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Dispersion Modeling of Air Pollution from Copper Smelter Emissions

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Keywords

Air pollution,
Emission inventories,
Ambient monitoring,
Dispersion modeling.

Abstract

This study was undertaken to assess the dispersion pattern of air pollutants in the vicinity of a copper smelter plant applying air pollution dispersion modeling which is the most useful, economic and reliable tool to predict air quality impacts of pollution sources. The main sources of air pollution for this plant are two stacks containing a dryer electrofilter and a converter electrofilter. The necessary input data for modeling analysis include stack heights and diameters, emission rates, outlet flow rates and exhausting temperatures that were collected through field studies and sampling. In addition, topological and meteorological data were gathered and analyzed. Gaussian-based model has been used to simulate the dispersion pattern of hazardous pollutants, including SO_2, NO_2, and PM10 near the plant up to 25 km distance. The calibration of the model was done considering the roughness and the main buildings that cause the maximum effect on pollutant dispersion within that area. To validate the model, eight ambient air monitoring stations considering four different directions related to the copper plant were specified. Model predictions showed a relatively good agreement with measured data at ambient stations with the correlation coefficient (R^2) of more than 0.7 for all pollutants.

1. Introduction

Industrial air pollution has become a major problem in countries within rapid industrialization. Use of older processing technologies, poor pollution control systems, and inadequate attention to the environmental impacts cause deterioration of environmental quality [1]. High demands for copper with growth in electronic industries and the associated higher prices along with high potential for employment have provided the necessary incentives for higher extraction and processing of the raw materials. Uncontrolled copper smelting processes, such as fugitive emissions from electric furnaces, flash furnaces and converters can emit large quantities of particulate matter and gaseous pollutants that can have adverse effects on human health. Generally, high level of air pollution affects human health, quality of life, water and soil, climate, vegetation, buildings, etc. [2]. Copper smelters emit both particulate (metal fumes) and gaseous pollutants (such as NO_2 and SO_2) [3].

Particles reduce air quality and visibility and adversely affect flora and fauna as well as human health [4]. Particulate matters are small enough to go through the respiratory system and cause some adverse effects on human. The proportion of particles which have greater size deposit in respiratory tract, but the smaller particles are more likely to penetrate the deeper parts of lung and cause toxicological effects on human [5]. They can be carried over long distances before deposition and have adverse impact on soil, ecosystems, and ground water [4]. Sulfur dioxide is water-soluble and can be absorbed in the upper airways of respiratory system [5]. Long-term exposure to increased levels of nitrogen dioxide may cause respiratory diseases such as bronchitis especially in vulnerable individuals such as children and elderly [2]. Using controlling methods such as collecting the gases and converting the SO_2 to some other products like setting up sulfuric acid plants for converting the SO_2 in emissions to sulfuric acid (H_2SO_4) can reduce pollution and provide economic benefits.

Considering the financial aspects, measurement of pollution is not always beneficial and efficient enough to evaluate different pollutant dispersion patterns around the pollution sources such as smelting industries. As a result, application of atmospheric air pollution models seems to be an acceptable method for determining ambient impacts from an industrial source. Application of different air quality models is discussed in some research papers such as modeling of the particle deposition around a zinc complex

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conducted by MacIntosh et al. [6]. Athar et al. assessed pollution dispersion patterns from three fossil fuel power plants using atmospheric pollution dispersion model (ADMS). They simulated concentrations of CO, NO, SO_2, and PM10 around the plant. Results showed that SO_2 exposure was high up to 20km from the emission source [7]. Nazari et al. estimated emission factors of SO_2, CO_2, and NO_X for thermal power plants in Iran by studying on fifty plants from 2000 to 2008 [8].

The purpose of this study is to ascertain potential impacts of PM10, NO_2, and SO_2 emissions from a copper smelter on the adjacent communities. Both monitoring and dispersion modeling were used to determine air pollutant impacts within and around a radius of 25 km from the copper smelter.

2. Experimental Methods

2.1. Study Site

This study focuses on modeling of particulates and gases dispersion generated by the copper smelter plant located at 30.08° latitude and 55.40° longitude with the copper production capacity of 80,000 metric tons per year (mtpy). The total area of this plant is about 60,517 square meters (m^2).

2.2. Modeling Program

The model used in this study was ADMS that is based on Gaussian plume emission formulations (Cambridge Environmental Research Consultants, UK). Provisions are provided in the package for modeling of different pollution sources such as point, line, area, volume and puff sources. The model inputs consist of source types, emission rate of each source and other physical characteristics of sources, meteorological and topographical data of the region and the location of sources and receptors [7, 9, 10].

