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Research Article

HEALTH RISK ASSESSMENT FOR EMISSIONS FROM JAMSHORO THERMAL POWER STATION USING AERMOD DISPERSION MODEL

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Key words: AERMOD, Dispersion modeling, Emissions, Health risk assessment, Pakistan, Thermal power station.

Abbreviations: AERMOD: American Meterological Society/Environmental Protection, Agency Regulatory Model, AERMAP: AERMOD Terrain Pre-processor, AERMET: AERMOD Metrological Pre-processor, ATSDR: Agency for Toxic Substance Disease Registry, HQ : Hazard Quotient, RfC: Reference Concentration, RfD: Reference Dose, EC: Exposure air Concentration, EIA: Environmental Impact Assessment, EPA: Environmental Protection Agency, GLC: Ground Level Concentration, IPP: Independent Power Plants, JPCl: Jamshoro Power Company Limited, MM5: Meso-scale Metrological Model Version 5, MMCF: Million Cubic Feet, NAAQS: National Ambient Air Quality Standards, NEQS: National Environmental Quality Standards, SSGCL: Sui Southern Gas Company Limited,TPS: Thermal Power Station, TPP: Thermal Power Plants, WHO: World Health Organization, WAPDA: Water and Power Development Authority, KESC: Karachi Electric Supply Company.

ABSTRACT

Thermal power plants generate about 65% of the world's electricity using fossil fuels, and Pakistan produces 61% of its electricity from such plants. Due to the use of fossil fuels such as natural gas, furnace oil and coal for electricity generation, there is a serious need to assess the health risks from emissions to people living near these thermal power plants. Up until now, studies of the health impacts from power plants have never been performed in Pakistan. This study was performed for the natural gas and oil-fired Jamshoro Thermal Power Station (JTPS), Sindh, Pakistan. Three pollutants, SO_2, CO and NO, were assessed for health risk to people residing near the power plant. Both long- and short-term effects on health were estimated. The AERMOD model was used to estimate air pollutants ground level concentrations (GLC) at 20 sensitive locations selected within a 10 km radius of the power plant. The results showed that short-term concentrations of SO_2 at several locations are 1.5-3.6 times higher than the guidelines of the Agency for Toxic Substance and Disease Registry (ATSDR) while long-term concentrations are within limits. The concentrations of CO and NO were within limits set by the National Environmental Quality Standards (NEQS) and the US-EPA However, further studies of the area are needed because these pollutants are not only being emitted from JTPS but also from the nearby Lakhra Coal Power Plant and vehicles.

INTRODUCTION

The Jamshoro Power Company Limited (JPCL) is one of the main public sector power plants in Sindh, Pakistan. It started operating in August 1988 and is owned by the state. The plant can operate on natural gas and furnace oil (JPCL, 2016. According to the Jamshoro thermal power stations (JTPS's) gaseous emission monitoring report of September 2016, JPCL contributes a huge amount of nitrogen oxide (NOx), sulfur dioxide (SO_2), carbon monoxide (CO) and particulate matter (PM). The maximum fuel consumption of both natural gas and furnace oil at

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JTPS is 3,700 tonnes per day when all of its four units run at maximum capacity. But the primary fuel is furnace oil, and this is particularly true in winter when gas is in short supply. When JTPS runs on furnace oil, it emits more gaseous pollutants and particulate matter than when fired on natural gas.

Pakistan produces 61% of its electricity using thermal power plants (TTP) while 33.5% is from hydro, 5.2% from nuclear, 0.5% from wind and 0.03% from solar (Khan and Ashraf, 2015). In Pakistan, three different groups produce electricity by thermal power plants: the Water and Power Development Authority (WAPDA), Karachi Electric Supply Company (KESC) and the Independent Power Producers (IPPs). WAPDA produces 4800 MW, KESC produces 1750 MW, Karachi and IPPs produces 6360 MW (Koolblue, 2017). The air pollution control devices (APCD) used by these plants include wet and dry scrubbers and electrostatic precipitators (Petition for Tariff Determination, 2014). The APCD are installed at TPP Jamshoro, but they have not been operational for several years.

Power generation by coal-fired power plants in Pakistan will increase as the price of natural gas will increase, and in 2018, 1320 MW coal-fired power plant at Port Qasim is expected to begin operation. The existing Jamshoro thermal power plant is also under expansion to add another 1320 MW of coal-fired capacity by 2019. These new plants will meet the rising energy requirements of Karachi and Hyderabad. Thus, the national consumption of coal is expected to rise to about 3.4 million tonnes per year (SEAL, 2017). This will increase air pollutants and presents a challenge to JTPS and all of Pakistan as it works to meet its growing energy needs. Estimates of emissions from the new coal-fired capacity at Jamshoro, without air pollutants equipment, is shown in Appendix 1, shows that the new 1320 MW of capacity at Jamshoro will result in 850 tonnes/year of CO, 36.83 ktonnes/year of NOx, 80.74 ktonnes/year of SOx, and 39 ktonnes/year of PM_{10}. The stack emissions can cause premature deaths due to lung cancer (Cohen, *et al*., 2017) respiratory diseases and heart illnesses (Brunekreef and Holgate, 2002). The emissions also increase the frequency of diseases such as chronic bronchitis and asthma, as well as heart attacks and strokes (Cropper, *et al*., 2012). Hence, in Pakistan, the Environmental Protection Act, 1997, requires an Environmental Impact Assessment (EIA) study before construction of any thermal power station (PEPA, 1997). Thus, in Pakistan, the law requires the reduction of emissions from power plants which are burning fossil fuels. In 2014 NEPRA suggested that coal-fired power plants should be run under principles of Low Emissions, High Efficiency (LEHE) (Sustainable Development Policy Institute, 2014).

