SIMULATION OF AIR POLLUTANTS DISPERSION OF A CEMENT INDUSTRY AT KALLAR KAHAR USING DISPER MODELLING SYSTEM

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ABSTRACT: The present study was done to determine the pollutants that cause serious threat to the environment as well as have negative impacts on human health of the nearby community. DISPER 3.0 modelling system was used to simulate concentration of air pollutants including particulate matter, oxides of sulfur (SO_x), Oxides of Nitrogen (NO_x) and carbon monoxide (CO) from stack of a cement industry. Screen view software was used for measuring the pollutants' concentration versus distance. WRPLOT was used to draw annual wind rose plot. Horiba ambient air quality analysers were used to monitor actual level of pollutants. The similarity index between predicted and actual results of PM, SO_x, NO_x and CO was 31%, 60%, 93% and 89.3% respectively. A significant correlation (r-value > 0.90) was observed for modeled and actual results. Model results concluded that SO_x is the major pollutant deteriorating the health and environment of the surrounding community. Annual windrose diagram showed that community on south and east receives most of the pollution from the factory and area on the north side was the least affected one. On the other hand, actual data showed high concentration of PM but low concentration of SO_x.

Keywords: air pollution, industrial emissions, dispersion modelling, cement industry.

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INTRODUCTION

Cement industry plays vital role in economic development of both developed and developing countries. Globally there are around 150 countries contributing in the production of cement. Prominent cement producer are China, USA and India (Zeb *et al*. 2019). In Pakistan, cement manufacturing is almost 5.5% of the total production in industries. In 1921, first cement plant was established in Wah, Punjab with the production of 44,500 tons (Ghulam and Jaffry, 2015). Cement industry of Pakistan is the 14th largest industry. Target cement plant is the largest producer of cement and now brownfield plant has been established in the northern area having the production capacity of 6000 tpd. In 2016, an increase of 17.6% in cement consumption has been observed and is reached 34.7Mt due to increase in housing schemes construction activities and government infrastructures (Zeb 2019). With respect to the report of International Cement Review report, for Pakistan, 2018 is a bumper year as production capacity increased to 95%. There will be significant effects of China–Pakistan Economic Corridor on production of cement in Pakistan (Nayyar *et al*., 2019). With the increase in the cement production and demand, air pollutants releasing from cement industry are also of serious concern which are responsible for air pollution. Air pollution is receiving considerable attention because it is one of main sources of air pollution (Emetere and Akinyemi, 2013). Production of cement produces different kinds of pollutants into the atmosphere that affect seriously human health, aquatic ecosystem, forests, vegetation and causes injuries to animals. These pollutants cause various health related issues among the local people living around industries (Singh and Pandey, 2011). Harmful effects are due to the different processes (milling, pyro-processing, quarrying of raw material and cooling) involved in the production of cement resulting in the emission of different pollutants i.e carbon monoxide (CO), Nitrogen oxide (NO) etc. (Adam, 2007). Particulate matter emitted during the process of kiln and processing of raw material (Farhadi *et al*., 2017; Goudarzi *et al*. 2016). Whereas, oxides of sulfur, carbon and nitrogen are produced as a byproduct of power generation fuel combustion (Khaniabadi *et al*., 2016). When limestone is used as a raw material, oxidation of volatile sulfur causes production of SO_2 (Jeff and Hans, 2014).

Human population in the nearby community of cement plant is frequently concerned due to potential impacts on health (Schuhmacher *et al*., 2009). Acute and chronic exposure to these pollutants is the main cause of mortality due to respiratory conditions, increase level of hospital admission and cardiovascular diseases (Khaniabadi *et al*., 2016). Fine Particulate matters are the main cause of lung diseases such as bronchitis, asthma, heart attacks, cardiac arrhythmias and increase susceptibility to respiratory infections (Engelbrech *et al*., 2013; Sicard *et al*., 2010). NOx inhalation causes worst effect on the human respiratory system and badly affects the health condition of asthma patients (Vallero 2014). SOx can cause chest pains, eye irritation, breathing problems and low resistance to lung and heart diseases (Liu *et al*., 2016).