2.3. Modeling Parameters

In this study, ADMS 4.2 is used for the modeling with the usage of an eight-year meteorological data set and topography of the area. Monitoring stations were set up within the copper smelter complex and the surrounding areas in different locations. The main sources of air pollution include the two stacks named Stack 30 and Stack 31 (Figure 1). Stack 30 had a height of 150 m, diameter of 2 m, flow velocity of 15 meter per second (m/s), and an outlet temperature of 353 degrees Kelvin (K). Stack 30 was located downwind of an electrostatic precipitator (ESP) connected to the dryer with a flow rate of around 180,000 actual cubic meters per hour (ACMH) and had an average particulate concentration of 934 milligram per cubic meter (mg/m^3). Stack 31 has a height of 120 m (other parameters similar to stack 30) and had two inputs from ESPs connected to a flash furnace (170,000 ACMH and particulate concentration of around 1200 mg/m^3) and converter (60,000 ACMH and a particulate concentration of around 900 mg/m^3).

Accurate estimation of the emission rates from each stack is needed to do the exact estimation and simulation of particles and gases emissions. In order to estimate the emission rates, the average concentration of each pollutant that was measured from the stack was multiplied by the flow rate of outlet flow. The average concentration of each pollutant is calculated based on the average of several sampling results from the stacks. Tables 1 to Table 3 show the average emission rate of the PM10 and SO_2 of each stack.

Meteorological data consists of parameters collected at the nearby station from 1997 to 2007 and showed the dominant wind direction from North to South and the semi-dominant wind direction from southwest to northeast (Figure 2).

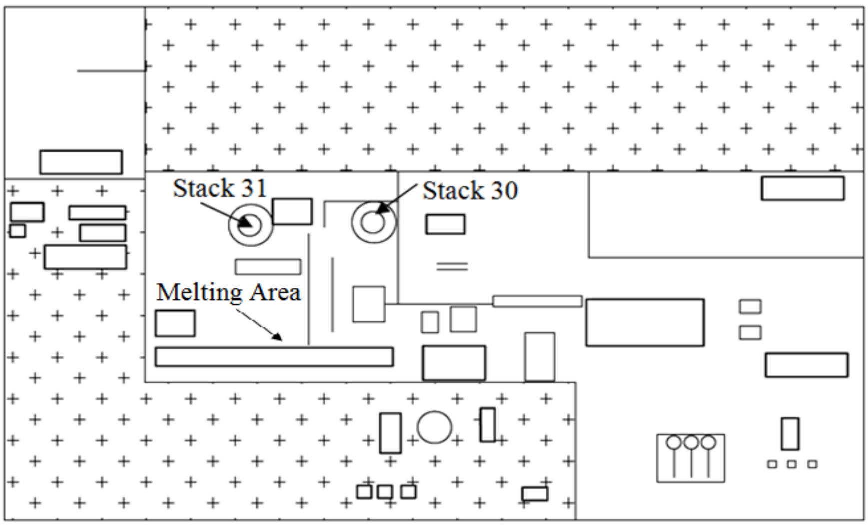

Figure 1. Location of pollutant sources in the plant

Table 1. Average of PM10 emission rate for stack 30

Average Flow Rate (m^3/hr)	Average Concentration (mg/m^3)	Average Emission Rate (g/s)
180,000	934	46.7

Table 2. Average of PM10 emission rate for stack 31

Parameters	Average Rate (m^3/hr)	Average Concentration (mg/m^3)	Average Emission Rate (g/s)
Electro filter of flash furnace output	170,000	1,200	56.7
Electro filter of converter	60,000	900	15
Total emissions	-	-	71.7

Table 3. Average emission rate (g/s) of output gas from stacks

Source	NO_2	SO_2
Stack 30	0.1	136
Stack 31	17	798

2.4. Calibration of the Model

One of the important input parameters of modeling is the building data. In this study, according to the height of stacks and buildings and dominant wind direction, two buildings with the higher effect on the dispersion pattern including the dryer building and melting hall were chosen as model inputs. General layout of the plant was shown in Figure 3. The model was run separately by selecting each structure as the main building at each time. Referring to the comparison between these two sets of modeling results and actual measurements, dryer building was chosen as the main building representing the actual barrier effect on the surrounded area. In the next stage, the model calibration was done through changing roughness length as another notable input parameter. After several running with different values of this parameter, finally, the amount of 0.3 m was chosen as the final roughness length that was showing a better compliance with the observations.