Therefore, there is a serious requirement to assess health risks to people living around thermal power plants because thermal power plants emit a large amount of noxious air pollutants. Assessment of health risk normally involves the following steps:

1. Determination of stack emission rates,
2. Assessment of pollutant transport,
3. Calculation of carcinogenic and non-carcinogenic health risks,
4. Health risk determination (Mokhtar, *et al*., 2014).

Assessment of health risk is usually conducted with dispersion modeling to estimate concentrations of ambient air pollutants at particular locations. Examples of available models include California puff (CALPUFF) (Lopez, *et al*., 2005), Industrial Source Complex Short-term Version 3 (ISCST3) (Karademir, 2004; Kansal, *et al*., 2011) and AERMOD (Gibson, *et al*., 2013; Mokhtar, *et al*., 2014). In Pakistan, the US-EPA validated model (AERMOD) was adopted for EIA as the standard tool to calculate pollutant concentrations in air. AERMOD has been applied to particulate matter (Kesarkar, *et al*., 2007), mercury and SO_2 from coal-fired power plants in Malaysia (Mokhtar, *et al*., 2014).

In Malaysia, a similar type of study related to health risk assessment from air pollutants emitted from a coal-fired power station was carried out. The new environment quality (Clean Air) regulation 201X (draft) evaluated two pollutants (Hg and SO_2) for non-cancer-causing health risks and two trace elements (Cr and As) for cancer-causing health risks. The AERMOD dispersion model was used to estimate GLC within 10 km radius of the source emission. For health risk from non-cancer-causing agents, short-term dispersion of SO_2 showed potential adverse effects, while long-term concentration found only acceptable levels of SO_2 concentration. For Hg, results for long and short-term dispersion were doubtfully causing a health risk to people living within vicinity of studied plant. For cancer-causing health risks, there was a chance to develop cancer, because of the short-term concentration of Cr and As, whereas the long-term dispersion of Cr and As were within satisfactory limits (Mokhtar, *et al*., 2014).

The rationale for conducting this research is that currently, Pakistan generates nearly 59% of its electricity from furnace oil and natural gas, but no study was conducted to assessing the health risk of emissions from such type of thermal power stations. For this study Jamshoro thermal power station was selected because two major cities, i.e., Hyderabad and Jamshoro; and many sensitive locations i-e Universities, Schools & Hospitals come within 10 Km radius of the studied plant. This study was conducted to determine the ambient concentrations of SO_2, NO, and CO being emitted from the Jamshoro Thermal Power Station (JTPS), within a 10 km radius, by using the dispersion modeling software AERMOD and to assess risks to human health due to SO_2, NO, and CO emitted from JTPS.

METHODOLOGY

An overview of Jamshoro Thermal Power Station (JTPS)

The JTPS is a 3 × 200 MW and 1× 250 MW power station located in the district of Jamshoro, adjacent to the Indus highway. It is about 18 km from the city of Hyderabad. JTPS has a contract with Sui Southern Gas Company Ltd (SSGCL) for the supply of natural gas of 62 MMCF per day for running its three units. But the maximum daily requirement for three units of 3 × 200 MW is 140 MMCF, and an average requirement is around 90 MMCF. To meet the remaining fuel requirements, furnace oil is used by JTPS (JPCL, 2016). Other basic information for JTPS is shown in Table 1.

Table 1. Capacity of JTPS, the design of its stack.

Parameters	Specification
Capacity (MW)	3 × 200 1 × 250
Number of Stacks	2
The height of each Stack (m)	147
Inside Diameter of each Stack (m)	12
Exiting velocity from stack 1 (m/s)	33.1
Exiting velocity from stack 2 (m/s)	36.6

Measurement of Emission Rates from JTPS

Measurements of stack emission rates were performed by JTPS to compare with the National Environmental Quality Standards (NEQS) guideline. Nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO) and carbon dioxide (CO_2) were measured on a daily basis for one year by using flue gas analyzers and an average of that emission rate was taken as shown in Table 2. Particulate matter was not modeled because of a lack of emission data.

Table 2. Average emissions rates.

