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Introduction and Application of New GIS_AQI Model: Integrated Pollution Control in Tehran

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ABSTRACT: The city of Tehran undergoes an increasing growth in population as well as industrial activities, both of which increase the concentration of air pollutants. The current research tries to turn a limited and focused system of air contamination measurement and control to an unlimited and extensive one that examines the concentration of each of the contaminants in any area of Tehran. Accordingly, information from twenty air-pollution measurement stations at certain points of the city helps measuring the concentrations of contaminants like SO2, NO2, CO, O3, PM2.5, and PM10 throughout a year on a daily basis. The index of AQI has also been used as the air quality index to determine the level of pollution in the city. Using ARC-GIS software, the AQI or the air quality index has been zoned and a comprehensive map, designed. Moreover, in order to illustrate this map, a map of the zoning has been drawn up for this purpose on December, 26, 2016, considered an unhealthy day in Tehran, the results of which show that only 27.8% of the city is unhealthy and the rest of the city does not fall in unhealthy area. However, due to the lack of a comprehensive map for determining the AQI in different parts of the city, the whole city closes down, leading in an economic loss of about $ 1 million a day for the city.

Keywords: Air pollution modeling, Monitoring system, Air pollution management.

INTRODUCTION

Currently, air quality has emerged as one of the most influential parameters of human life, especially in densely-populated and industrialized areas. In order to prevent pollution in the long run, pollution control is essential. In this way, by training people or restricting the traffic and industries, preventive measures should be made to assist the community health, reduce the need for hospital treatment, and even prevent early death, thus avoiding adverse socio-economic impacts on community (Huang et al., 2015; Li et al., 2018; Hosseini and Shahbazi, 2016). The information from air pollution forecasting can be used to alert citizens about the emergence of air pollution and facilitate managerial decisions, made by both managers and urban planners (Pendlebury et al., 2018; Abbaspour et al., 2011). As Iran's capital, Tehran is one of the most polluted cities in the world with a population of 12.4 million citizens, 8.4 million of whom live in the main urban area of Tehran. Therefore, for the sake of people's health in this city and in order to control pollution, one must accurately measure pollution, itself, at first and future predictions should be made. Therefore, several indicators are used to measure the air pollution, the most commonly one being

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AQI. It has been employed as the main indicator of air pollution since 1999 by supplementing the particle size to above 2.5 microns while fine-tuning its previous range of indices such as PSI which classifies air into five main categories, namely good, moderate, unhealthy, very unhealthy, and hazardous. AQI, however, adds a new category called unhealthy for sensitive groups and gains a remarkable advantage over its past indexes (García et al., 2009). There have been numerous studies in recent years on the benefits of AQI index (e.g. Lanzafame et al., 2015; Pant et al., 2016; Ruggieri and Plaia, 2012; Kumar and Goyal, 2011; Trippetta et al., 2013; Zhang et al., 2016). In this regard, the GIS system is considered a powerful tool for designing and creating air pollution database (Greene et al., 2011). A computer system, comprised of software, hardware, and manpower, this system's task is to process, manage, and analyze spatial information, while it is able to store, collect, and display geographic information (Ansari et al., 2015). By collecting and integrating common database data, this technology provides illustrations and geographic information analyses for drawing maps, used to make the results clearer and more predictable (Al-hanbali et al., 2011; Sumiani et al., 2009; wingle et al., 1999; Ghanghermeh et al., 2017). The history of GIS system dates back to mid-1960s in the United States which in the 1970s, with the advancement of technology and availability of computer technology, it also gained the power of analyzing large volumes of geographic data (Babanezhad et al., 2018). Previous studies that predicted air pollution situation via GIS are as follows:

In 2006, an air quality database was developed in India, based on which AQMS air quality management was designed. The study also examined the role of GIS in continuation of air quality improvement, showing that this technique was very suitable for air quality management in case of the five inputs (Ebrahimi ghadi et al., 2019).

In 2007, other studies in the United States were conducted to develop a technique based on the initial tools for assessment of air quality via GIS system. (Mauroulidou et al., 2007)

Another study in Thailand in 2006 addressed a combination of air pollutant measurement sensors, explained the data analysis method by GIS software, and dealt with the status of Bangkok's air pollution as well as the implementation of GIS plans for prediction and management of air pollution in the city (Pummakarnchona et al., 2005).

On the whole, GIS technique is used to manage urban crises, risk management, and urban planning. Researches on natural disasters like floods and earthquakes are samples of this kind. (Ebrahimian-Ghajari et al., 2016; Fernandez et al., 2016; Hashemi and Alesheikh, 2011). The purpose of this study is to investigate the effect of each of SO2, NO2, CO, O3, PM2.5, and PM10 contaminants on air quality in different regions of Tehran. It also aims at analyzing the concentration of the six contaminants, using the GIS technique, monitored at 20 stations in Tehran on a daily basis in 2016, to ultimately design a comprehensive map of the concentration of various contaminants in Tehran, so that each of the arbitrary points within the map will display the concentration of the six contaminants and evaluate their AQI.