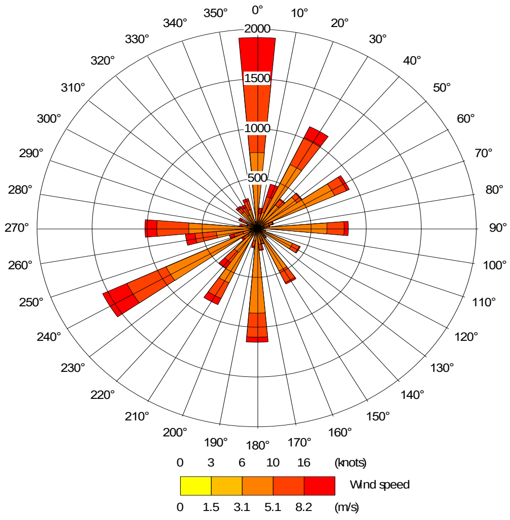

Figure 2. Wind rose of the study area (1999-2007)

2.5. Parameters Measurement

Measurements of PM10 were performed at 1.5-2 m above ground level height (human breathing height) at receptor points. Particle concentrations were measured using the standard procedure of differential weighing of a filter before and after exposure to a constant airflow for 24 hours [6]. To achieve this purpose, Ambient FRM OMNI Air sampler pumps were used. The OMNI measures the amount of particles in the air and can produce readings at determined times. Gaseous concentrations were also monitored applying absorbent solutions exposed to airflow.

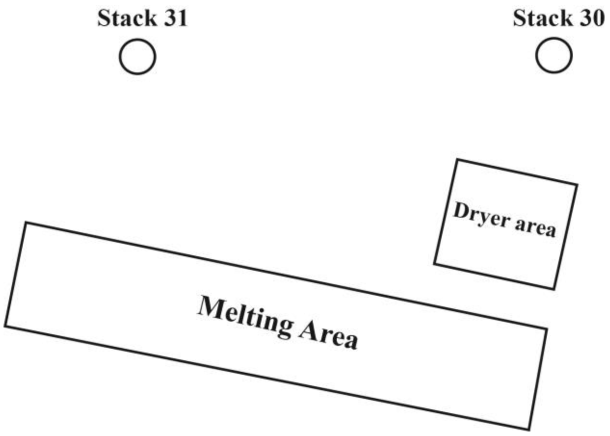

Figure 3. General layout of main buildings toward main stacks in the plant

3. Results and Discussion

3.1. Particulate Dispersion Pattern

The 24-hour average concentrations of PM10 resulting from the model indicate the maximum concentration occurs in a small area close to the melting zone. The resulting trend shows a reduction in concentration with the increase in distance from the melting area (Figure 4). The 24-hour average concentrations of PM10 in the residential areas (villages in the vicinity of the plant) located at about 25 km far from the plant are approximately 57, 56, and 55 microgram per cubic meter (μg/m^3). The contours show that the dispersion of PM10 extends in the dominant wind direction from the South West to the North East and the North to the South (Figure 5). Although the PM10 concentration is below the daily standard value of 150 $\mu g/m^3$ recommended by the Iranian department of environment (DOE-2010), particulate matters accumulation over the years can cause high concentration of copper and the other components of emitted particles and cause specific environmental issues, such as soil and underground water pollution and human adverse health effects.