Parameters	Emission rate
Average SO_2 emission rate from stack 1 (g/s)	610
Average SO_2 emission rate from stack 2 (g/s)	288
Average NO emission rate from stack 1 (g/s)	95
Average NO emission rate from stack 2 (g/s)	34.12
Average CO emission rate from stack 1 (g/s)	13.23
Average CO emission rate from stack 2 (g/s)	140
Average CO_2 emission rate from stack 1 (g/s)	39870.
Average CO_2 emission rate from stack 2 (g/s)	27033.

AERMOD Dispersion Modelling

AERMOD is short range steady state model and is an upgraded version of the Industrial Source (ISC) Model. This dispersion model is suitable for both complex and simple terrains for receptors within 50 kms radius of the source. In this study, Breeze AERMOD (Version 15181) was run. The steps involved in the AERMOD modelling and subsequent data analysis are shown in (Fig. 1).

According to the air quality modelling guidelines provided by US-EPA (2005b), when predicting air pollutants concentration, five years' meteorological data should be used. The most recent successive

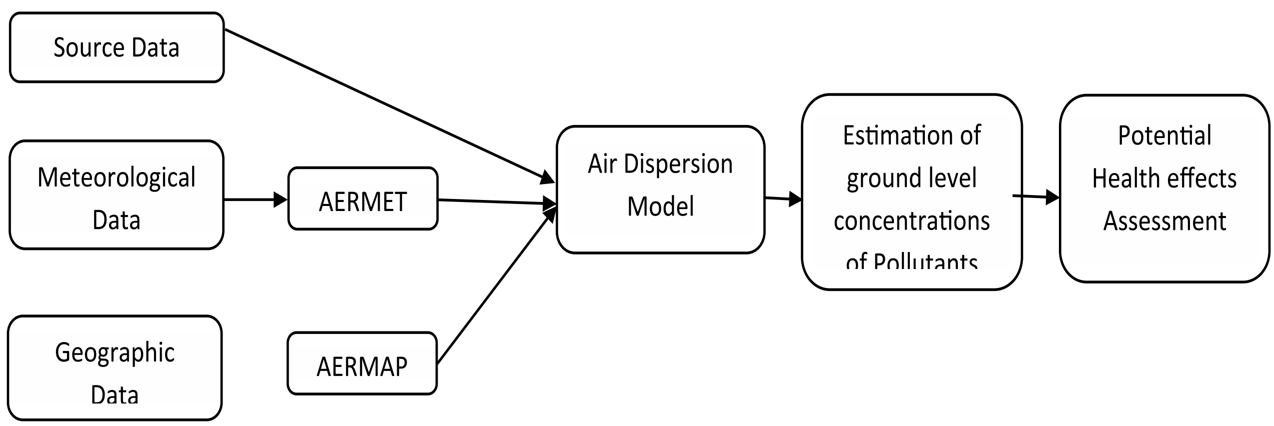


Fig. 1 AERMOD Dispersion Modeling Flow Diagram.

five years of data are preferred (US EPA, 2005b). Five years of data, from January 2011 to December 2015 was used in this study; the data was collected from Hyderabad airport meteorological station which is at a distance of 19.5 kms. It was purchased from Lake Environmental in TD-6201 and Samson file format and was produced from the mesoscale meteorological model (MM5). Breeze AERMET 7 was used to pre-process the meteorological data to a format that works with the AERMOD. AERMOD requires meteorological surface data (hourly values) and upper atmosphere data (daily values) that define situations near ground level and in the higher atmosphere respectively. Surface data comprise the dry bulb temperature, wind speed (m/s), wind direction, wet bulb temperature), relative humidity (%), hourly amount of precipitation (hundredths of inches), cloud ceiling height (m), opaque and total cloud cover, station pressure (millibar). Convective mixing heights (m) are required for upper air data. AERMOD uses boundary layer parameters containing the surface roughness, Bowen ratio, and albedo. According to the US EPA (2005b) these parameters are needed within a 3 km radius of the study area. The surface roughness, land use classification, Bowen ratio and albedo are acquired from AERMET [17]. (Fig. 2) shows the Jamshoro, 5-year wind rose.