MATERIALS AND METHODS

As the capital of Iran with an area of over 730 square kilometers, Tehran is one of the most polluted cities in Iran and the world, being surrounded by Alborz mountain range in both of its Northern and Eastern sides. Many fixed and moving resources affect the increase of air pollutants such as SO2, NO2, CO, O3, PM2.5, and PM10. The number of these pollutants in this metropolis increase due to population growth, traffic, and the presence of various industries. As a result, it is necessary to install measuring and application tools for statistical analysis and evaluation in order to provide a robust management system for pollution reduction and control. The pollutants mentioned are essential. Figure 1 illustrates the location of Tehran on the map.

Tehran has 20 air pollution monitoring station in which either all or some of SO2, NO2, CO, O3, PM2.5, and PM10 pollutants are constantly measured. The results are transmitted daily to Tehran Air Pollution Control Center. Since 2010, due to the presence of particles in this city, the status of suspended particles smaller than 2.5 microns has been also examined. The results are announced on the basis of AQI. Table 1 shows the average concentration of each pollutant in each station.

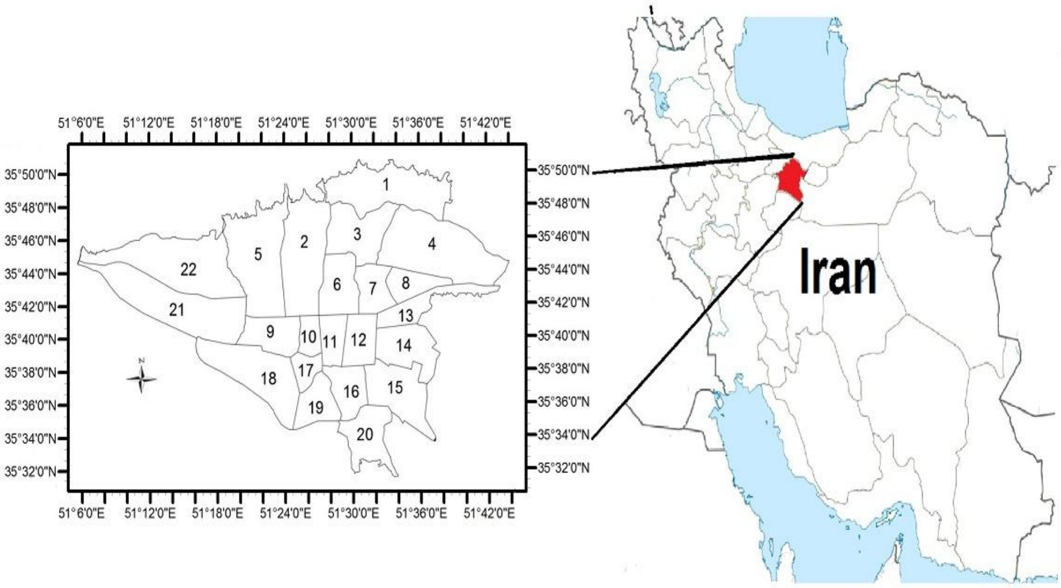

Fig. 1. Location of Tehran and its 22 areas

Table 1. Air pollution monitoring stations

	SO2(ppb)	NO2(ppb)	O3(ppb)	CO(ppm)	PM10(μg/m^3)	PM2.5(μg/m^3)
Station 1	9.83	45	19.42	21.73	76.36	69.89
Station 2	9.67	76.7	70.72	31.27	73.92	45.58
Station 3	9.58	68	52.62	28.73	73.63	52.67
Station 4	6.16	95.37	43.9	34.39	68.02	56.16
Station 5	12.79	54.34	44.8	28.35	74.66	68.4
Station 6	12.68	49.68	44.13	37.97	95.89	68.95
Station 7	10.95	64.56	42.21	39.61	96.32	62.87
Station 8	9.5	94.79	43.69	47.78	102.31	57.95
Station 9	13.46	26.66	37.67	20.67	105	75.86
Station 10	11.84	63.93	21.95	26.34	107.45	66.42
Station 11	19.25	63.24	17.76	38.26	101.27	65.75
Station 12	9.48	66.56	40.93	36.79	69.65	44.64
Station 13	11.86	91.74	33.8	50.25	106.71	68.23
Station 14	24.47	101.23	35.24	42.44	90.87	58.36
Station 15	13.18	110.23	60.75	35.57	102.62	24.8
Station 16	22.11	102.03	37.67	69.18	78.56	62.25
Station 17	14.01	75.08	25.66	34.35	86.33	58.08
Station 18	23.27	76.51	45.84	20.68	88.3	75.28
Station 19	11.3	110.67	30.08	64.89	74.4	72.53
Station 20	9.41	24.87	43.62	30.62	64.94	64.45

Table 2. Different levels of AQI index

Air Quality Index (AQI) Values	Levels of Health Concern	Colors	
0 to 50	Good	Green	
51 to 100	Moderate	Yellow	
101 to 150	Unhealthy for Sensitive Groups	Orange	
151 to 200	Unhealthy	Red	
201 to 300	Very Unhealthy	Purple	
301 to 500	Hazardous	Maroon	

Air Quality Index is an indicator of air pollution quality on a daily basis, which informs people about the air quality. This indicator uses concentration of air pollutants such as SO2, NO2, CO, O3, PM2.5, and PM10, as well as suspended particles, which has a different limit compared to the various units, turning them into a unitless number, displaying the state of air quality in six qualitative modes of good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous. Table 2 shows the different levels of AQI index for various contaminants. It should be noted that for easy use of the various strata of the community, each of the 6 AQI levels are reported to the general public with a certain color.

