15	12.4	5.5	4.5	225	190

Source: [4]

suspended particulate. These grids were further modeled to view the cumulative impacts of air pollution in various areas of Karachi metropolis by the following function:



$$\text{Cumulative Risk} = \sum_{i=1}^{i=n} Zi \qquad \text{(iii)}$$

3. RESULTS AND DISCUSSION

Karachi was ranked as one of the worst third world cities [17] even among top ten [18] with very high air born lead levels. Atmospheric pollution in Karachi was 40 percent higher than other cities of Pakistan that was on alarming stage.

One lac fifty nine thousand and thirty rickshaws (Table 2) are generally blamed for creating multidimensional environmental problem in which air pollution is leading. Experts have observed that Karachi city vehicles emit 1,813 tons of smoke daily, which cause whooping cough, asthma and nervous disorders [19].

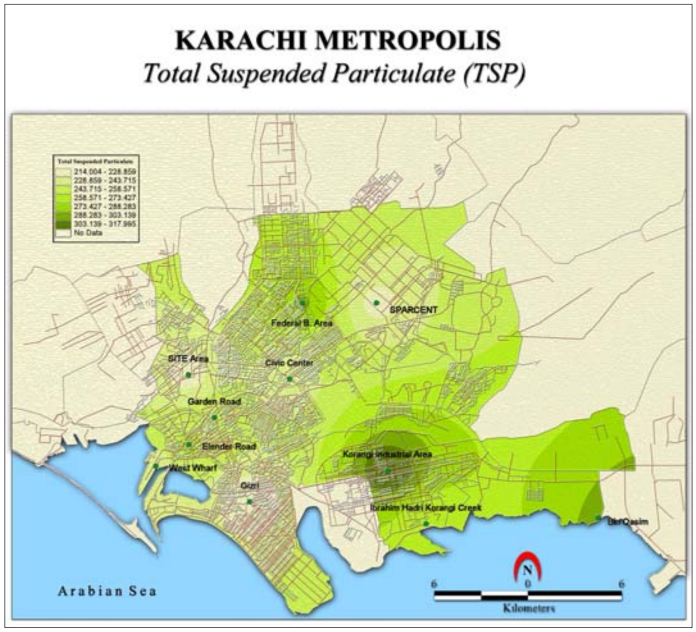


Figure 3

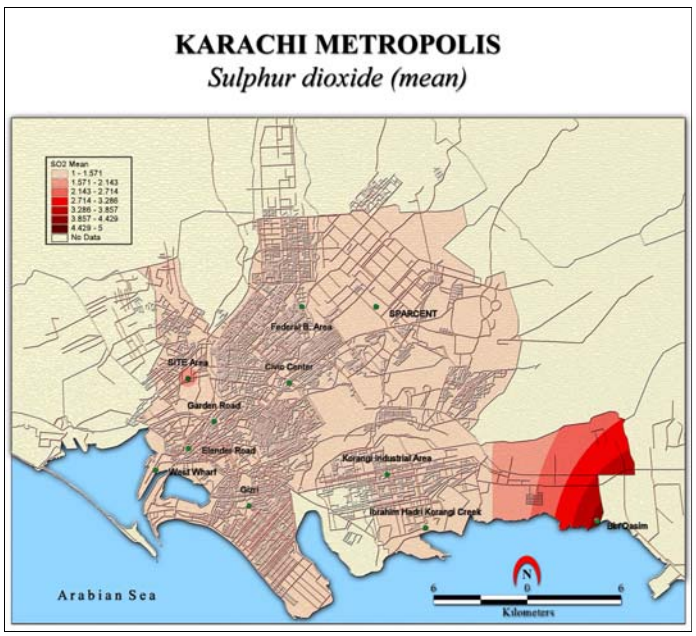


Figure 4

The aerosol contents of the atmosphere are sensitive to the location of local sources and meteorological conditions. Human-induced particle emissions result from sources such as cars, trucks, steel mills, cement plants, ceramic industries, construction dust and waste incineration. The fine fraction of the suspended particles PM_{10} in an urban area is combustion product of I-C engines (vehicles).