Different actual and theoretical methods are used to measure pollutant concentration in ambient air. Both actual and theoretical methods are reliable but most of the time direct measurement of pollutants is not possible at any time and point. So, in this condition dispersion models can be used to measure pollutant concentration. Dispersion modeling is very successful technique for simulation and forecasting of dispersion of pollutants (Ma *et al*., 2013). It has many advantages such as short- and long-term estimation of contaminants at specific points of monitoring. It can also calculate dispersion distance from the point source. These models are used in risk analysis, source apportionment studies, emergency planning, and environmental impact assessments.

The major objective of the study is to determine the ground level air quality of the surroundings of the cement industry at Kallar Kahar within a radius of 15000 meters in order to determine the impact of cement plant on the nearby community.

MATERIALS AND METHODS

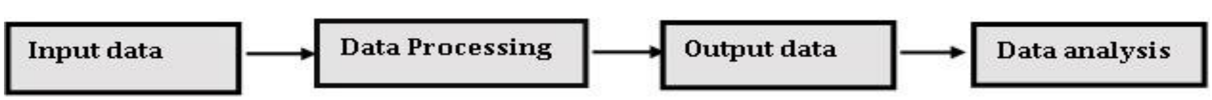
Study Area: The target industry (X cement plant) is located at Kallar Kahar in the Chakwal district in the Province of Punjab, Pakistan. Chakwal district is bordered by Jhelum (East), Mianwali (West), Rawalpindi (North East), Attock (North West) and Khushab (South). Motorway M2 also passes through Chakwal district. Target cement industry is a market leader cement industry in Pakistan in term of capacity as well as in term of sale. This industry plant has production capacity of 6700 ton. During the production of cement, there is exposure of people with various types of pollutants i.e. SO_x, NO_x, Particulate matter (PM_{10}, $PM_{2.5}$), CO and O_3 released from the stack. Therefore, stack emission was selected as pollution source for research.

Actual Data Collection: For ambient air quality monitoring by actual means, Horiba ambient air analyzers was used. Chemiluminescence (ISO7996) method was used to measure NOx concentration by using APNA-370. For measurement of carbon mono-oxide concentration (COx), non-dispersive infrared ray method (ISO4224) was applied and analyzer was Model APMA-370, Horiba. For SOx analysis, APSA-370, Horiba was used and its detection method was U.V. fluorescence (ISO10498). PM sampler was used for suspended particulate matter concentration and applied method was Beta Attenuation Method.

Windrose Diagram: Wind rose diagram was exercised to determine the frequency, speed and direction of wind. WRPLOT view version 8.0.2 was used for this purpose. Windrose was constructed by using the annual meteorological data of the last year.

Dispersion Modeling: Air dispersion modeling is carried out of the distinct stack to measure its dispersion concentration at ground level. Pollutants (CO, SOx, NOx and PM) concentrations had been measured by using Software. It is a computational method for predicting concentrations downwind of a pollutant source on the basis of knowledge of the emissions characteristics including plume temperature, stack exit velocity, stack diameter, etc., terrain characteristics including local topography, surface roughness and nearby buildings and atmospheric state including wind speed, mixing height, stability, etc.

For air pollution dispersion modeling two softwares i.e. DISPER-version 3.0, and SCREEN 3-version 4.0.1 were exercised for pollutant concentration of concerned project. Pollution source plays a critical in atmospheric pollution. On the basis of emission source and meteorological condition, pollutant dispersion concentration has been calculated. Air pollutant dispersion modelling process that get through is given below.



Input data includes prevailing meteorological conditions and emission source information.
Pasquill stability and mixing height are important features of the input data. In input data, Pasquill-Gifford (PG) Stability classification was used in the study. The mixing height is the height where the atmosphere is uniformly mixed and it is measured by upper atmosphere temperature inversions or wind shear (changes in speed of wind with height).

Statistical Analysis: For comparison, percentage difference and determination of correlation between actual and modeled results MS-Excel 2010 was used.