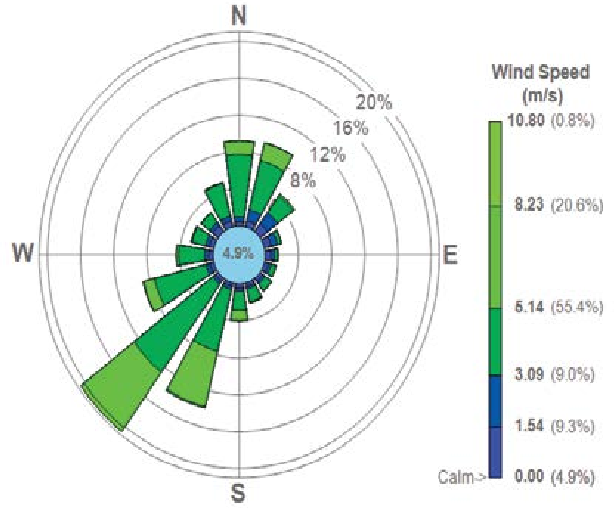
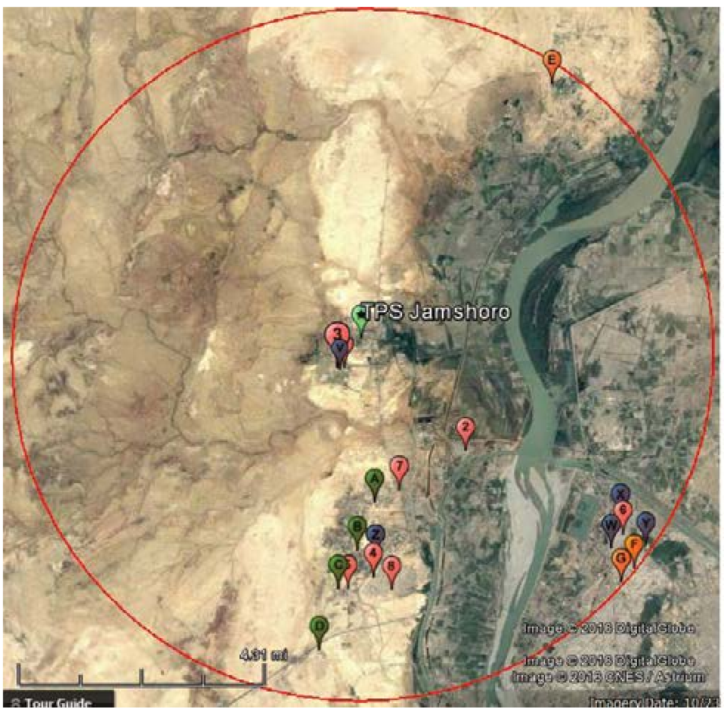


Fig. 2 Jamshoro wind rose from 01-01-2011 to 12-31-2015.

For site, topographical effects terrain data was purchased from Breeze Company in DEM file format with 90 m resolution. AERMAP was used to pre-process the terrain data before modelling in AERMO (Mokhtar, *et al.*, 2014). In this study, 20 sensitive locations were chosen as model receptors, including universities, schools, hospitals and colleges were selected, lying within 10 km of the source area as shown in (Fig. 3).



Legends

Schools
Universites
Hospitals
Colleges

Sign	Name	Distance from TPS Jamsoro
1	IQRA Public School	0.98 kms
2	IQRA Academy	4.43 kms
3	WAPDA high School	1.08 kms
4	The Educator School	6.68 kms
5	MUET Public School	7.33 kms
6	Gul Usrani School	9.34 Kms
7	Pak Turk School	4.52 kms
8	Govt: Boys High School	7.33 kms
A	LUMHS Jamshoro	4.81 kms
B	Sindh University	6.03 kms
C	MUET Jamsoro	7.23 kms
D	CEAD MUET	9.11 kms
E	Cadet College Pataro	9.20 kms
F	Bahria Foundation College	9.90 kms
G	Govt: Boys Degree College	9.99 kms
V	TPS Hospital	1.10 kms
W	Suhai Clinic and Maternity Home	9.34 kms
X	ABM hospital	9.06 kms
Y	Rajputana Hospital	9.97 kms
Z	Sindh University Dispensary	6.39 kms

Fig. 3 Sensitive locations within radius of 10 km.

Health Risk Assessment (HRA)

The health risk assessment methodology was taken from (Doe, 2012; Shaikh, *et al.*, 2017; Mokhtar, *et al.*, 2014; US-EPA. 2005a). Human health risk assessments involve the four steps as shown in (Fig. 4) which is taken from US EPA website (US EPA, 1991).

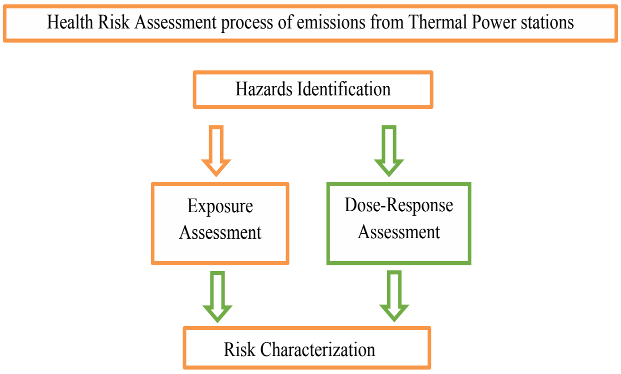


Fig. 4 Human health risk assessment flow diagram.

Hazard Identification

The key pollutants released from JTPS that affect human health are CO, SO_2, NOx, particulate matter and trace metals. For health risk assessment NO, CO and SO_2 were selected. Particulate matter, trace metals and NO_2 are not considered in this study because emission of NO_2 at the exit of TPS Jamshoro stacks is zero or negative and particulate matter, and trace metals data are not available.