The interpolated surfaces of total suspended particulate concentration all over the sampling area are shown in Figure 3. Localities where TSP concentration of the order of 214 ~ 318 µg/m3 were Gizri, SITE, Civic Center, West Wharf, Garden Rd., Elender Rd., and Federal B. Area. On the average 10 to 20 % of the total suspended particulate were found to be PM_{10} in the study

Table 2: Estimated pollution levels from different modes of transport

Types of vehicles	Consumption (%)	Total Vehicles	TSP Kg / 1000 Km	SO_2	NOx	CO
Light duty (Cars)	39.6	368280	3403	825	32998	412480
Motorcycles/ Scooters	31.9	296670	593	59	208	50439
Rickshaws	17.1	159030	5248	1272	50890	636120
Diesel powered Buses / Trucks	9.3	86490	6487	12974	181629	109842
Others	2.1	19530	440	381	967	1075

Source: [4]

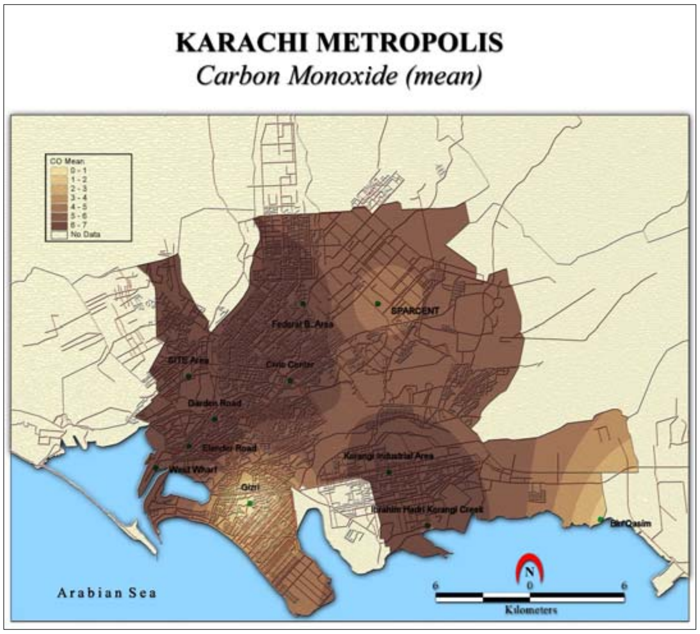


Figure 5

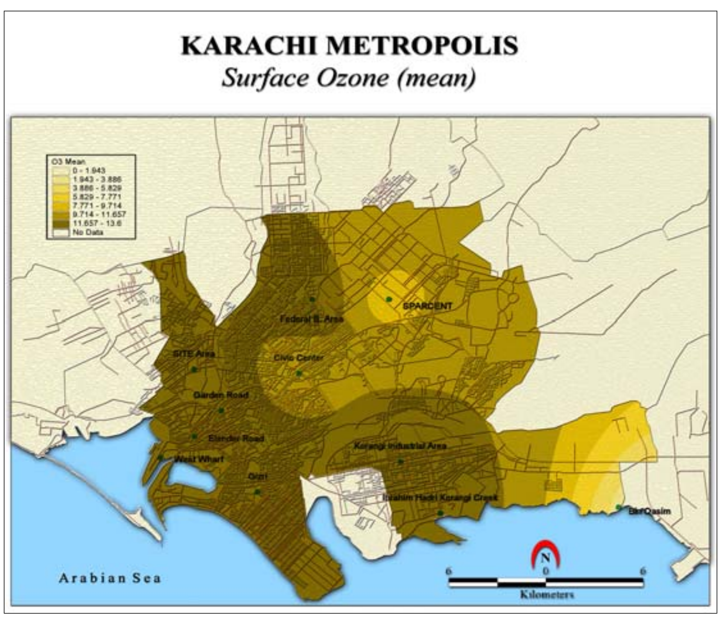


Figure 6

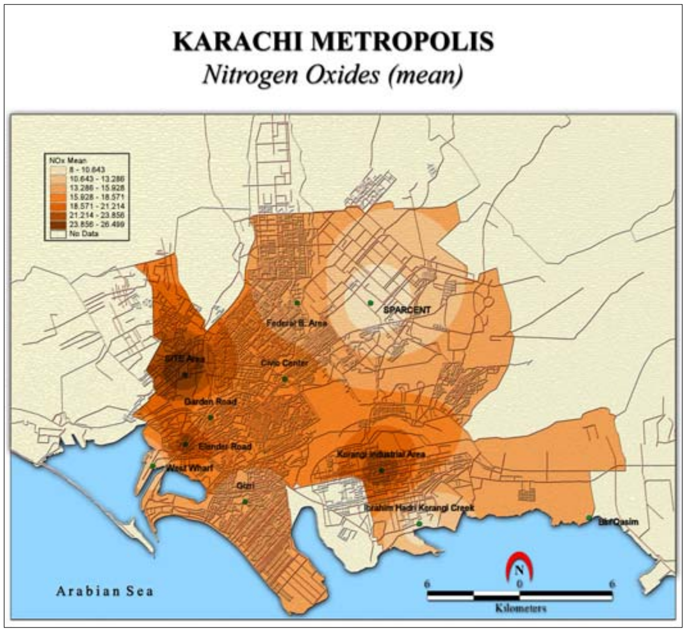


Figure 7

area. High concentrations of PM_{10} are indicative of high density of vehicular traffic. TSP concentrations on the average have been found within permissible limit described by US-EPA, except vicinity of Korangi Industrial Area, Federal B. Area and Elender Road.

Figure 4 is the locational variation of average concentrations of sulphur dioxide in ambient air within the sampling area. The industrial activity at Bin Qasim has emerged out as the prime contributor of sulphur dioxide emissions in the metropolis as a result of KESC thermal power plant and Pakistan Steel Mills. Since this pollutant is induced by the location of industries, in figure 4, the Sindh Industrial Trading Estate (SITE) is arising as the second major risk zone in the metropolis.

Carbon monoxide is a vehicular traffic induced air pollutant, which reacts with the oxygen in the atmosphere yielding oxides of carbon. The highest mean concentration of CO is due to the readings taken at Elender Road off I.I. Chundrigar Road, the famous business area Figure 5. It is anticipated that if the traffic flow data were correlated with these results in future, many exiting similarities would prop up.