The formula for air quality index calculation depends on air pollution data along with the pollutant type. The AQI can be calculated from Formula 1, below, based on the pollution data:

$$AQI = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \qquad (1)$$

where,
AQI: Air Quality Index,
C: The amount of air pollutant
C_{low}: Lower limit of the pollutants in the C domain
C_{high}: Lower limit of the pollutants in the C domain
I_{low}: Lower limit of AQI corresponding to C_{low}
C_{high}: Higher limit of AQI corresponding to C_{high}

GIS was first introduced and expanded in Canada in early 1960s. A collecting, storing, controlling, retrieving, updating, integrating, processing, analyzing, and modeling tool, which represents various geographic data, the system is consisted of five components of hardware, software, geospatial data, manpower, and information processing models. It also includes four data sub-categories, including data input, data storage and retrieval, data processing, and data analysis, providing output information. Figure 2 demonstrates a schematic representation of GIS sub-system and how they are communicated.

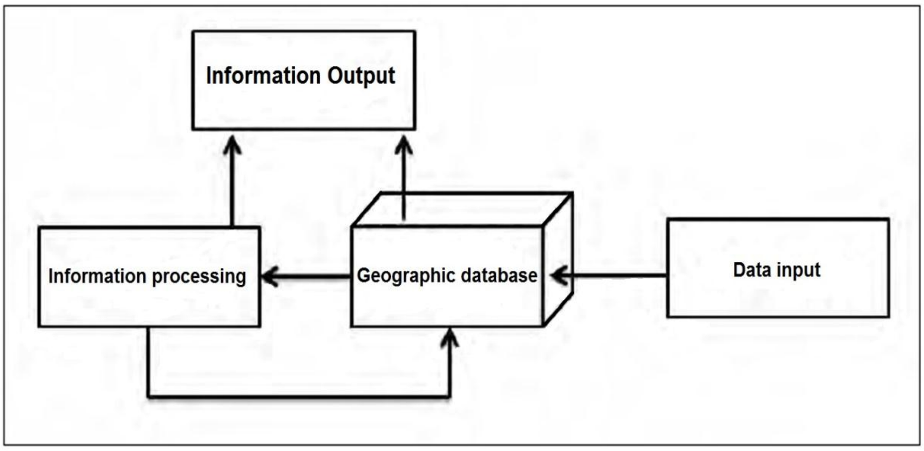

Fig. 2. The overall performance of GIS System

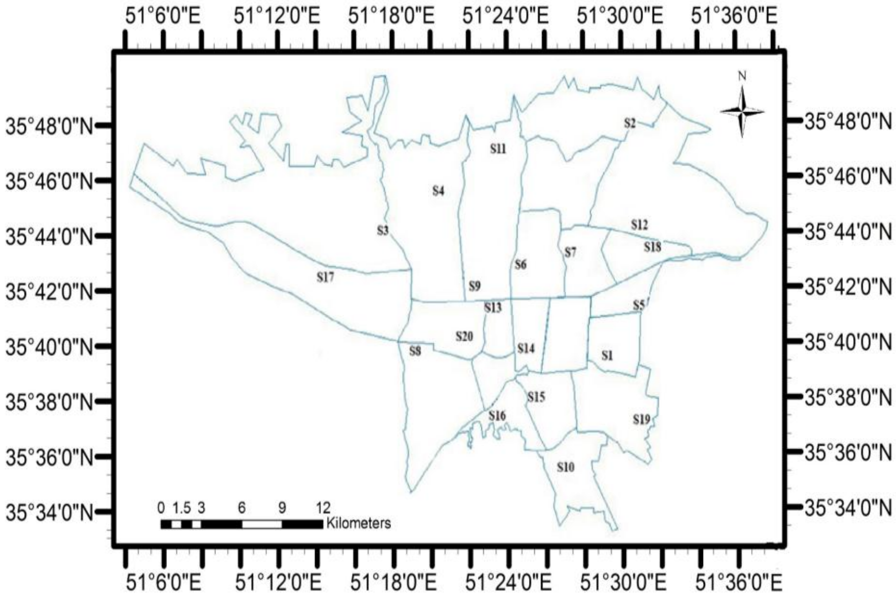

Fig. 3. Location of air pollution measurement stations

What distinguishes GIS from mapping is its analytic capability, which allows geospatial and descriptive data to be combined and tailored for specific purposes. The tools of this system can be computer programs that extract descriptive data in databases, mapping them to graphical effects on a map. Topological modeling, neighborhood, topography, continuity, network proximity, and overlapping are the most important analytical functions of GIS. Based on the abovementioned capabilities, it can be used to solve problems such as resource allocation, display and understanding of spatial and temporal distribution of phenomena, analysis of the relationship between the variables and phenomena, and classification and distinction of places, not to mention planning and management of natural and socioeconomic resources. GIS is the basic computer system for spatial data; therefore, it plays an outstanding role in research on this subject, since air pollution occurs at a location.