Dose Response Data

Dose-response data provide a link between dose and adverse health effects. For example, daily mortality and morbidity due to air pollutants have been reported by (Levy, *et al.*, 1999; Ha, *et al.*, 2001). For non-carcinogenic effects, the inhalation reference concentration (RfC) and reference dose (RfD) are used to define the dose and response. The RfD is predicted by the daily exposure. The RfC is the predicted daily pollutant concentration in air that can be borne by humans without any adverse effect (Louvar, 1998).

When RfC is not present, the RfD can be used for prediction by the following equation (Louvar, 1998).

$$Inhalation\ RfC = Oral\ RfD \times Body\ weight \times Inhalation\ rate \quad (1)$$

Where

Inhalation RfC is in µg/m^3

Oral RfD is in mg/kg day

Body weight is 70 kg

Inhalation rate = 1000 µg/mg divided by 20 m^3/day

Exposure Assessment

The current study analysed exposure of people living within a 10 km radius of the study area including children and adults of all ages. People working in the JTPS were excluded. Distinction by sex was also not made (Meneses, *et al.*, 2004a). AERMOD was used to predict 1, 8, 24-hour, and annual mean pollutant concentrations; and were used as input to evaluate health effects (Meneses, *et al.*, 2004a).

Risk Characterization

Risk characterization for non-carcinogenic inhalation is performed by using hazards quotients (HQ). The HQ is defined as follows (Doe, 2012; US EPA, 2005a).

$$HQ = EC / RfC \quad (2)$$

Where

RfC= Reference concentration in µg/m^3, and

EC = Exposure air concentration in µg/m^3

If HQ is less than one ($HQ < 1$), then the concentration is less than RfC value and no action is required That is, $HQ < 1$ is considered safe. If HQ is greater than 1, it does not necessarily mean that there will be adverse effects. It is more appropriate to use it as a warning of potential risk (US EPA, 2013).

RESULTS AND DISCUSSION

Evaluation of model results

(Fig. 2) shows that the prevailing wind in the study area is from the southwest. The average wind speed is 4.8 m/s. (Fig. 5-10) shows both short and long-term dispersion of CO, SO_2, and NO. Where the short term of dispersion of CO and SO_2 are 1-hour and for NO it is 24-hour; while long-term dispersion of NO and SO_2 are annual and for CO it is 8-hours. The annual ground level maximum concentrations of all pollutants occurred 9.24 km from the source in a northeast direction. The 1-hour maximum ground level concentration of all pollutants occurred 1.03 km from the source in a southeast direction. The 8-hour and 24-hour maximum ground-level concentrations of all pollutants occurred 1.12 km from the source in a southeast direction. Of the 20 receptors shown in (Fig. 3), E is predicted to have the highest annual concentration of all pollutants. Receptor 1 experienced the 1-hour highest concentration of all pollutants and receptor V experienced the highest 8-hour and daily con-centration of all pollutants.

The predicted maximum and minimum concentrations for short-term and long-term averages are summarized in Table 3. Ambient concentrations are compared with the National Environmental Quality Standards (NEQS) guidelines by Pakistan EPA in Table 3, which showed that exposure of receptors with-in a radius of ten kms around the source is low and within acceptable limits.

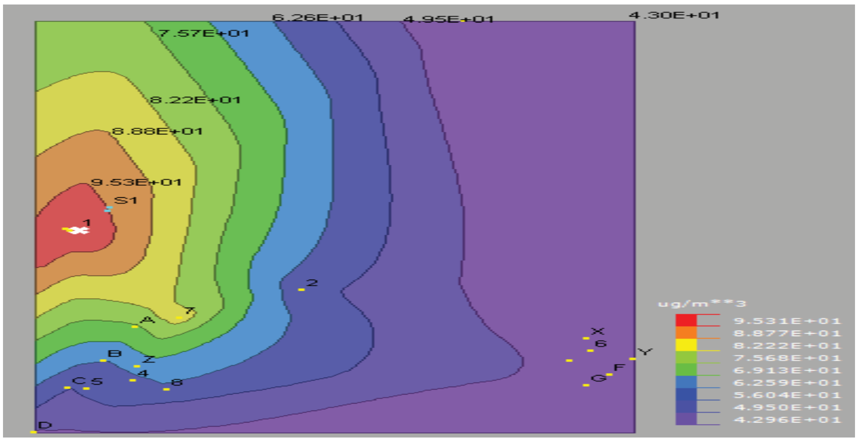


Fig. 5 1-hour average SO_2 concentration.