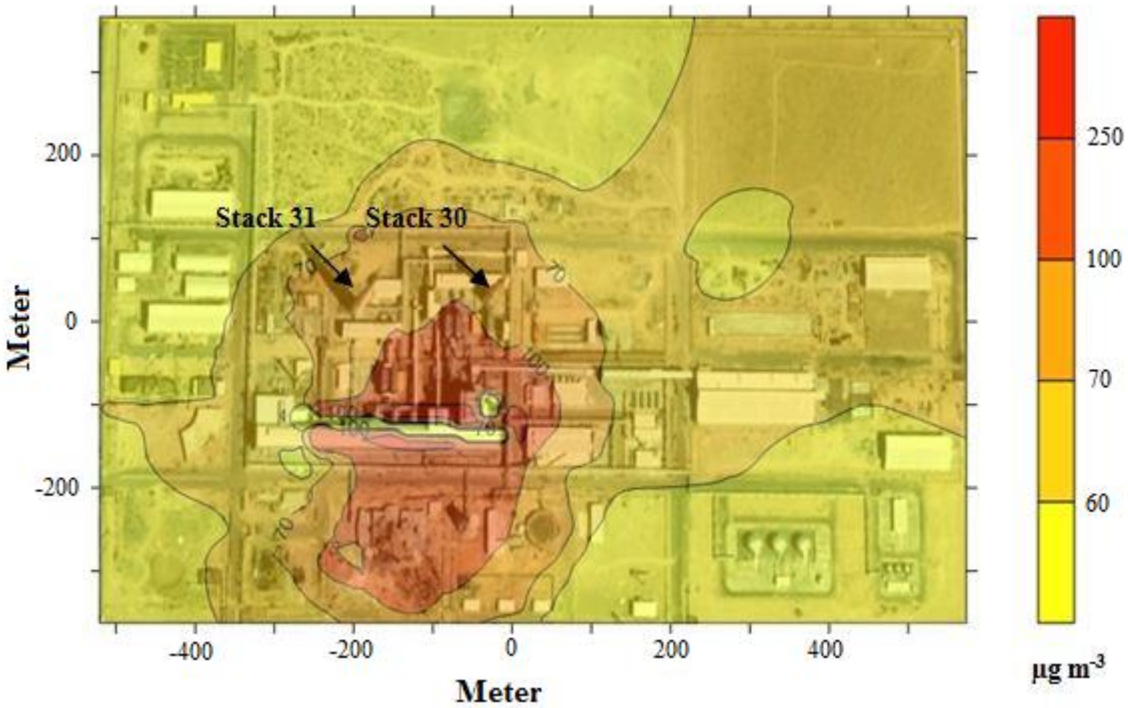

Figure 4. Modeling results for PM10 inside the plant

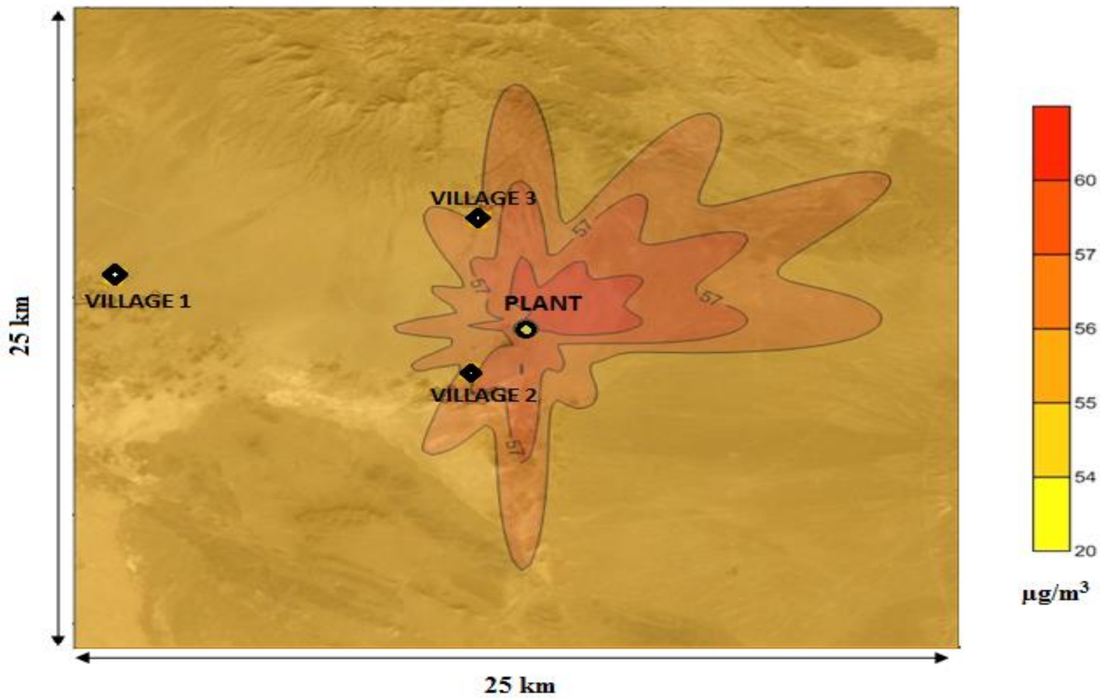

Figure 5. Modeling results for PM10 outside the plant

3.2. NO_2 Dispersion Pattern

Figures 6 and Figure 7 show the dispersion of NO_2 inside and outside of the complex. The concentration of NO_2 is less than 50 $\mu g/m^3$ in the whole complex while it extends to the northeast side of the complex because of the semi-dominant wind direction and plume deposition. According to Figure 7, by getting away from the complex in the northeast and south direction, the contaminant concentration is increased and then gradually decreased. NO_2 concentration in villages is less than the annual DOE standard value (100 $\mu g/m^3$).