Prominent pollutants emanating from the cement industries include CO, NOx, SOx and Particulate matter which have significant harmful and environmental degradation potential. To determine the air quality of Kallar Kahar and its surrounding micro-meterological data play an important part in the analysis of the impact of the pollutants emitted from the stack of the industry. Wind rose diagram and Disper 3.0 software was used in this study to simulate the dispersion of pollutants in the surrounding of the cement plant and then compared with the actual values taken from the same points during monitoring.

Windrose Analysis: Windrose diagram illustrates the direction, frequency and speed of wind of the study area by central coordinate system (Figure 1). Point source input data for windrose is given in the table 1. Stack impart the role of pollutant emission and is designed pertaining to pollutant dispersion. Stacks with different heights having different dispersion rate.

Table 1. Point source input data for windrose

Input data	Units
Physical stack height	76m
Stack exit temperature	430K
Stack gas exit velocity	20m/s
Stack inside diameter	2.5
Source type	Coal

Figure 1. Site map of the cement industry in Kallar Kahar

RESULTS AND DISCUSSION

Windrose diagram showed that most of the time wind was prevailing toward south. It means that areas present in the south of the industry were highly affected by the pollutants released from the cement factory. In the present study windrose diagram (blowing to) was overlaid over the study area to clearly demonstrate the areas affected by the wind direction, direction of plume and dispersion of pollutants in the studied area. It was found that wind direction has a significant effect on the dispersion of pollutants (Atabi and Mirzahosseini, 2013). A study was conducted in detail the meteorological parameters for an air polluting plant from September 1998-August 1999 (Gujral *et al*., 2001). On the basis of suspended particulate matter he concluded that meteorological parameters are important and involve in the enhancement of the pollution potential of the area. Stack height is another important factor in distribution of pollutants concentration (Sriram and Gopalasamy, 2001).

Windrose diagram only showed the affected area by cement plant but the concentration of pollutants was determined by the using Disper 3.0 software. In this software, concentration of indivisual pollutant can be determined. Meteorological data is also used as input data for dispersion modeling. Important meteorological parameters include wind speed and direction (for transport), turbulence and mixing height of the lower boundary layer (for dispersion). In modeling study, meteorological data is considered as a critical input data.

The following input data is entered into the software (table 2).

