DISPERSION MODELLING OF AIR POLLUTION FROM OPEN PIT COPPER MINE

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ABSTRACT

Copper mining operations have increased in Iran in the past decades due to price increases and potential for creating jobs in developing countries. Iran consists of many copper mines. The mining operations have a positive economic impact on the region, but may also be the cause of adverse environmental effects. Environmental aspects and the health impact of respirable particulates on the communities and agricultural production in the immediate vicinities have been under scrutiny by the regulatory agencies to ensure sustainable development. The impact of an open-pit mine on the air quality and extent of particulate pollutant dispersion in different directions and times is the focus of this paper. The results of the modeling have been validated through ambient air monitoring. Monitoring stations were installed in different areas within the mine unit operations and around it including background areas where PM10 values were 7 µg/m^3. Outside the Complex, particulate concentrations were monitored in 9 different stations and up to 25 km distance. Modeling of point, area, and volume sources was conducted using a 9-year meteorological database. The results showed that particulate quantity decreases rapidly below local standard value of 150 µg/m^3 at 2.5 km around the mine and the main pollution is due to the crusher and tailings dump areas. Model outputs were compared to the actual values measured by the air quality monitoring network including villages and crop fields. High overall correlation of about 76% was obtained for most of the locations but lower values were reported for more complex terrain in the region. Remedial actions recommended included road water spraying and better management practices to avoid overloading trucks.

KEYWORDS

Open-pit mining, Air pollution modelling, ADMS, PM10

INTRODUCTION

All major mining activities directly or indirectly contribute to the problem of air pollution and related health hazards. The growing emphasis on open-pit mining operations in recent years to achieve ever increasing production targets has further aggravated the problem of air pollution.

Particulate air pollutants including particles with an equivalent aerodynamic diameter less than 10 µm (PM10) arises from open-pit mining operations and constitute the main environmental concerns, and emissions of gases such as NO_2 and SO_2 can be ignored (Huertas et al., 2012). The mining activities that generate these particles are drilling, blasting, loading and dumping, road transport over unpaved roads, and losses from tailing dumps. Particles reduce air quality and visibility and adversely affect flora and fauna as well as human health. They can be carried over long distances by wind and then settle on ground or water bodies and cause environmental damage to other ecosystems (Morawska et al., 2004).

Air pollution measurements give important quantitative information about ambient concentrations and deposition, but they can only describe air quality at specific locations and times. Simulation of different operations as well as ambient environmental conditions using dispersion modelling is required for environmental impact assessment of an open-pit mine and to predict long term risks and health effects (Daly and Zannetti, 2007). Chakraborty et al. (2002) developed empirical formulas to calculate the emission rate of particulates due to various open-pit mining activities by studying seven coal and three iron ore mining sites in India. Huertas et al. (2012) modeled the dispersion of total suspended particles (TSP) by ISC3 and AEROMOD using meteorological data collected by three local stations and the high correlation were obtained between the actual concentration of particles and modelling results.

METHODS

Study Site

This study focuses on modelling of particulates' dispersion at Meydook area of Kerman province in Iran. The open-pit copper mining region is located 30° 25' latitude and 55° 10' longitude. The local topography consists of rounded hills with gentle slopes and shallow valleys. The highest elevation above sea level is 2842m.

Figure 1 – Location of study site (the red dot)

Modelling Program

The model used in this study was Atmospheric Dispersion Modeling System (ADMS) which is based on Gaussian plum emission formulations (Cambridge Environmental Research Consultants, UK). Provisions are provided in the package for modelling 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.

The modelling was performed from 2.5 to 25 km distance around the mine to conduct off-site impact and deposition studies. Emission sources and emission rate determination studies showed that particulates are the main pollutant resulting of mining activities. The main potential sources of particles are drilling, blasting, road transport over unpaved roads, loading and dumping to the crusher and losses from exposed tailing dumps (Chakraborty, 2002; Driussi & Jansz, 2006).

Emission Inventory

Emission formulas recommended by the USEPA (AP-42) were applied to estimate the emission rate of each source. Table 1 and table 2 show the emission formulas and emission factors of each mining activity.