The present study investigated six hazardous pollutants such as SO2, NO2, CO, O3, PM2.5, and PM10 in Tehran. The pollutants were collected on a daily basis from one of the twenty pollutant monitoring stations in Tehran each year. After analyzing the statistical data in Excel, the geographic location of the stations was determined in accordance with UTM system, being pictured in Tehran map based on Figure 3 which Figure represents the highest density of stations in the center of Tehran as the most polluted section of the city.

RESULTS AND DISCUSSIONS

In order to model air pollution through calculation of air pollution index AQI, the daily data on 6 pollutants of SO2, NO2, CO, O3, PM2.5, and PM10 has been used, forming the basis for calculation of this index. The data have been obtained from twenty pollutant measurement stations, located in Tehran. In order to control the sum of pollution in Tehran map, the amount of each pollutant must be first implemented at its own station. Afterwards, using the Arc GIS 10.3 software, these stations should get zoned. The spatial analysis and mapping of the above-mentioned contaminants' zone was done, using ArcGIS software distributed by ESRI Company and the Ordinary Kriging (OK) interpolation tool. This regression-based interpolation method is to assign weight not only to the distance between the points but also to the correlation between the measured ones (Shad et al., 2009; Diodato and Ceccarelli, 2004). Considering that the Kriging method is a geo-statistical estimation one, based on the weighted moving average, it can be regarded as the best linear unbiased estimator (Qaderi et al., 2018; Peng et al., 2014; Liu et al., 2015). This kind of Kriging is called linear Kriging because it is the linear combination of n data, and the condition for using this estimator is the normal distribution of contaminants' concentration. Otherwise, either nonlinear Kriging should be used or the distribution of the variables should be converted to normal. The present research used the linear method.

For this purpose, the study collected qualitative information on six pollutants and considered the output of the Excel file as input data for Arc GIS 10.3 software. Each of the air pollution monitoring stations had a geographic coordinate based on UTM as well as daily concentration of each of the six air pollution parameters. With the institutionalization of the stations' coordinates, the study area was enclosed within an area of 730 square kilometers. Then, for each of the air pollution parameters, separate shape files were created, each to get converted to a TIN file so as to provide the data transfer conditions to the RASTER mode, being a continuous form. Finally, by use of the VECTOR files and joining them, all parameters of air pollution at any point in Tehran got determined in a way that by selecting any point in the study area, the air pollution quality of that point determined each of the six parameters of air pollution.

The research measured the average of SO2, NO2, CO, O3, PM2.5, and PM10 along with their AQI index over a year period. The measurements were then calculated and recalled by Arc GIS software. Figure 4 gives the results of the dispersion state of each of these pollutants. Figure 4.A represents the dispersion map of CO in Tehran. In the North and Northeast of Tehran, CO concentrations were higher. Since Tehran is surrounded by north and east by the Central Alborz mountain range of Iran, most of the wind enters the city from the south, or the central plains of Iran, moving northwards. On the other hand, the factor that leads to CO production is fuel consumption from transportation and traffic, with the latter often taking place in the center of Tehran. As a result, the CO, produced in the city center, moves northward with the wind, there to be prevented by the mountains from getting dispersed, thus observing the accumulation of this pollutant north of the city.

Figure 4b shows the distribution of NO2 in the city. This map often indicates the concentration of this pollutant in the center and north of this city due to heavy traffic load in the former and transference of the pollutant to the latter where it is accumulated due to the Northern mountains.

Figure 4c shows the dispersion of SO2 in Tehran, indicating that the majority of pollutant concentrations belong to the southern and southwestern part of the city. Most industries and factories in the city are located south thanks to the low economic value of the land, there. The main factors that produce SO2 include factories, industries, and diesel consumption by heavy vehicles.

Figure 4d shows the dispersion of O3 in Tehran. This pollutant does not enter the air directly, but is produced by chemical reactions between NOx and volatile organic compounds (VOCs) in the presence of sunlight. Thus, ozone is mostly seen during the summer and at noon. The dispersal of this pollutant is chiefly in the city center where the traffic jam is the heaviest as well as the eastern part of the city, in which the main busy highways are located.