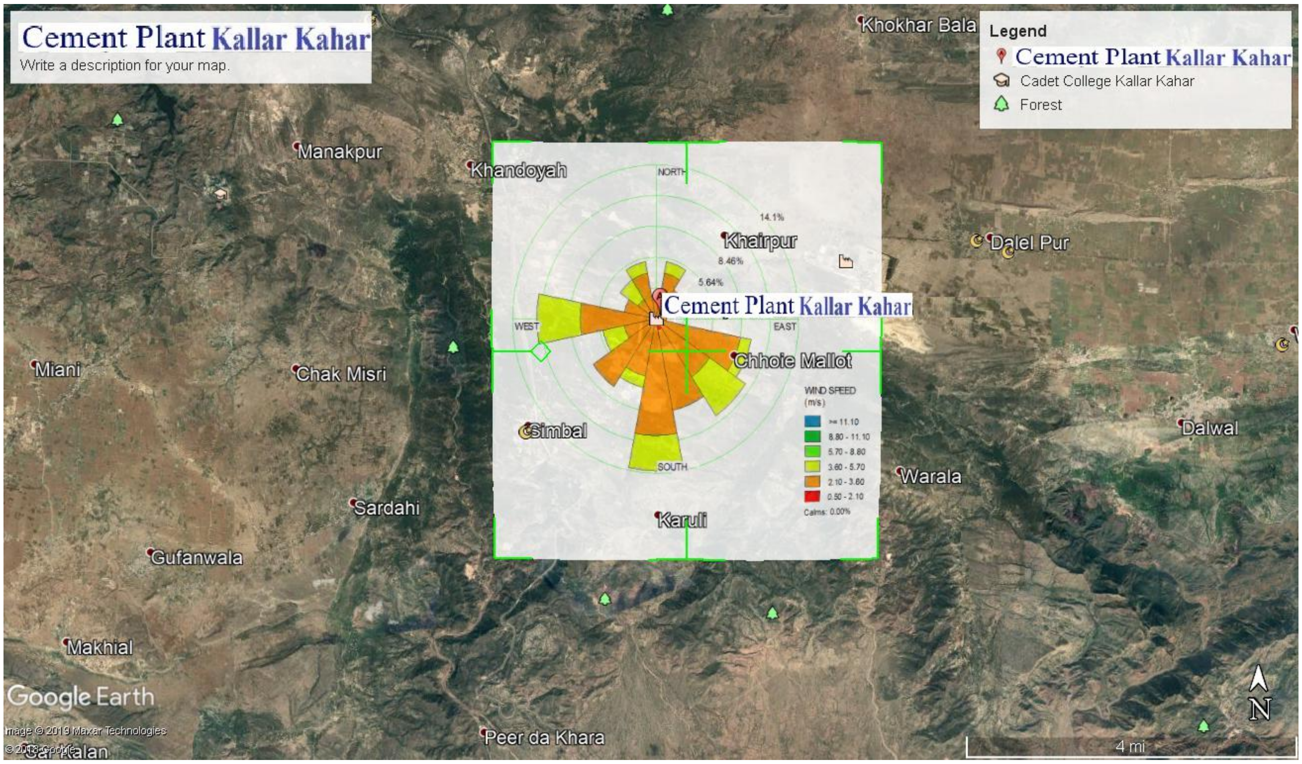


Figure 2. Windrose diagram (blowing to) overlay on map of study area

Table 2. Input data used for DISPER 3.0 version.

Input Data	Units
Pasquill stability	B
Wind speed at reference anemometer height	3m/s
Wind angle	200 degree
Ambient temperature	310K
Mixing height	250m
Anemometer height	10m

Figure 3(a) showed that the maximum concentration of PM was 24.8749µg/m^3 which is within the permissible limit. The maximum observed value of NO_x was 16.8987µg/m^3 at nearby area of the cement plant which is within the permissible limit of the WHO guidelines (40µg/m^3) while minimum concentration was 4.2247µg/m^3. NOx is usually released by the processor units (kiln and calciner) that used fossil fuel as energy source. The maximum value of SOx predicted by the model was 205.4912µg/m^3 which was beyond the permissible limit of the WHO guidelines (20µg/m^3) and the minimum SOx concentration measured by the software was 51.3782µg/m^3. Maximum value of CO observed was 0.8449µg/m^3 and the minimum value 0.2112µg/m^3. Mostly carbon monoxide is released due to incomplete burning of fuel. Results of dispersion modelling showed that PM, NOx and CO were in permissible range (Table-3). While SOx values were beyond the permissible limit. When modeled values were compared with the actual values it was concluded that observed concentrations of PM were high than the predicted ones while, actual concentrations of SOx were low than the modelled values (Figure 4). On the other hand, results also showed that concentration of PM, NOx and CO obtained from dispersion model were within the permissible limit whereas SOx concentration was very high. But actual concentration of SOx obtained from the same point was low as compared to model values. Similar trend was described earlier by the Chervenkov (2013) when the concentration of the harmful substances such as course PM (PM10), SO_2, CO, NO_2, ozone O_3 and NH_3 in the surface layer taken from modelling simulations were obtained to estimate the statistical values. These values were further used for comparison with the EC directives. So, from the above results there is a need to understand that the predicted results should be carefully accepted because model evaluation is just estimation to a set of complex processes. Similarity Index between actual and theoretical readings was 31% for PM concentration. Contribution of PM from other sources like dust may enhance the level of actual PM as compared to modeled results. On the other hand, 60%, 93% and 89.3% similarity was observed in concentrations of SOx, NOx and CO respectively between theoretical and actual values. Although a significant correlation (r-value > 0.90) was observed for all monitored parameters.