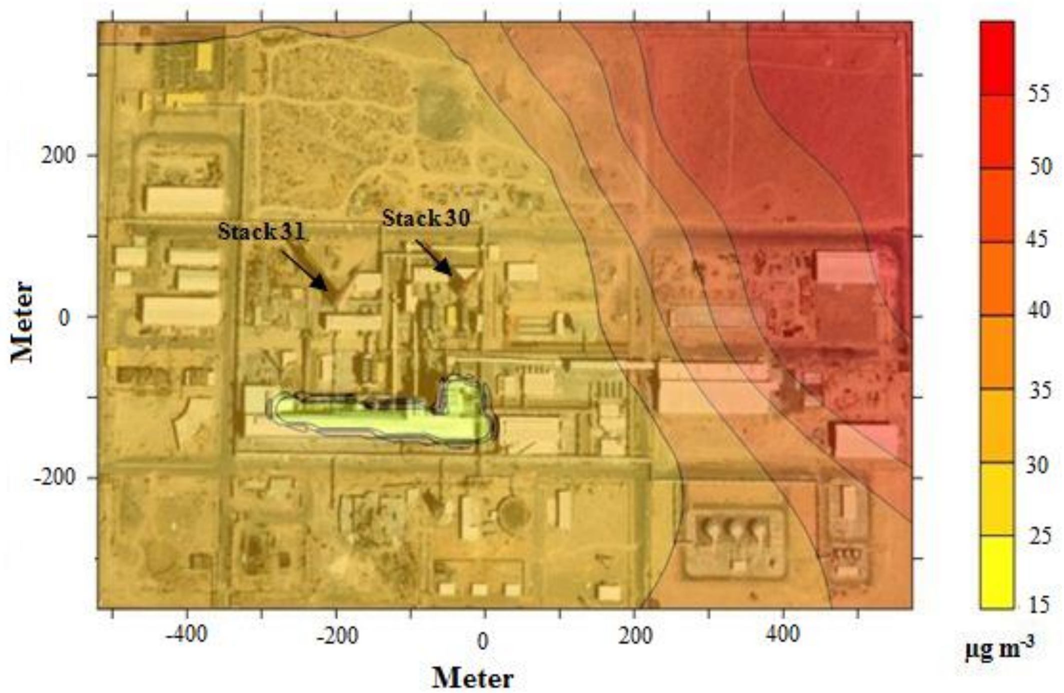

Figure 6. Modeling results for NO_2 inside the complex

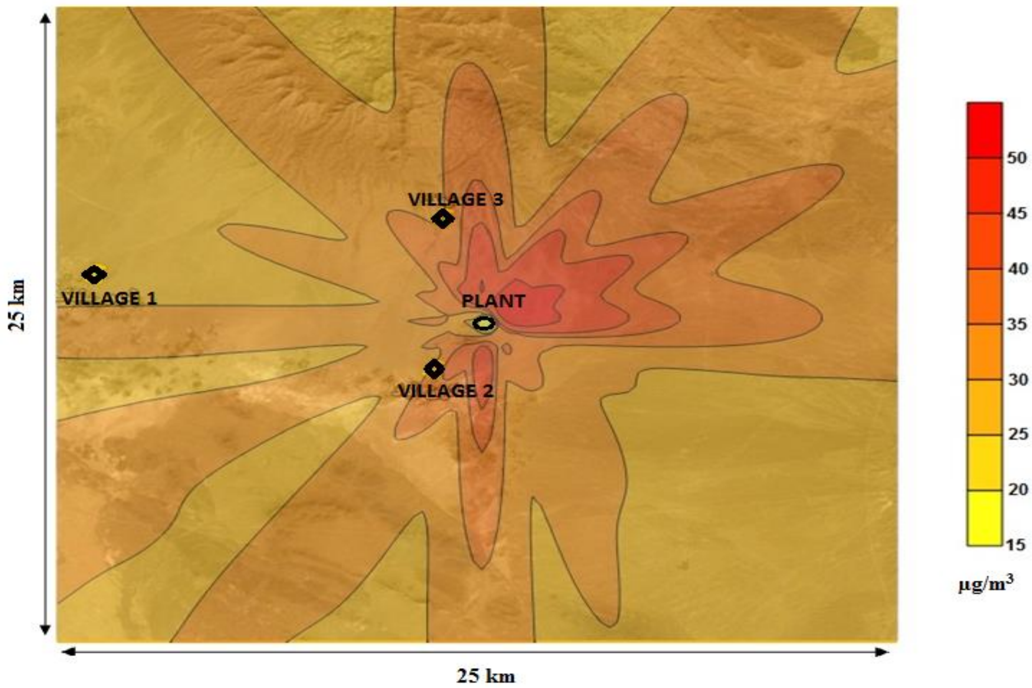

Figure 7. Modeling results for NO_2 outside the complex

3.3. SO_2 Dispersion Pattern

The emission of SO_2 in the copper smelter plant is depicted in Figure 8. The maximum value of SO_2 concentration occurs near the melting area and the flash furnace (400 $\mu g/m^3$) which exceeds annual standard value (80 $\mu g/m^3$) introduced by DOE (2010). The average concentration of SO_2 within the plant is about 70 $\mu g/m^3$ and concentration of 80 and 50 $\mu g/m^3$ are shown to affect village 2 and village 3, respectively (Figure 9).

3.4. Validation of the Model Results

Several monitoring points were selected up to 25 km around the plant at four directions (Figure 10) to compare the modeling results that are averaged during a year to the actual values measured by the monitoring network. The results of the modeling and monitoring for PM10 and SO_2 are shown in Figures 11 to 13. The correlation coefficient (R^2) equals to 0.97 and 0.75 for PM10 and SO_2, respectively. It shows that the model is able enough to predict the pollution dispersion pattern up to 25 kilometer around the plant.

A comparison between the monitoring and modeling results is given in Table 4.