Table 1 – Empirical formula for emission rate of each activity

Activity	Empirical equation	units
Drilling	$E=0.0325[99100-m)S*U)/((100-S)m]^{0.1}*(D*F)^{0.3}$	kg/s
Transport over unpaved roads	$E=422.85(S/12)^{0.9}\ (W/3)^{0.45}$	g/VKT*
Overburden dumps	$E=k(0.0016)(U/2.2)^{1.3}\ (M/2)^{1.4}$	kg/ton
Blasting	$E=344\ [A^{0.8}/(M^{1.9}*D^{1.8})]$	kg/blast
Crushing	$E= P*N$	g/s

*VKT: vehicle km transferred

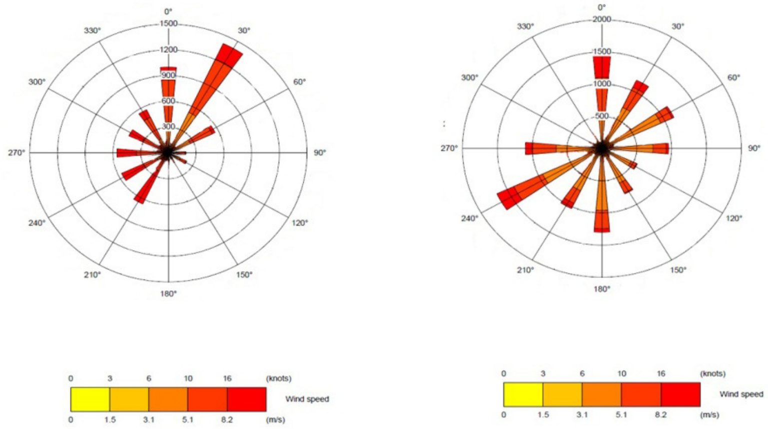
Note: parameters and units and symbols used are: moisture content (%) M; silt content (%) S; wind speed (m/s) U; hole diameter (mm) D; frequency (No. of holes/day) F; explosion area (m^2) A; weight of trucks (ton) W; amount of loaded and unloaded materials to the crusher (ton/s) N; for primary crushing P=4 g/ton of unloaded materials.

Table 2 – Type of sources and emission factors

Activity	Source type	Emission rate	unit
Drilling	Point	0.4966	g/s
Loading and unloading	Point	5.3521	g/s
Transport over unpaved roads	Line	0.0291	g/s/m
Overburden dumps	Area	0.0003	$g/s/m^2$
Blasting	point	0.3186	g/s
Crushing	Point	1.1404	g/s

Meteorological Data

The meteorology of the region was characterized by 3-hourly data collected from the two closest meteorological stations from 2000–2009. The data consisted of wind velocity and direction, temperature, pressure, relative humidity, amount of cloud, etc. Since Meydook mine is located between the two meteorology stations of Shahr-e-Babak and Anar (34 and 52 km away), the meteorological parameters were calculated by means of interpolation. Figure 2 illustrates the wind rose of each station and the interpolated wind rose.



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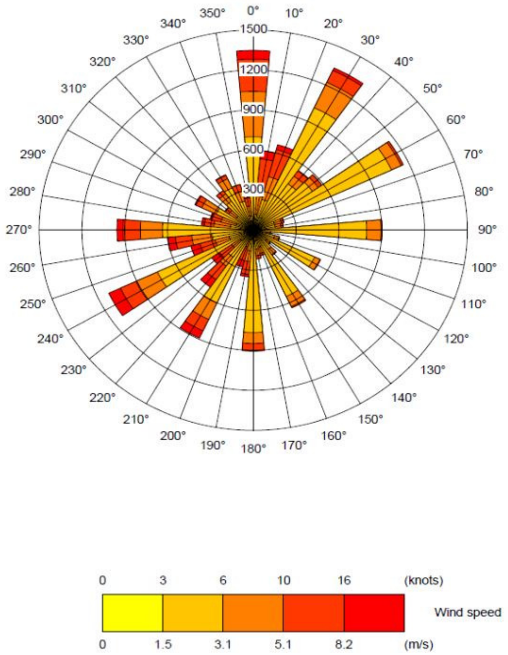

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Figure 2 – a: Wind rose of Anar meteorology station, b: Windrose of Shahr-e-Babak meteorology station, c: interpolated windrose of Shahr-e-Babak and Anar stations (2000–2009)

Calibration of the Model

Model calibration was done through changing roughness length as the important input parameter to the model. After several running with different values of this parameter, finally, the amount of 0.3 m was chosen as the final roughness length which was showing a better compliance with the observations.

