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GIS-assisted Dispersion of SO_2 in the Industrial Regions

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Abstract: Sulfur dioxide is one of the most important pollutants in urban areas which cause respiratory problems and acid rain. The aim of this research is to study the feasibility of using passive diffusive air sampling and GIS technique to determine the dispersion level of SO_2 in the industrialized Zarghan area and assessing the contribution level of generating sources of SO_2 in the urban areas. It is also essential to determine the contribution of other sources and dispersion radius of pollutants in the area as well. In this study, we used passive sampling method to measure the concentration of sulfur dioxide at 10 monitoring stations. Interpolation tools in ArcGIS technique create a continuous surface from measured values to predict SO_2 concentration in other parts of the city. The concentrations of SO_2 around Shiraz oil refinery and Dudej region located at 3 km from the oil refinery were 60 and 19 μg m^{-3}, respectively. In conclusion the results indicated that SO_2 concentration was not exceeded the standard limit in the residential area and the role of the local highway and industrial park was not significant.

Key words: Zarghan, SO_2, passive sampling, GIS technique, interpolation

INTRODUCTION

Sulfur dioxide is one of the most important pollutants in urban areas which cause respiratory problems and acid rain. The available data indicated that short-term exposure to sulfur dioxide is associated with daily mortality (Chen *et al*., 2011, 2012). Maantay reported that people living in industrialized area were more susceptible for asthma (>66%) due to sulfur dioxide (Maantay, 2007).

Previous studies showed that oil refinery is one of the major sources of SO_2 emission (Odat, 2009). Highways have a significant effect on emitting SO_2 in the ambient air (Brugge *et al*., 2007). Industrial parks are also another source of SO_2 in the atmosphere. The size of industry, its distance from the neighboring town and the direction of the wind are important parameters that affect the pollution levels.

To represent the range of geographical distribution of a pollutant, simultaneous air sampling is needed. Although active sampling requires a pump to collect the air sample, passive sampling does not require a pump and gases in the air are collected by diffusion. Passive diffusive air sampling is simple and low cost with high precision widely used to monitor the large-scales air pollution (De Santis *et al*., 2004; Cruz *et al*., 2004).

Geographic Information System (GIS) technique is a powerful tool to assess the contribution levels of SO_2 sources (Matejicek, 2005; Pummakarnchana *et al*., 2005). The comprehensive emission inventory approach showed that industrial sources account for 77% of the total emissions of SO_2. However, dispersion modeling approach demonstrated that more than 50% of SO_2 was emitted from industrial sources (Bhanarkar *et al*., 2005). Luvsan *et al*. (2012) used multiple regression models to predict the effect of climatic conditions on SO_2 concentration. According to their data, the SO_2 concentration increased with the decrease of wind speed, temperature drops or the increase in relative humidity (Luvsan *et al*., 2012). Yim *et al*. (2010) found that the contribution of the power plant located in marine sources regions in Hong Kong is significant during both summer and winter time (Yim *et al*., 2010).

Since the industrial regions of Zarghan (northeast of Shiraz) is affected by numerous air pollution sources, the rapid and precise monitoring systems are absolutely essential to detect and quantify polluting sources. Therefore, the objectives of this study are to (1) Determine the dispersion level of SO_2 using passive diffusive air sampling and GIS technique and (2) Assess the contribution level of generating sources of SO_2 in the urban areas.

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MATERIALS AND METHODS

Locating air pollutant sources in the study area: Zarghan is located 25 km northeast of Shiraz, nearby Shiraz-Tehran highway. The town is also surrounded by many different air pollution sources. Industrial complexes are located about 10 km from Zarghan such as, Shiraz oil refinery, Abbarik industrial park with more than 35 industries, Hafez ceramic industry, Loab Iran industry, Fars and Sina chemical industries. In addition to these industrial complexes, the rocky cliff with a height of 300 m in the east side of the town blocked the air flow through the town.

Determination of SO_2 by diffusive sampler: We used a diffusive sampler to adsorb SO_2 in the air by a tube consisting of adsorbent material. SO_2 entered the adsorbent tube by molecular diffusion. The tube is 20 mm in diameter and made of polypropylene. To reduce the effects of wind and rain, the sampler were fixed into a fiberglass container by a metal clamp as shown in Fig. 1. The adsorbent samplers were installed at the elevation of 3-4 m from the ground. Air sampling was conducted for a period of 17 days in January 2012. After the adsorption period, the sampler tubes were sealed and returned to the laboratory for further analysis.

After collecting the specimens, they were sent to Pasam Company in Switzerland for determination of SO_2. The extraction was done by a mixture of potassium carbonate and glycerin. Ion chromatography was used to analyze SO_2.