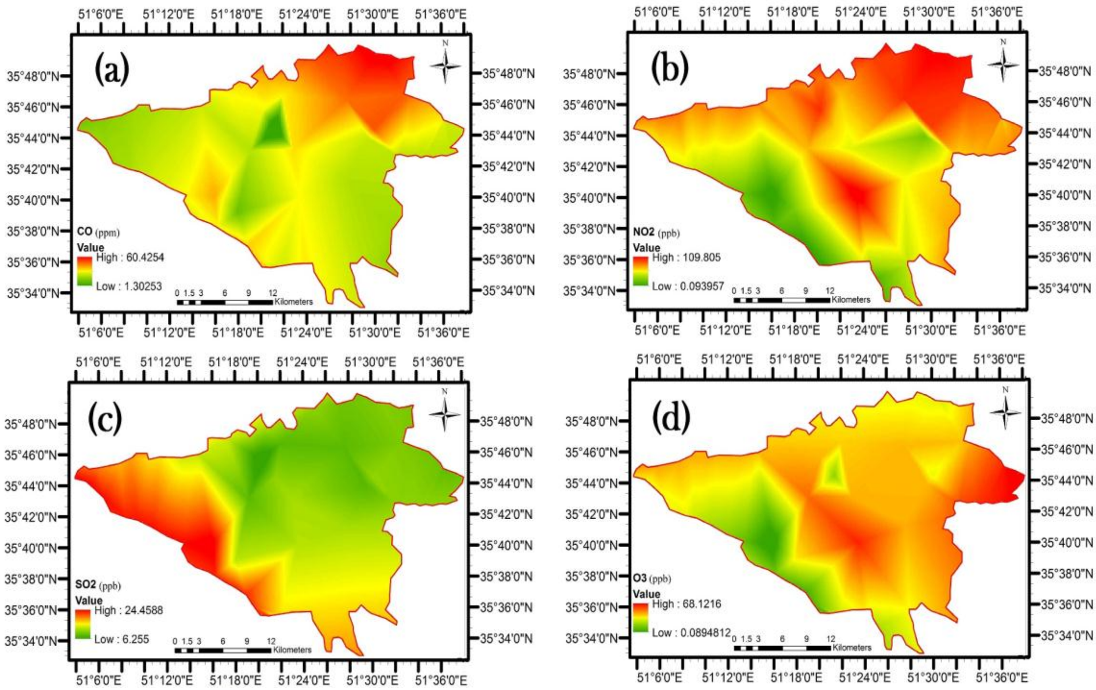

Fig. 4. Dispersion of concentrations of (a) Co, (b) NO2, (C) SO2, and (d) O3

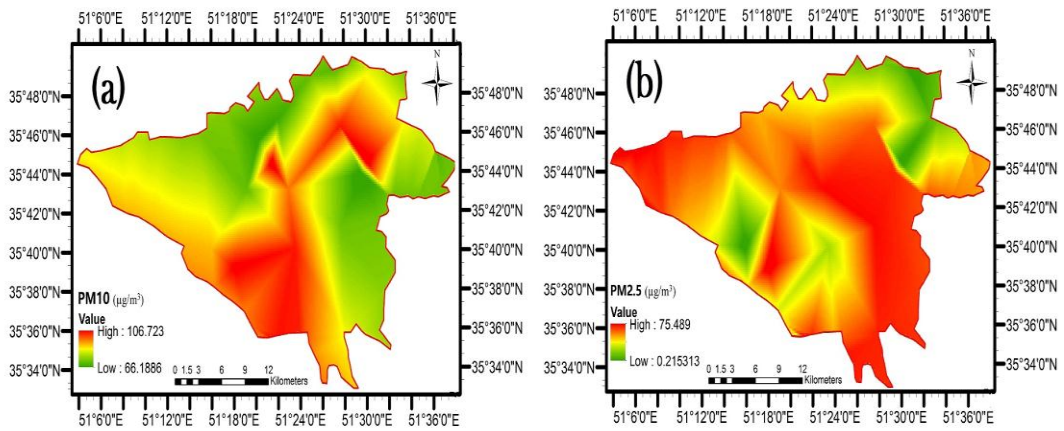

Fig. 5. Dispersion of (a) PM10, and (b) PM2.5 concentrations

Figure 5 shows the distribution map of PM10 and PM2.5 contaminants, which having particles below 2.5 microns and 10 microns, are the result of processes wherein fossil fuels such as oil, gas, and coal are burned. Dispersal of these pollutants in Tehran occurs in densely-populated areas with high urban density, and the concentration of this pollutant increases. Moreover, in the southern and southeastern parts of the country, close to central plains of Iran, the concentration of these pollutants increases as a result of significant number of industries and factories, the desert dust, and burning fossil fuels, not to mention agricultural fields.

Figure 6 summarizes the AQI dispersion map for these six pollutants during 2016, reporting that the concentration of pollutants increases in the city center due to urban traffic and urban congestion, along with the southern part of the city thanks to the presence of factories.