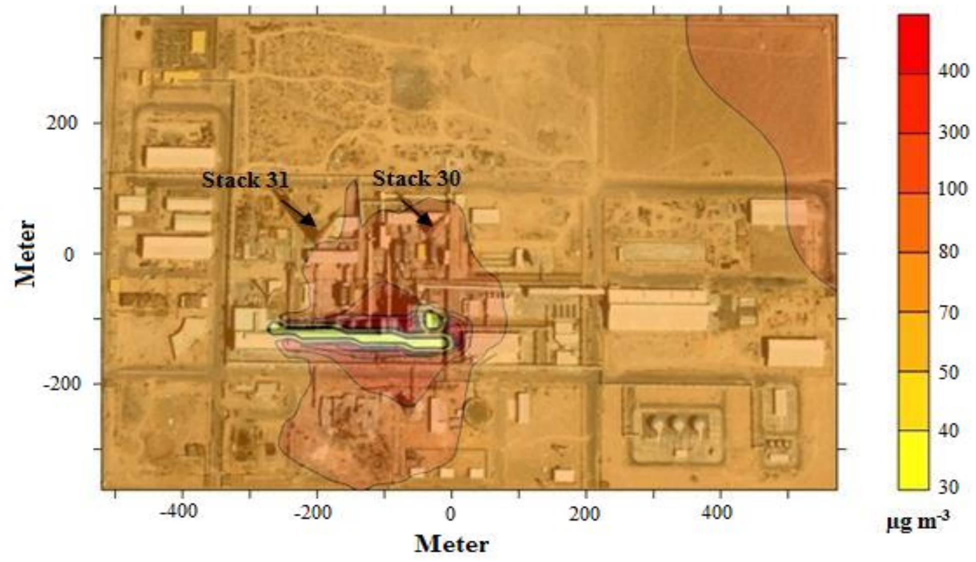

Figure 8. Modeling results for SO_2 inside the plant

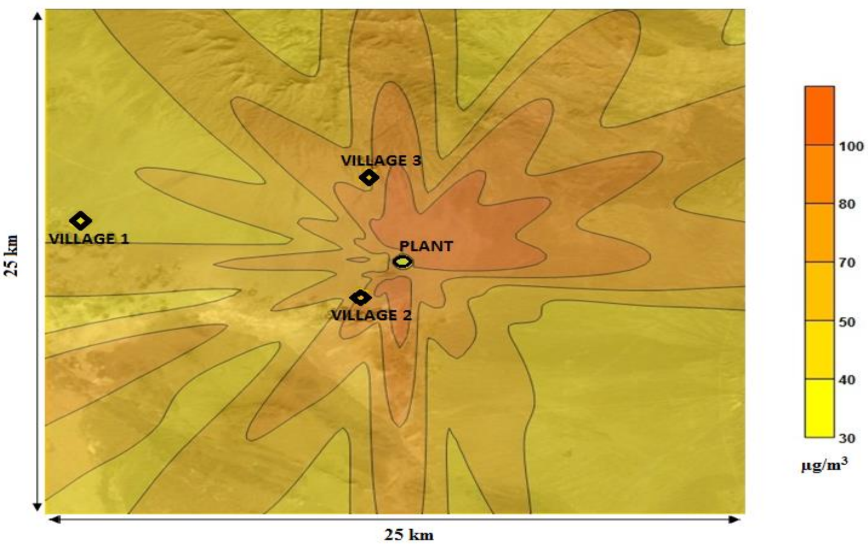

Figure 9. Modeling results for SO_2 outside the plant

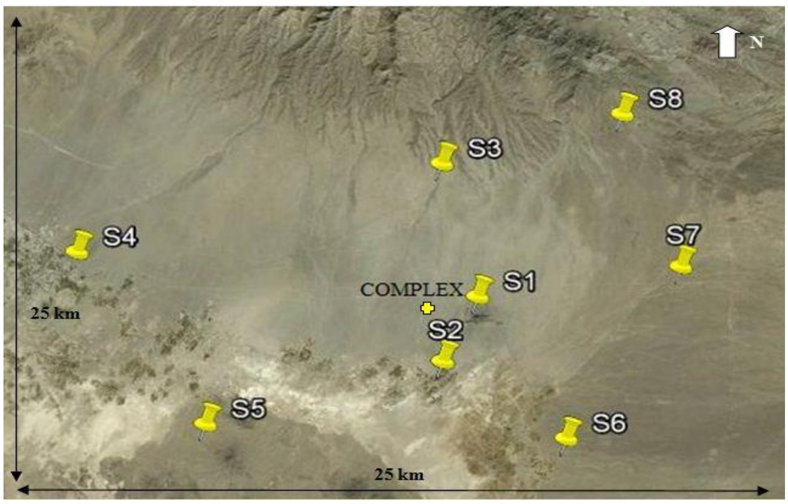

Figure 10. Location of monitoring stations

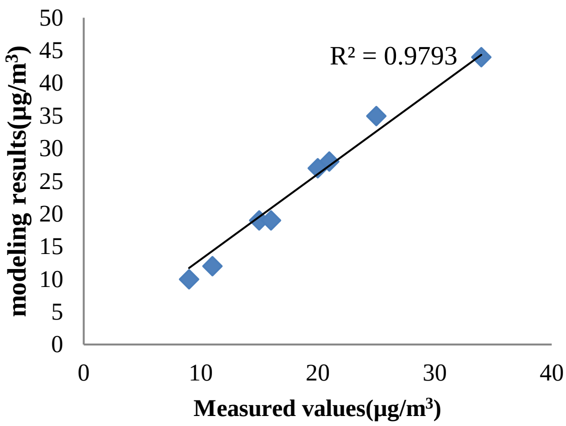

Figure 11. Comparison between predicted and averaged monitored values for PM10

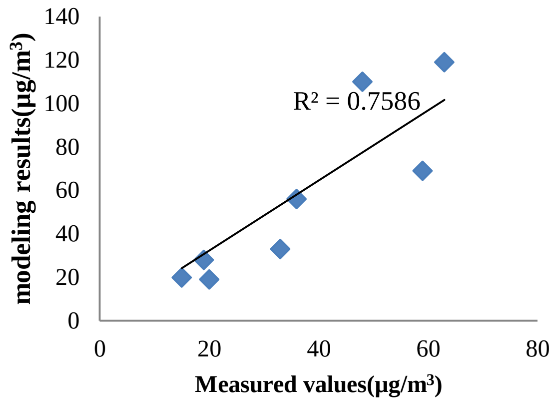

Figure 12. Comparison between predicted and averaged monitored values for SO_2

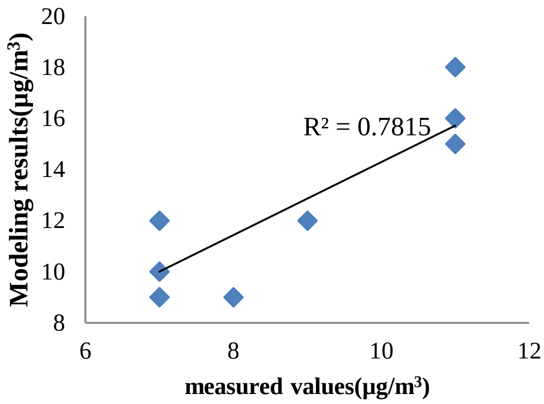

Figure 13. Comparison between predicted and averaged monitored values for NO_2

Table 4. Comparison of monitoring and modeling results

Control points	PM10 (μg/m³)		NO_2 (μg/m³)		SO_2 (μg/m³)	
	Measured values	Modeling results	Measured values	Modeling results	Measured values	Modeling results
S1	21	28	11	18	36	56
S2	34	44	11	16	63	119
S3	15	19	7	12	33	33
S4	16	19	11	15	20	19
S5	9	10	8	9	15	20
S6	11	12	7	9	19	28
S7	25	35	9	12	59	69
S8	20	27	7	10	48	110

3.5. Sensitivity Analysis

Any change in the input parameters will lead to a change in the output results. Some scenarios for sensitivity analysis of the model for particulates were implemented including, fluctuations in emission rates of pollutant sources and roughness length of 25 % and the model was run for each one, separately (Table 5).