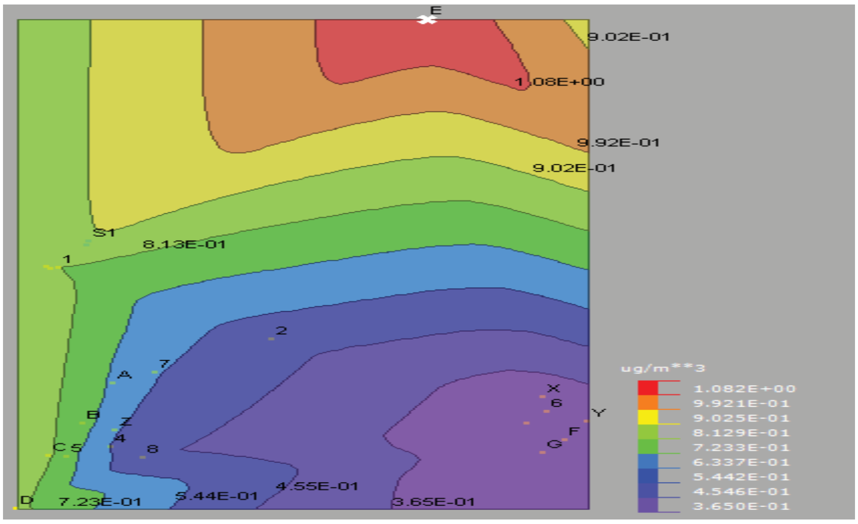


Fig. 6 Annual average SO_2 concentrations.

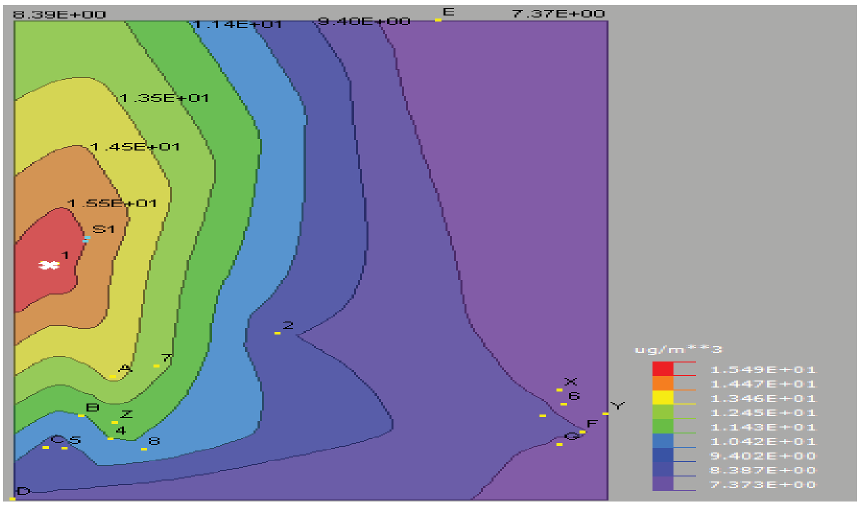


Fig. 7 1-hour average CO concentration.

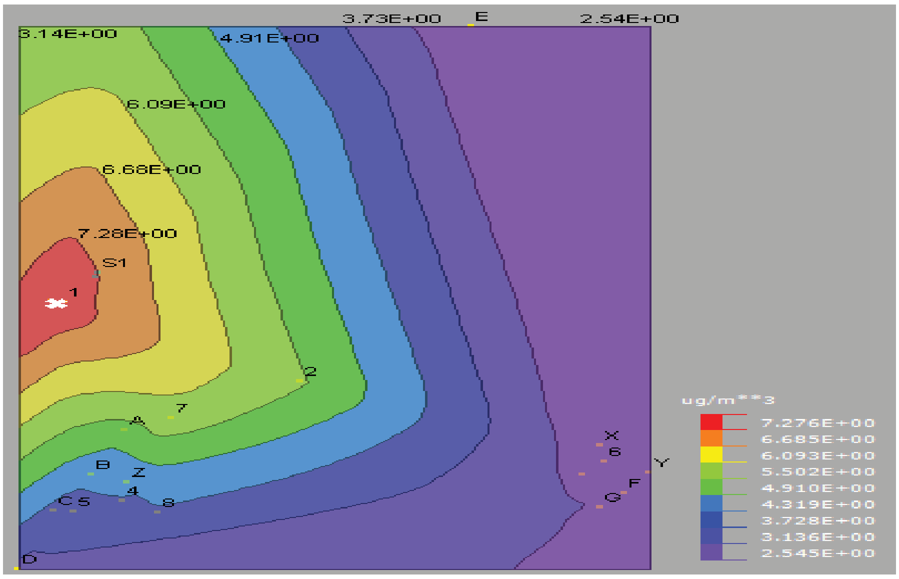


Fig. 8 8-hour average CO concentration.