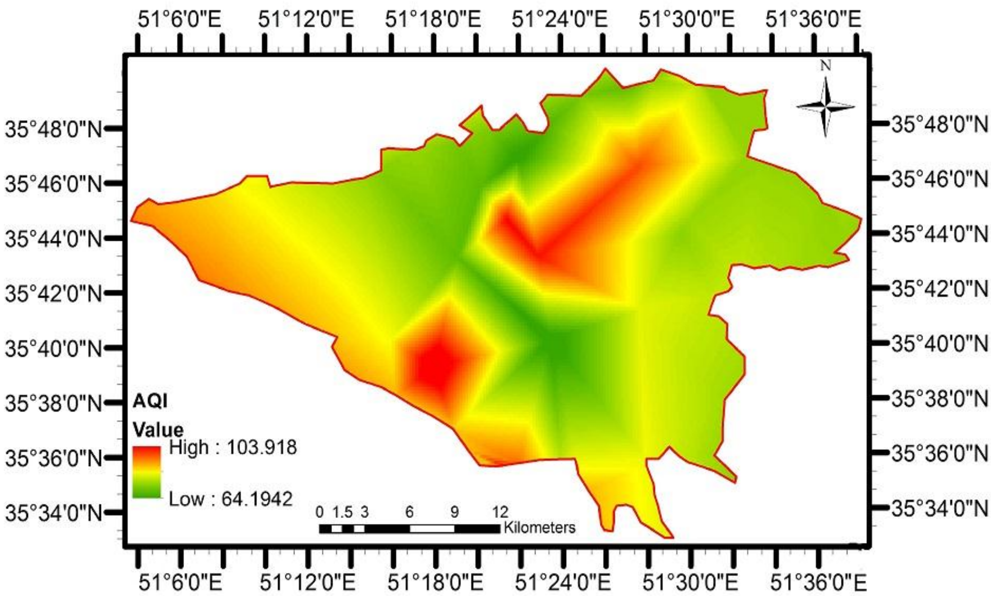

Fig. 6. Distribution of AQI in Tehran

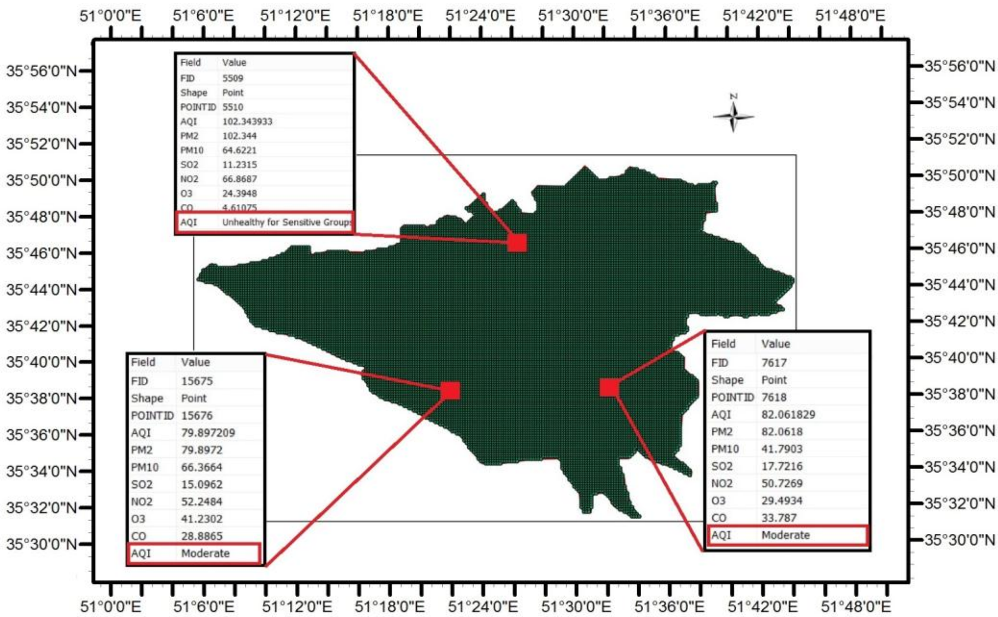

Fig. 7. Comprehensive map of pollutants' dispersion

Investigation of air quality in Tehran due to the lack of a comprehensive and continuous map, covering the whole city with proper distribution, has always been a problem for researchers and managers of air pollution control in the city. However, the air pollution crisis, especially in recent years has intensified the necessity of studies in this regard, making the present study to design a comprehensive map to control Tehran's air pollution. Figure 7 represents a comprehensive map of Tehran, wherein each point indicates the concentrations of SO2, NO2, CO, O3, PM2.5, and PM10 contaminants. It evaluates them in terms of AQI, determining which point in the city has a critical condition for the community due to air pollution.

One of the most important points in this way is to reduce the level of control. Since the total area of Tehran is estimated to be about 730 square kilometers, with only twenty pollution measurement stations operating in the city, it can be said that on average, the output information from each station covers an area of 37 square kilometers. In other words, for every 37 square kilometers, there is a set of data for air quality measurement. Considering that Tehran is divided into 22 separate regions, and assuming that each of these areas can be assigned to a measuring station, the hypothetical range can be displayed as the map in Figure 8. However, by means of the new GIS method in this research, the number of quality measurement stations increased from 20 stations to 18153 stations. In this case, the average covered area for each station reduced to about 40,000 square meters (0.04 square kilometers), i.e., about 1000 times more accurate than the previous one. For a better understanding of this point, Figure 8 magnifies only one region, considered as a unit in the whole region, itself split through implementation of GIS method into smaller ranges.