The sensitivity percent of the model (S) to each of the parameters was estimated according to Eq. (1)

$$S = \frac{\frac{100}{N}\sum_{i=1}^{N}\frac{X_{ni}-X_{ci}}{X_{ci}}}{\Delta} \qquad (1)$$

where, N is the number of output results, X_{ni} and X_{ci} are the new and old output values of parameter at point i, and Δ is the change in the input value.

The results depicted in Figure 14 show that the model outputs are affected by the changes in emission rate of sources more than other input parameters. It shows that in the case of the poor performance of stacks even in a short period, the pollution in the area would be affected more than the other conditions.

Table 5. Results of sensitivity analysis

Fluctuations	Scenario	Sensitivity Of The Model (%)
1	25% increase in emission rates	-2.1
2	25% decrease in emission rates	2.02
3	25% increase in roughness length	0.08
4	25% decrease in roughness length	-0.16

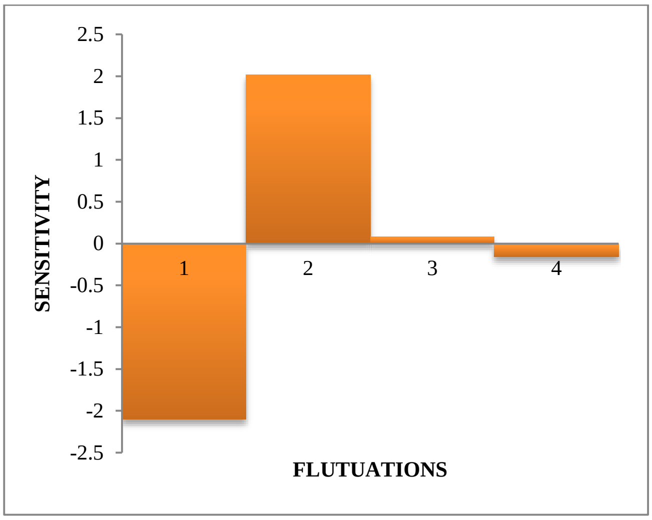

Figure 14. Sensitivity of the model to the input parameters

4. Conclusions

In this study dispersion of particulate matters and gases emitted from a copper smelter plant were modeled up to 25 kilometer distance. A high correlation (R^2>0.7) was observed between the results obtained by the model and the data measured by the air quality monitoring stations for pollutants including PM10, NO_2, and SO_2 indicating that the model is capable to predict pollutant emissions up to 25 km around the plant. The results showed that the output concentrations at receptors are much sensitive to the sources emission inventories. Therefore, these values should be calculated more precisely in order to boost the model accuracy. In addition, because SO_2 concentration exceeded the allowed dosage, Controlling output emissions are necessary to reduce emissions from factory outlets. Methods such as flue gas desulfurization and reuse of SO_2 by converting to sulfuric acid, modifying the furnace, replacing the old equipments with newer technology, installation of highly efficient particles and gases control equipments, repair of existing control devices, and developing green space around the plant to enhance natural purification of air pollutants are necessary.

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