SO_2 sample collecting locations: Since many different sources of air pollution are located in the vicinity of the residential area of Zarghan, the boundary conditions sampling points were selected by mesh. The Geographical coordinates, names, and reasons for choosing the sampling points are given in Table 1. Due to the small size of the study area, 10 points were selected and one sample was collected at each point.

Drawing GIS maps: An image of the coverage area was obtained by Google Earth software. Geographical coordinates of 4 points of suitable dispersion were determined by the software and used in an Excel file as the ground reference (Fig. 2).

Using ArcGIS technique, the image was processed as the ground reference and the result saved in TIFF format with a pixel size of 5 m. The data obtained from sampling of SO_2 were interpolated using the passive sampling

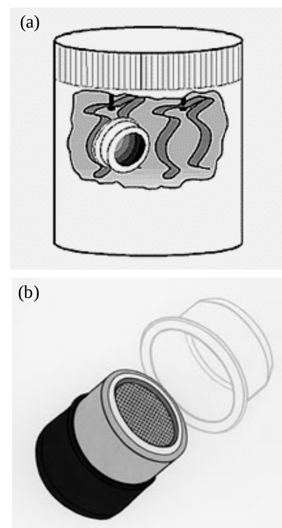

Fig. 1(a-b): Clamp and SO_2 adsorbent sample

The coordinates of the reference points for the image

No	Coordinates X	Coordinates Y
A	657464.42	3291344.04
B	657257.63	3296201.07
C	668805.38	3296600.4
D	670176.94	3291373.34

Fig. 2: Coordinates of the reference points

Table 1: Sampling locations at 10 different stations in the industrial regions of Zarghan, Universal Transverse Mercator (UTM) coordinates and reasons for the selection of that location

Sampling stations	UTM coordinates	Reasons for selection
Municipality	32995362.28 MN 665921.42ME	Municipality location is an appropriate point inside Zarghan residential area in mesh boundary
Basij Sq.	3294970.72 MN 666140.93 ME	This point is a boundary residential location suitable for examining air pollution due to the SO_2 of the highway
Department of education	3295352.39 MN 666550.56ME	This is one of the central points in the town near to a mountain and suitable to examine air inversion effects
Old cemetery	3294683.63 MN 667416.25ME	This point is located at southeast of the town on the border line near to a mountain
Old Central Sq.	3294978.72 MN 666740.94ME	Most of the air pollution in this area is due to heavy terrific jam than the other sources of contamination
The city limit of town	3295906.31MN 666331.92 ME	This residential point is located at the end of the town and farthest to the oil refinery
Dudej Sq.	3291485.09MN 663854.37ME	This is the nearest residential area after Shiraz oil refinery, located between Zarghan and the oil refinery
Kargar St.	3293675.11MN 664173.69MN	This is a cross point of the highway and Zarghan located 60 meters from Shiraz-Tehran highway
Shiraz oil refinery	3295362.28MN 6659211.42ME	Shiraz oil refinery is a major source of SO_2. Its distances from nearest residential points in Zarghan and Dudej are 6155 m and 2668 m, respectively
Industrial park	3292829.20 MN 6634148.2ME	This point was selected to examine the pollution roles of the oil refinery and industrial park

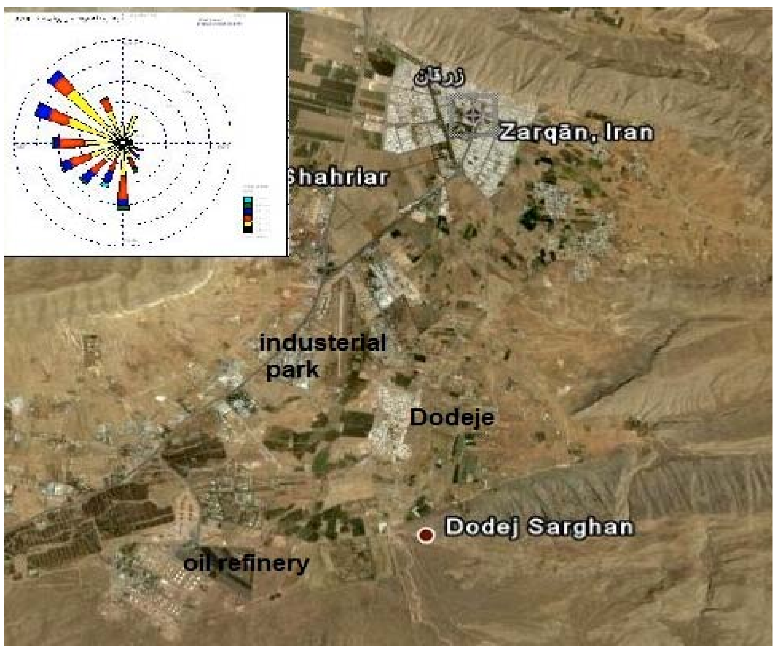

Fig. 3: Maps of Zarghan and the wind rose at the time of air sampling Nearest neighbor method B-Kriging method C-IWD method