Monitoring Stations

Stations for monitoring particle concentrations were selected based on the location of the mine relative to villages and other residential areas, dominant wind direction and meteorological and topographical data. The monitoring program consisted of 4 seasonal measurements at regular intervals during 2011 for environmental assessment goals at 9 stations. Figure 3 and Table 3 show the locations of the selected monitoring stations in- and outside the complex with the probable affected villages up to 25 km from the mine.

Table 3 – Monitoring station locations

Stations	Coordinate toward the mine	
	X (m)	Y (m)
Administrative unit	-2936	611
Crushing site	-568	626
Mine steps	0	0
Dumping area	689	-1072
Meydook village	-3185	-2405
Geshnizoie village	-3338	-6559
Kam-Sefid village	-2333	6538
Latela village	648	2777
Garik village	2360	-2382

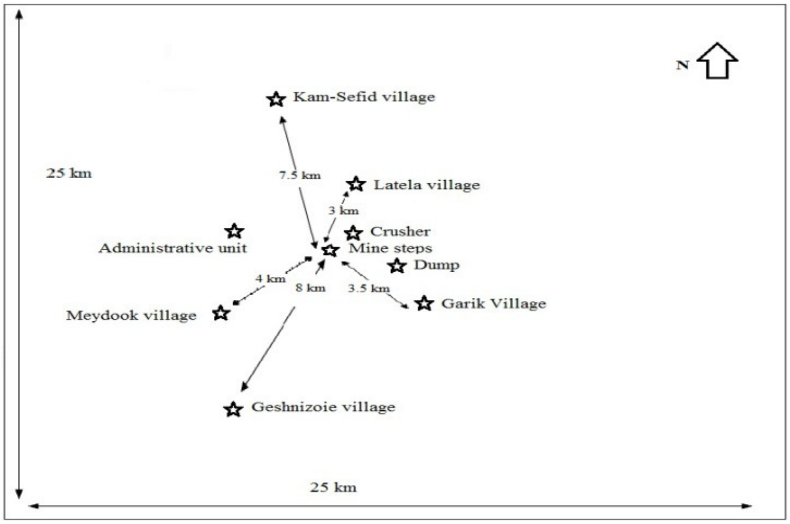

Figure 3 – Location of monitoring stations

Parameters Measurement

Measurements were performed at 1.5-2 meters above ground level. Particle concentrations were measured using the standard procedure of differential weighing of a filter before and after exposure to a constant air flow for 24 h (USEPA, 1999) using OMNI ambient air samplers.

RESULTS AND DISCUSSION

Modelling Results

The results of PM10 dispersion modelling up to 25 km around the mine are shown in Figure 4 and Table 4. The main points of interest were concentrations in the nearby villages with concentrations varying between 10 and 30 μg/m^3. Local environmental standard call for a 24-h maximum value of 150 μg/m^3. Table 4 shows that Meydook village at 4 km distance from the complex is the most affected village. This result is in a good agreement with the wind rose data of the region where the relatively dominant wind direction is from NE to SW. The Garik village which is located near the complex (at 3.5 km distance) and at the south east side of the complex is not adversely affected.