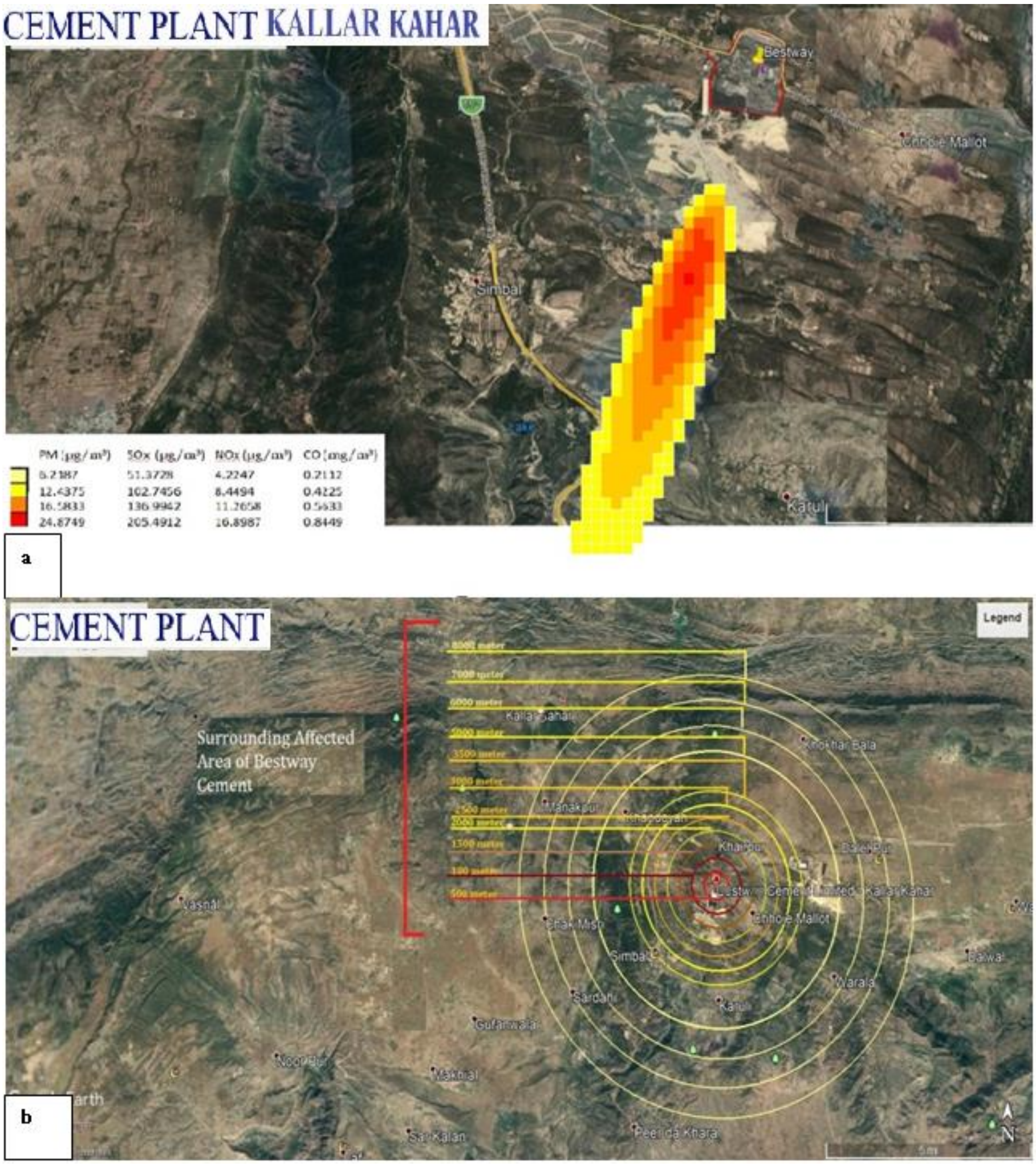


Figure 3. (a) Air dispersion modeling (b) Effected area around cement factory

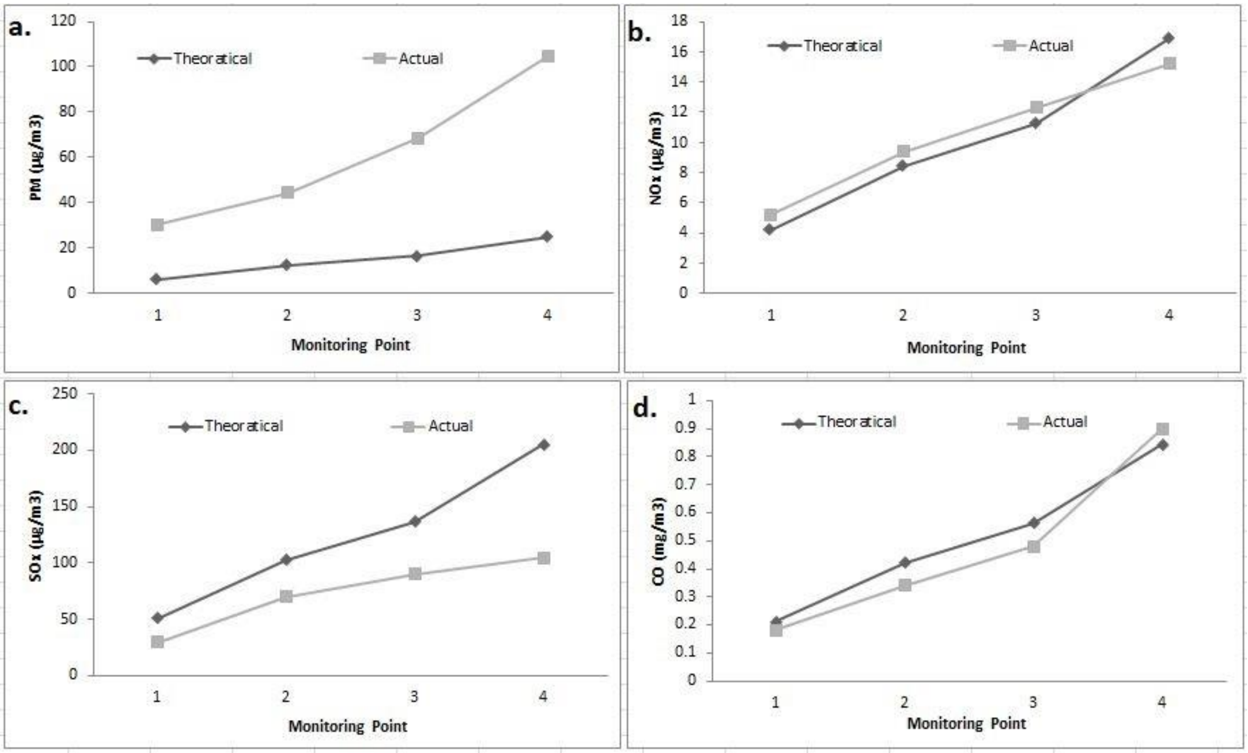


Figure 4. Comparison of actual and modeled results a. PM, b. NOx, c. SOx, d. CO.

Table 3. Maximum and minimum concentrations of pollutants measured by dispersion modelling

Sr. No	Pollutants	Mini. Conc. (µg/m^3)	Max. Conc. (µg/m^3)	WHO Guidelines 1999 (µg/m^3)	NEQS (µg/m^3)
1.	PM	6.2187	24.8749	-	500
2.	NOx	4.2247	16.8987	40	40
3.	SOx	51.3728	205.4912	20	120
4.	CO	0.2112	0.8449	-	5000

From the present study it can be concluded that overall management and control of air pollution is not satisfactory in terms of SOx concentration. According to Nielsen *et al*. (2011) increase in the concentration of SO_2 may be due to the increase in temperature and redox alternation. According to WHO guidelines, SOx has effects on respiratory system including lungs, also causes eyes irritation. SO_2 reacts with water in atmosphere and forms sulfuric acid (acidic deposition) that affects ecosystems.