method with different methods such as inverse weighted distance to the power 2 $(IWD)^2$, natural nearest neighbor. File Format (TIFF) is a raster image format with a pixel size of 5 m for each specimen was prepared (with at least 10 sample points). All interpolated layers were then cut into the size of sample point's area to perform interpolation for all layers.

RESULTS

Table 2 showed the results of SO_2 measurements in different sampling stations in the industrial regions of Zarghan. According to data, the maximum and minimum concentration of SO_2 are related to Shiraz oil refinery (63.3 μg m^{-3}) and old cemetery (4 μg m^{-3}), respectively. Due to the importance of wind direction, the maps of the wind rose of the sampling season with the map of Zarghan are shown in Fig. 3. As shown in Fig. 4, the geographic coverage area of SO_2 concentration has been studied using different methods of Nearest Neighbor (NN), Inverse Distance Weighted IWD, and Kriging. SO_2 pollution maps were prepared using passive sample interpolation.

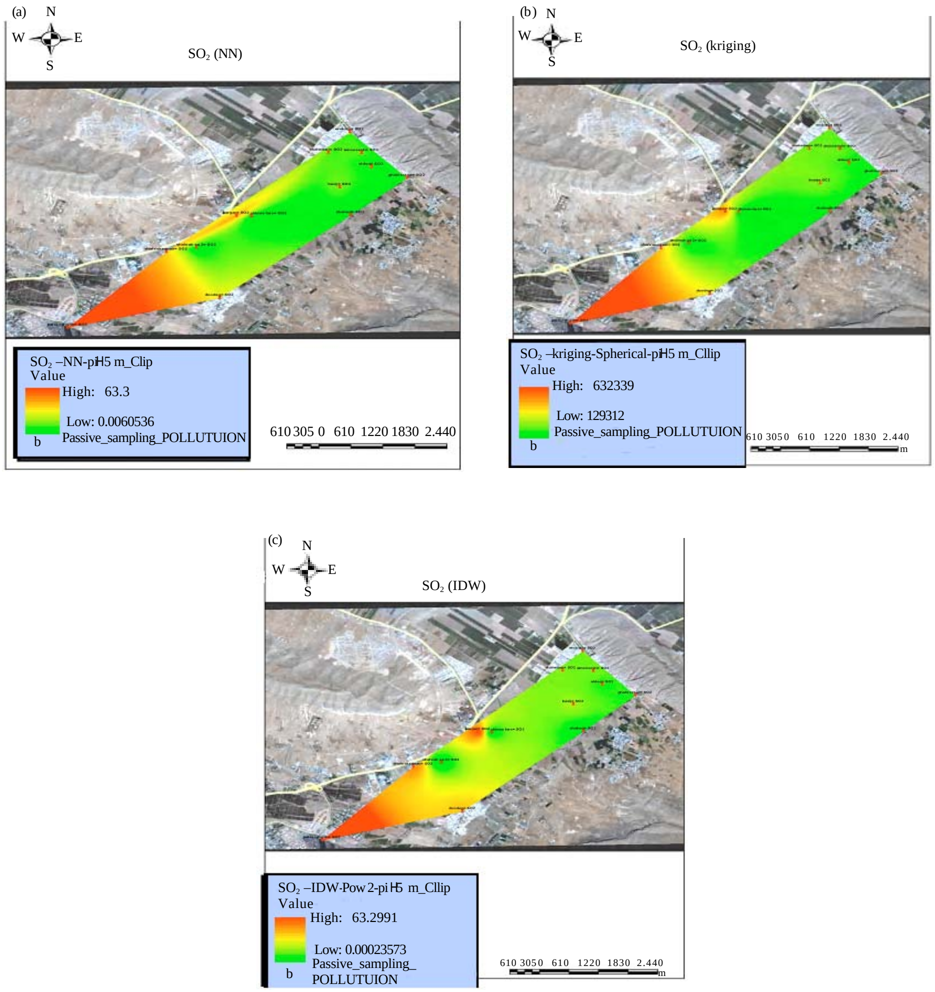

Fig. 4(a-c): GIS results using different interpolation methods (a) Nearest neighbor, (b) Kriging and (c) IWD methods Sampling stations in the industrialized Zarghan area