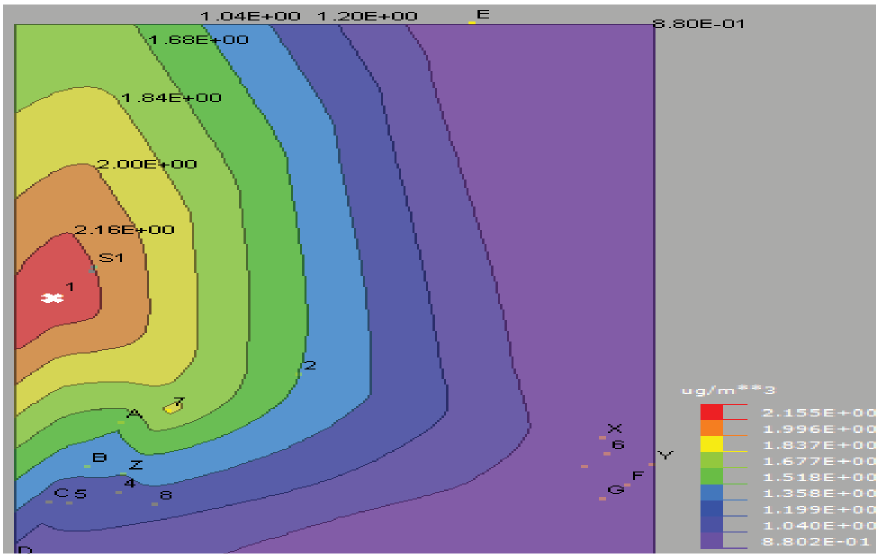


Fig. 9 24-hour average NO concentration.

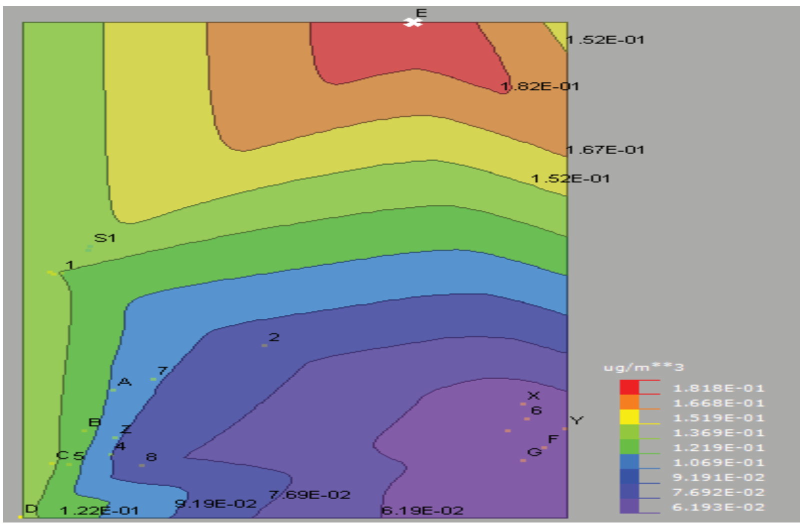


Fig. 10 Annual average NO concentration.

Table 3. Predicted ground level maximum and minimum concentration compared with NEQS.

Pollutants	Short term average concentration (μg/m³)	NEQS guideline (μg/m³)	Long-term average concentration (μg/m³)	NEQS guideline (μg/m³)
SO_2 (max)	101.86[d]	750	1.17[a]	80
SO_2 (min)	43.[d]	750	0.365[a]	80
CO (max)	16.5[d]	30000	7.9[c]	10000
NO (max)	2.3[b]	40	0.20[a]	40

[a]Annual Concentration [d] one-hour concentration
[C]8-hour concentration [b] 24- hour concentration

Health risk of pollutants

The hazards quotients (HQs) of SO_2, CO and NO were calculated to determine short-term and long-term health risk and are presented in Table 4. The HQs for short-term exposure to SO_2 exceed one at every receptor, maximum and minimum values of HQ are 3.6 and 1.5 respectively. Long-term (annual) concentrations of SO_2 are less than one. It is clear that for reduction of health risk from air pollutants meteorological conditions play an important role. The HQs for NO & CO are less than one at all locations and durations. And are not expected to cause a human health risk within a ten km radius of the thermal power station Jamshoro.

Table 4. Assessment of health effects from pollutants studied at the thermal power station.

Pollutants	Predicted ambient air exposure (μg/m³)		RfC (μg/m³)	Hazard Quotients	
	Short-term	Long-term		Short-term	Long-term
$SO_{2\,(max)}$	101.86[d]	1.17[a]	28.2[x]	3.6	0.04
$SO_{2\,(min)}$	43.[d]	0.374[a]		1.5	0.013
$NO_{(max)}$	2.3[b]	0.201[a]	40[y]	0.058	0.005
$CO_{(max)}$	16.5[d]	7.9[a]	10000[y z]	0.0016	0.0008

[a]annual concentration
[b]24-hour concentration
[c] 8-hour concentration
[d] 1-hour concentration
[x]Agency for toxic substance and diseases registry (ATSDR) (1998)
[y]National Environmental Quality Standards (NEQS) by Pakistan EPA
[z]US Environmental Protection Agency (US EPA)

Similar health risk analysis of SO_2 and mercury (Hg) emissions were performed by Mokhtar et al., (2014). That study shows an inhalation HQ for short-term and long-term SO_2 values of 1.8 and 0.1 and for Hg, 0.0014 and 0.0009 respectively (Mokhtar, *et al*., 2014).