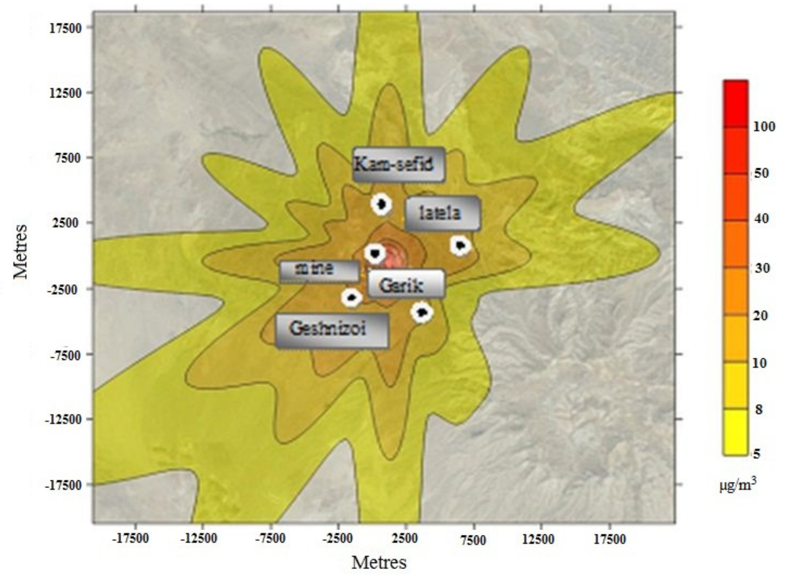

Figure 4 – Modelling results at 25 km around the mine

To investigate the pollution inside the complex the model was performed at 2.5 km distance around the mine. The presented results in Figure 5 are in line with previous studies (Huertas et al., 2012) in which the main sources of generated pollution in the mine are the crusher and dump area. Also the roads contribution to the pollution is low because they are sprayed by water regularly.

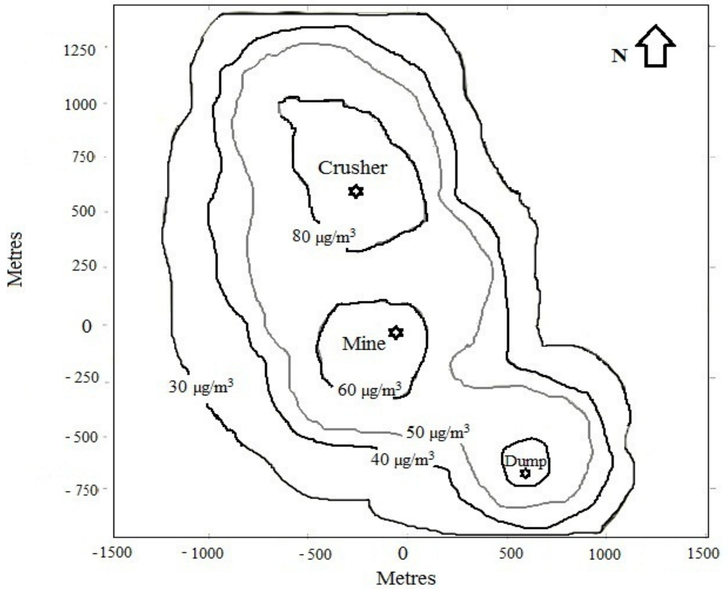

Figure 5 – Modelling results inside the complex

Comparison with values suggested by National Ambient Air Quality Standards (NAAQS) show that particulate concentrations are under 24-h standard value (150 μg/m^3) in all selected monitoring stations but they exceed the annual standard value (50 μg/m^3) at the crusher site (Table 4 and Figure 6). The situation can potentially have adverse health effects on workers as well as agricultural yields due to the cumulative effects of heavy metals on the soil.