SCREEN 3-version 4.0.1 was exercised to determine the pollutant concentration with respect to distance. Figure 5 clearly showed that particulate matter concentration (PM) is maximum (24.8) in the area at a distance of approximately 1000 meter from the cement plant. It gradually decreases with increase in distance from the pollutant source point. At distance of 1500 meter its minimum concentration was 6.2187µg/m^3. While NOx, SOx and CO concentrations were also maximum (16.8987, 205.49912 and 0.8449 µg/m^3, respectively) in the areas present at distance of 1000 meter while pollutant concentration decreased with gradual increase in distance to 15000 meter i.e 4.2247, 51.3728 and 0.2112 µg/m^3 respectively. Khairpur and Chhoie Mallot are highly effected areas by the pollutants especially SOx while its effects decreased as distance from the cement industry increased (Figure 5).

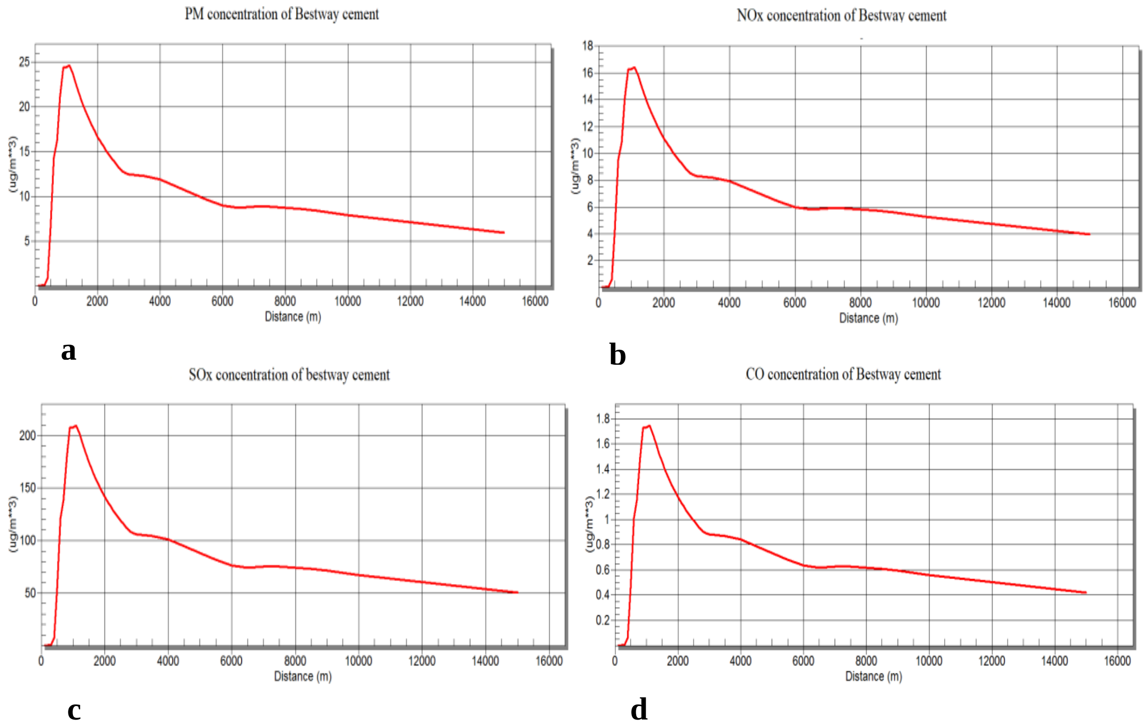


Figure 5. Graphical representation of the pollutants concentration v/s distance by screen

Conclusion: Air pollutants dispersion is one of the factors that affects the ecosystem and environment of the adjacent areas and can threaten the lives of people living in the locality of these units in the long run. In the present study, the dispersion model was used for an appropriate determination of maximum and minimum concentration of all pollutants (PM, SOx, NOx and CO) affecting the population, emitted from the point sources and actual values were compared with the predicted ones. Based on the model results, it can be concluded that value of CO, NO_2 and PM is less than the limit value which showed that heating plant had no negative impacts on the quality of ambient air. While high concentration of SOx badly affects the surrounding area especially at a distance of 1,000 meter. But actual results were different in case of SO_x. Its concentration was low and within the permissible limit.

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