CONCLUSION

Dispersion calculations were conducted to predict the ground-level concentrations of CO, NO, and SO_2 being emitted from the Jamshoro Thermal Power Station (JTPS). Twenty sensitive locations were identified in the ten km radius of the source, and dispersion calculations were performed using the AERMOD model. The results were compared with ambient air and health risk assessment guideline. In the health risk assessment, three pollutants (SO_2, NO, CO) were assessed for short-term and long-term health impacts. The comparison of ground-level concentrations with NEQS guidelines showed that the concentration was generally acceptable.

According to the human health risk assessment, we found that SO_2 caused a short-term health risk, while long-term concentrations of SO_2 were acceptable. The study also found that the short-term and long-term exposure to CO and NO do not cause adverse health effects hence, except for SO_2, short-term and long-term concentrations of all other pollutants were within acceptable limits. However, the researchers recommend that air pollution control devices such as dry and wet scrubbers and electrostatic precipitators should be maintained or replaced for existing thermal power plants. Low sulfur content fuel should be used, emission rates collected from TPS Jamshoro should be compared with the US EPA AP-42 method for calculating emission rates and a detailed assessment should be carried out by taking ambient air sample from theses sensitive locations, as these pollutants are not only being emitted from the thermal power station at Jamshoro but also are being emitted from vehicles and from the Lakhra coal-fired power Plant, located at a distance of 25 km from the JTPS. Existing regulation needs to be enforced for excess emissions.

Outcomes of this study could help the Pakistan EPA in revising National Environmental Quality Standards (NEQS). The study will be useful for other researchers working on the treatment of receptors as they can use the findings of this study to treat and use prevention measures for different diseases due to air pollution such as asthma and bronchitis etc. This study will also be useful for researchers working on air pollution levels in the city as one of the main air pollution sources in the Jamshoro city is JTPS. Similarly, the city administration, SEPA, etc. can use the results of this study for the treatment of different sources.

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APPENDIX 1

Calculation of Emissions from under expansion coal-fired power plant at Jamshoro thermal power plant

As per Air Pollution Control Book by Noel DE Nevers emissions factors for sub-bituminous coal without control equipment's for wall fired, dry bottom boiler are

PM_{10}	2.3A	where A is percentage of ash
SOx	38S	where S is percentage of Sulfur
NOx	21.7	
CO	0.5	

According to the petition for tariff determination, under expansion coal-fired power plant will use sub-bituminous coal and it will consume 3.4 million tonnes of coal which is equal to 3.4* 2204/2000 = 3.7468 million tons.

As per www.thebalance.com Sub-bituminous coal contain 0.5-2.0% sulfur and 10% of Ash for calculation we take an average of sulfur which is 1.25%

The formula for emission rate

$$(Emission\ rate) = (emission\ factor) \times (coal\ consumption\ rate)$$

For PM_{10}

$$(PM_{10} emission\ rate) = (emission\ factor) \times (coal\ consumption\ rate)$$

$$(PM_{10} emission\ rate) = (2.3A\ lb / ton\ coal\ consumption) \times (3.7468\ Mtons / year)$$

$$(PM_{10} emission\ rate) = (2.3 \times 10) \times (3.7468) = 86.1764\ million\ lb / year = 86176.4\ kilo\ lb / year$$

As we know that 1tonne = 2204lb, than

(PM_{10} emission rate) = 86176.4/2204

(PM_{10} emission rate) = 39 ktonnes/year

For SOx

$$(SO_x emission\ rate) = (emission\ factor) \times (coal\ consumption\ rate)$$

$$(SO_x emission\ rate) = 38S\ lb / ton\ coal\ consumption \times (3.7468\ Mtons / year)$$

$$(SO_x emission\ rate) = (38 \times 1.25) \times 3.7468 = 178\ million\ lb / year = 178000\ kilo\ lb / year$$

As we know that 1tonne = 2204 lb, then

(SO_x emission rate) = 178000/2204

(SOx emission rate) = 81 ktonnes/year

For NOx

$$\left(NO_x emission\ rate\right) = \left(emission\ factor\right) \times \left(coal\ consumption\ rate\right)$$

$$\left(NO_x emission\ rate\right) = \left(21.7\ lb/ton\ coal\ consumption\right) \times \left(3.7468\ Mtons/year\right)$$

$$\left(NO_x emission\ rate\right) = \left(21.7\right) \times \left(3.7468\right) = 81.3\ million\ lb/year = 81300\ kilo\ lb/year$$

As we know that 1ton = 2204 lb, then

(NOx emission rate) = 81300/2204

(NOx emission rate) = 37 ktonnes/year

For CO

$$\left(CO\,emission\ rate\right) = \left(emission\ factor\right) \times \left(coal\ consumption\ rate\right)$$

$$\left(CO\,emission\ rate\right) = \left(0.5\right) \times \left(3.74680\right) = 1.8734\ million\ lb/year = 1873.4\ kilo\ lb/year$$

$$\left(CO\,emission\ rate\right) = \left(0.5\right) \times \left(3.74680\right) = 1.8734\ million\ lb/year = 1873.4\ kilo\ lb/year$$

As we know that 1tonne = 2204lb, than

(CO emission rate)= 1873.4/2204

(CO emission rate) = 0.85 ktonnes/year