Surface ozone concentration relates directly to nitrogen oxides and hydrocarbon, which means that it has some linkage with vehicular traffic, refuse burning, sunshine and wind direction. This analysis Figure 6 is providing a new GIS based risk zone concept of interpolated ozone surface. The regional affects on the inhabitant population could in future be monitored if spatially referenced epidemiological data on eye irritation and asthma cases be compared simultaneously. The affected areas comprise the core city center, industrial areas and residential areas. However, the Cantonment areas are well safe of ozone.

The interpolated surface of average NO_x concentration all over the sampling area is shown in Figure 7. It is evident that regions where risk is higher are the vicinities of Korangi, SITE, and Elender/I. I. Chundrigar Road. The reasons for higher concentration are the vicinity of industrial activities especially the thermal power generation and the heavy traffic volume spots. The residents and commuters of these regions are vulnerable to eye diseases, and broncriolitis pneumonitis.

Among the many environmental degradation processes that continue in Karachi, air pollution is of the major concern, which is affecting localities. The pollutants are being discharged into the atmosphere from a number of sources but the vehicular traffic and the industries are major contributors. Due to low average vehicle speeds, traffic jams and large number of traffic signals and high-rise buildings now coming up across the narrow roads, the air pollution has crossed permissible levels.

As discussed earlier the GIS techniques of data integration and surface interpolation have proven to be effective environmental investigation tools. Now, by merging grid layers through algebraic functions, cumulative intensity assessment can be carried out to portray the overall scenario of air pollution in the Karachi Metropolis. See Figure 8.