Table 4 – Comparison of monitoring and modelling results

Stations	PM10 concentration (µg/m^3)						
	Predicted by model	Monitoring results					
		1	2	3	4	average	STD
Administrative unit	20	12	14	9	11	11.5	1.80
Crusher	85	62	83	50	43	59.5	15.17
Mine steps	53	18	23	19	24	21	2.55
Dumps	49	12	16	11	13	13	1.87
Meydook village	29	8	9	8	10	8.75	0.83
Geshnizoie village	25	6	7	7	8	7	0.71
Kam-Sefid village	20	6	5	8	10	7.25	1.92
Latela village	19	7	7	7	6	6.75	0.43
Garik village	12	9	10	9	10	9.5	0.50

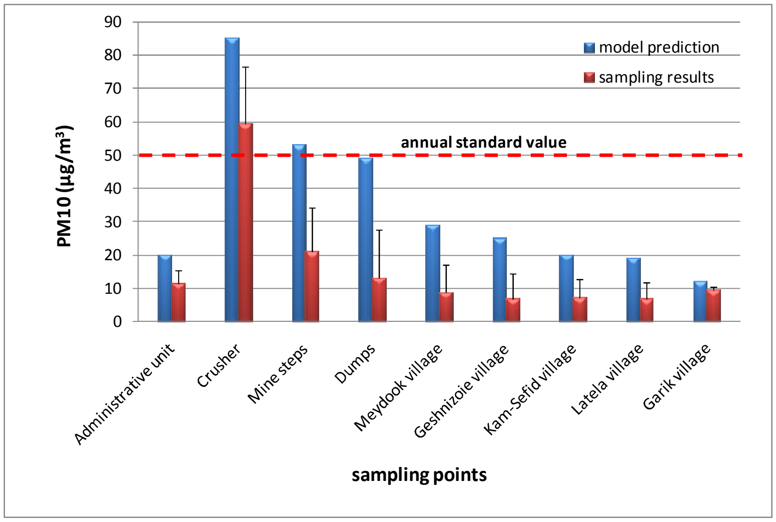

Figure 6 – Comparison of four-stage monitoring results to standard values

Comparison of Predicted and Measured Data

The degree of agreement between the modeling results and the actual measurements by monitoring network at the monitoring stations were evaluated and the results are shown in Figure 7 with a correlation coefficient of 0.76 between the predicted and the measured values. It shows that the model is able enough to predict the pollution dispersion pattern up to 25 km distance around the mine.

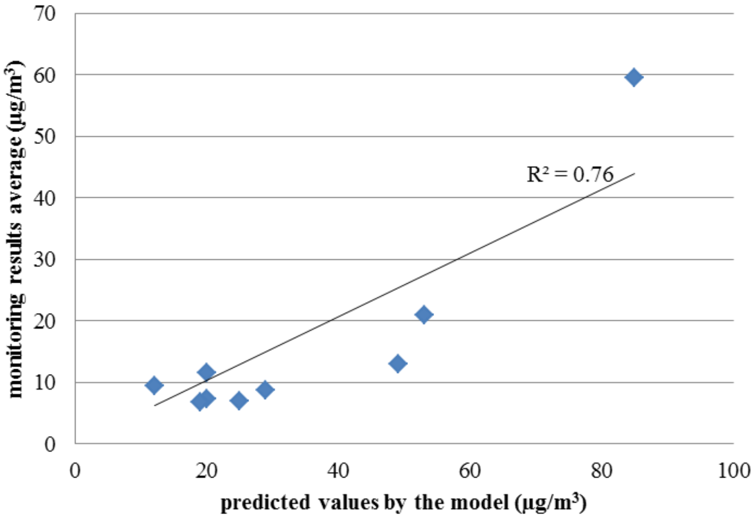

Figure 7 – Comparison between predicted and averaged monitored values

CONCLUSIONS

Dispersion modeling was performed to assess the impact of open-pit copper mining on air quality within the mining area and the nearby villages. Emission factors from literature were used to estimate emissions. Actual measurements up to 25 km distance from the mining operations were recorded in different directions and different seasons. A high correlation of 0.76 was observed between the results obtained from monitoring and the values predicted by the model which shows the model can solve the problem of air quality measurements at different locations and times. However, dust emission models could be used to predict the pollutants dispersion from surface mining sites by employing well documented and validated based upon micro meteorological data. It is concluded that about 50% of the particulates were retained inside the mine site due to their impaction effect and settling (Silvester et al., 2009). Particulate emissions can be reduced by regular water spraying during the operations and on the roads as well as stabilizing chemicals in the tailings dump areas.

ACKNOWLEDGMENTS

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