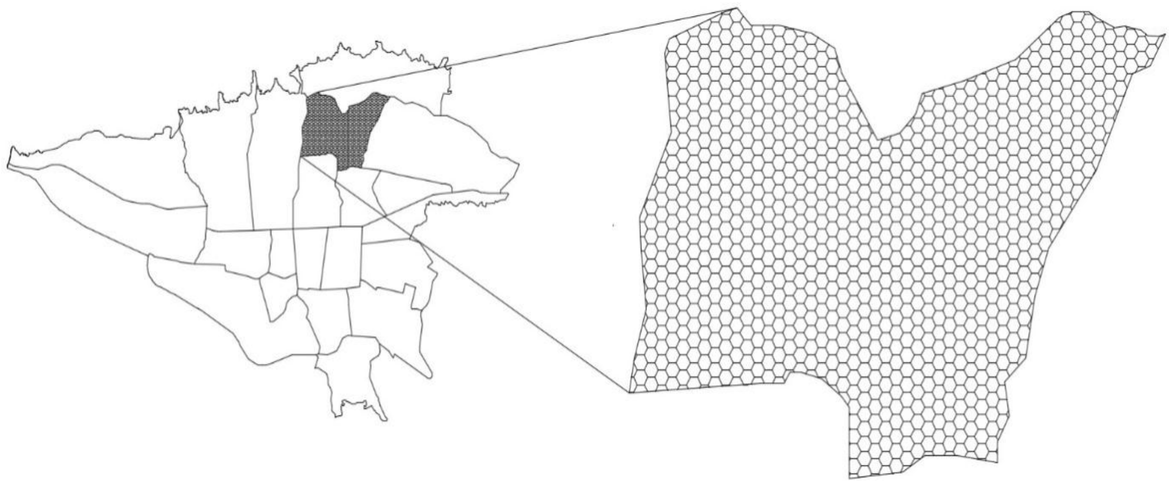

Fig. 8. Change in the control area in the city of Tehran

Determining the actual concentration of pollutants and describing the air quality status in comparison with the standard situations as well as providing a simple, fast, and accurate body of information to people significantly affects them take precautionary and preventive measures for cases where air pollution exceeds the standard amount. Therefore, in order to manage the quality of Tehran's air pollution, the lack of a comprehensive map which enables checking every single point in Tehran causes the majority of the air pollution stations to announce the whole city as unhealthy and in need of closing down. However, as explained in Table 3, the present study used a comprehensive map for a sample unhealthy day in this city. It evaluated the AIQ index on 26.12.2016 and showed that among the 20 air quality control stations, there were only seven unhealthy and six unhealthy for sensitive groups stations. According to the zoning map No. 9 designed for this day, it can be observed that the air quality was unhealthy and the air pollution exceeded the standard amount only in the center of the city due to traffic and high population. However, the rest of Tehran was only unhealthy for sensitive groups. Thus, only 27.8% of the city was unhealthy, while 69.8% was unhealthy for sensitive groups and 2.4%, moderate. In terms of urban management, the map shows that it is unnecessary to declare that the entire city should be closed down due to critical conditions. It is enough to declare the crisis for certain people and in certain areas.