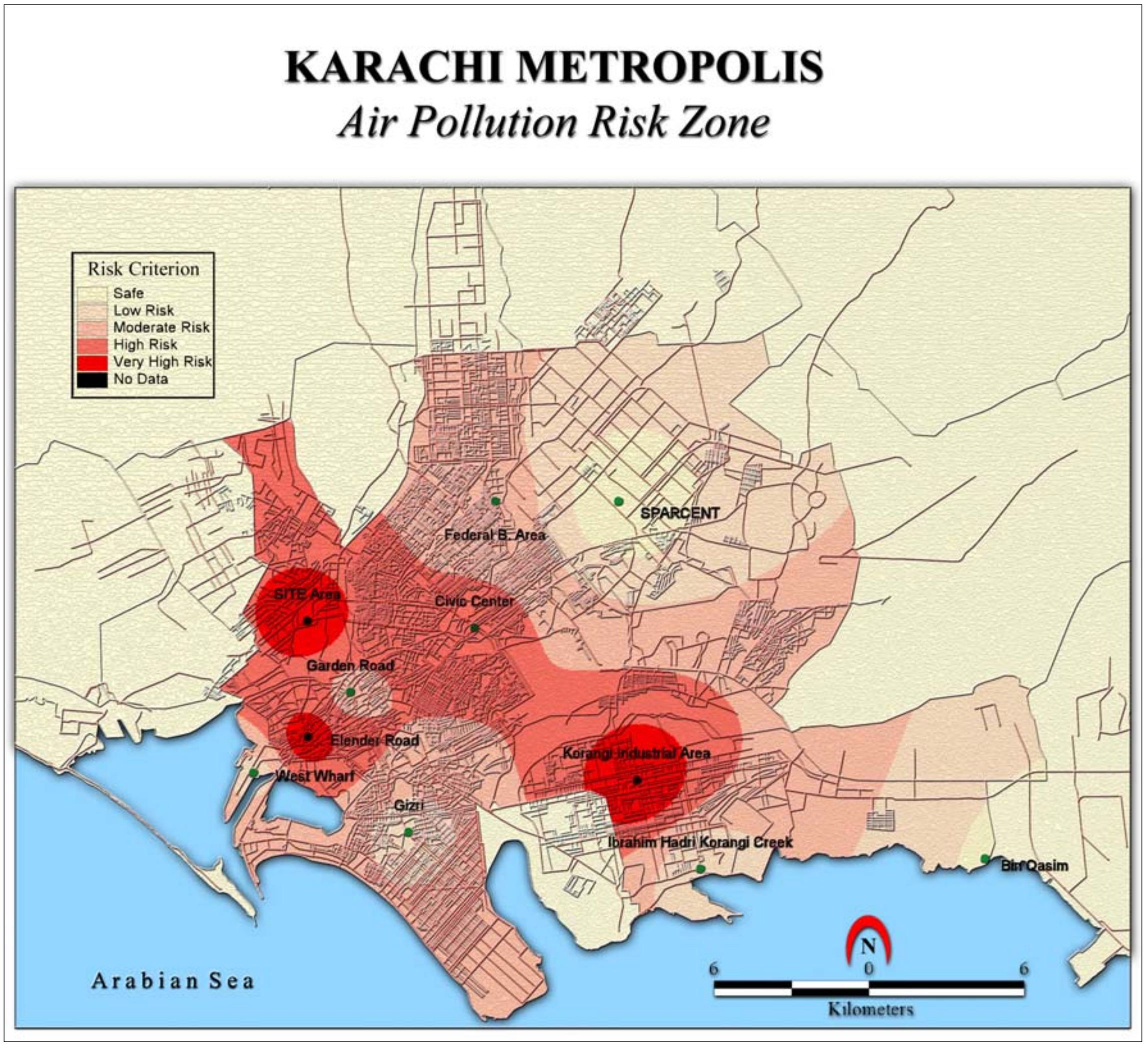


Figure 8

From a geographical point of view, it is demonstrated in Figure 8, that the densely built-up localities of old city area (District South), Landhi Korangi industrial/residential area (District East), and SITE Industrial region (District West) are under high risks attributed to air pollution, on an aggregate level.

The effective use of Geographic Information System for exploration of spatial patterns and risk evaluation of air pollution over the large metropolis has been established. High traffic volumes and industrial activities especially thermal power generation have been identified as the major sources of pollution in this mega populous city. The densely built-up localities of old city area (District South), Landhi Korangi industrial/residential area (District East), and SITE Industrial region (District West) are under high risks attributed to air pollution, on an aggregate level.

It is recommended that a comprehensive study on micro geographic scale, with substantially large sample size to modulate the information pertaining to Karachi's air quality and its adverse affects on human health is the dire need. Such a study e.g. [20] would facilitate in devising the remedial measures countering air pollution.

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