Table 2: SO_2 concentration (μg m^{-3}) at different sampling stations in the industrial regions of Zarghan

Sampling stations	SO_2 concentration (μg m^{-3})
Municipality	7.5
Basij Sq.	9.3
Department of education	7.2
Old cemetery	4.0
Old Central Sq.	4.2
The city limit of town	7.0
Dudej Sq.	19.3
Kargar St.	29.7
Shiraz oil refinery	63.3
Industrial park	24.4

DISCUSSION

A comparison of measured SO_2 concentration with the values recommended by the WHO air quality guidelines:

- The 24 h WHO (World Health Organization) guideline value for SO_2 is 20 μg m^{-3} (WHO, 2005). Since in this study the passive sampling method was used and the specimens were exposed to the air for the period of 17 days, the data were comparable to the average 24 h SO_2 value. In most of the sampling stations, SO_2 concentration was in the acceptance limit of the average 24 h SO_2 value, but SO_2 concentrations in the following four stations were considerably high
- Shiraz oil refinery sampling station with the SO_2 concentration of 63.3 μg m^{-3}
- Kargar St. with the SO_2 concentration of 29.7 μg m^{-3}
- Industrial park with the SO_2 concentration of 24.4 μg m^{-3}
- Dudej with the SO_2 concentration of 19.3 μg m^{-3}

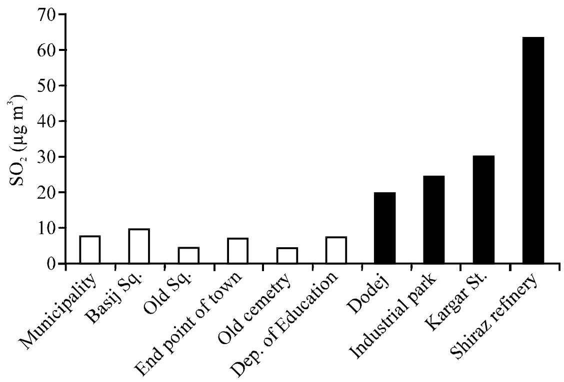

Fig. 5: SO_2 concentration at different sampling stations in the industrialized Zarghan area

Figure 5 shows SO_2 concentration in different sampling stations. According to this Figure, SO_2 concentration in Zarghan residential areas is within the acceptance limit.

GIS data analysis: As the GIS figures showed, the oil refinery and the highway are among the most important sources of SO_2 pollutions. In general, the concentration of SO_2 in the area near the oil refinery was much higher than the area near the highways. The prevailing wind direction was not toward Zarghan at the time of sampling; although, it could affect Dudej area which is located at a distance of about 3 km from the oil refinery. According to GIS figure, the industrial park did not have a significant effect on sulfur dioxide levels in Zarghan. The SO_2 concentration in the industrial park having a distance of 4000 meters from the oil refinery was 24 $\mu g\ m^{-3}$ which is still much higher than the concentration in Dudej area. Interestingly, SO_2 concentration at the distance of 200 m from the highway close to the industrial park was significantly higher than the one at Kargar station near to the highway. As a result, the industrial park had intensified air pollution caused by the oil refinery by an amount of 5 $\mu g\ m^{-3}$. Despite the prevailing wind in the highway directed toward Zarghan, it has affected a maximum radius of 150 meters around. The SO_2 concentration in Dudej was in the upper limit of 24-hour guideline value, while it was within the standard limits in Zarghan residential areas. The reason for higher level of SO_2 in Dudej was due to its closer distance to the oil refinery. According to Figures, the nearest neighbor interpolation method showed the linear effects of pollution on the highway clearly. Figures obtained by interpolation method revealed the expansion of pollutions in the area. As shown, Zarghan has been located in the green zone and SO_2 could not be accumulated in the town despite the existence of wind. According to the wind rose map, during December the prevailing direction was not toward Zarghan. It would be possible to record higher level of SO_2 concentration in Zarghan if samples were collected during windy months directed toward the city. On the contrary, the pollution due to the highway was affected by prevailing winds blowing toward the city, and as seen in the GIS images, the highway pollution could not affect the city.

CONCLUSION

The contribution of different sources and dispersion radius of SO_2 in the study area were determined by the passive sampling method and interpolation tools in ArcGIS technique. The concentrations of SO_2 around Shiraz oil refinery and highway were high. The results indicated that SO_2 concentration was not exceeded the standard limit in the residential area and the role of the local highway and industrial park was not significant during December. It is highly recommended to determine SO_2 concentration in the area during other months of the year, especially October, which the prevailing wind directed toward Zarghan.

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