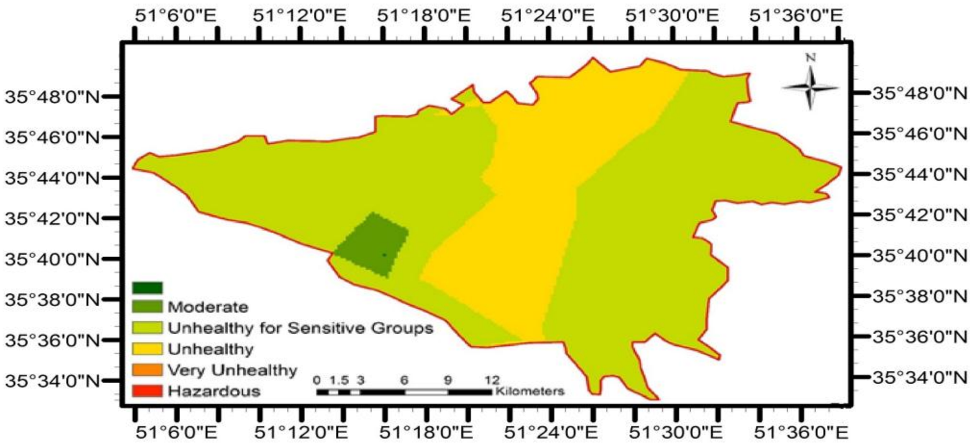

Fig. 9. Pollution zoning on 26.12.2016

Table 3. Pollution situation at different stations in Tehran on 26.12.2016

Station	AQI		
Station 1	115	Unhealthy for Sensitive Groups	✓
Station 2	129	Unhealthy for Sensitive Groups	✓
Station 3	109	Unhealthy for Sensitive Groups	✓
Station 4	136	Unhealthy for Sensitive Groups	✓
Station 5	164	Unhealthy	✓
Station 6	156	Unhealthy	✓
Station 8	159	Unhealthy	✓
Station 9	162	Unhealthy	✓
Station 10	153	Unhealthy	✓
Station 11	168	Unhealthy	✓
Station 12	81	Moderate	✓
Station 14	158	Unhealthy	✓
Station 19	125	Unhealthy for Sensitive Groups	✓
Station 20	117	Unhealthy for Sensitive Groups	✓

From an economic point of view, according to the rules of labor of Iran, the minimum wage per person is about USD 167.00 per month. Taking the population of 500,000 workers in government sectors and sensitive industrial centers of Tehran into account, a one-day closure at all levels will cause an economic loss of USD 8 million for the city. Nonetheless, designing a comprehensive map by means of the new GIS method with the power of pixelation and point to point calculation of pollution in the city showed that about 139,000 people faced unhealthy air quality, about 349,000 people were affected by unhealthy for sensitive groups air quality, and about 12,000 people in the region were only exposed to moderate air quality. Thus, 139,000 people needed to stop working that day, while the rest of the population could have continued working. Using this method, therefore, could reduce the daily loss from USD 8 million to about USD 2 million. This map is an example of applying this research in air pollution management of Tehran.

Crisis management is a science that helps urban managers lower air pollution. In this regard, the study described the amount of unhealthy and healthy days in Tehran. To solve this problem, for the first time, in order to improve the decision-making capability of urban indicators, a comprehensive map of Tehran's air pollution was designed with the model's resolution being based on 40,000-squaremeter pixels in the city. The map pixelation made a significant contribution to calculation of the AQI anywhere in the city, according to which a part of the city that did not show any non-standard AQI ought not to get closed down. This is so, while in the past, due to the absence of a pixelation map in the city, AQI was calculated for the entire city and management was done on that basis. As AQI was calculated in terms of the highest concentrations of the six air pollutants, the total AQI of the city got measured in terms of the pollutant with the highest concentration and the management only decided on pollutants with the highest concentration. The innovation in this research, however, led to the identification of the highest concentrations of each pollutant in each of the pixel locations of the city. For example, a point of the city had the highest concentration of NO2, while another had the highest concentration of CO. Using this map, it is possible to calculate the concentration of the most significant pollutant for every single point in Tehran, and take controlling measures to reduce them, hence having a more effective management. On the other hand, this comprehensive map shows its effectiveness in time of crisis, so that areas with higher pollutant concentrations are detected and control measures are taken from these areas.

Yet, in the past, due to the absence of an integrated map for the entire city and the use of an integrated AQI for the entire city of Tehran, the concentration of any pollutant for every single point of the city could not be calculated. Hence, it was impossible to declare a crisis in the more polluted areas. Another benefit of this comprehensive map is the possibility of its instantaneous updates, making it designed instantly at each time interval by giving an Excel input containing concentrations of pollutants by the air pollution monitoring stations in Tehran, available for air quality control managers of Tehran municipality.

CONCLUSION

Air pollution in urban areas is one of the consequences of the industrial revolution that began 300 years ago and still increases on a daily basis with development and industrialization. Due to this rapid growth and spread of various pollutants by human beings in industrial and urban areas, it is necessary to control and monitor them with methods that are faster and more accurate, while cost less. Therefore, today, the major concern of the urban planners is to control air quality in metropolises such as Tehran precisely. GIS is an appropriate technique for combining different layers and determining their weight and importance for the purpose of zoning, evaluation, and management of air pollution crisis. Therefore, this study was conducted to control air pollution in Tehran by collecting concentrations of SO2, NO2, CO, O3, PM2.5, and PM10 from twenty monitoring stations in Tehran in 2016. Using the ArcGIS software, a comprehensive map of pollution in Tehran was developed. The map was designed to report the concentration of six pollutants in every single point of the city, posing a possible risk to the residents of that area via AQI index. The lack of such a comprehensive map in Tehran has so far caused numerous urban management problems. For example, in Tehran, if most air pollution monitoring stations show the city's air quality as unhealthy, the city managers declare the situation as critical and close down the entire city to maintain the health of the urban community. This research attempts to solve this urban management problem by using a comprehensive pollution control map to investigate the air quality on 26.12.2016, identified as an unhealthy day by all community members. It was concluded that on this day, 27.8% of the area was unhealthy; 69.8%, unhealthy for sensitive groups; and 2.4%, moderate. Thus, there was no need to announce a critical situation and close down the whole city. As a result, this comprehensive map has been designed for the first time in urban management and crisis declaration for Tehran's air, which can contribute to the economy and management of the air pollution crisis in Tehran and other metropolises around the globe.

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