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Examining Contamination of Arsenic in Soil Around Thermal Power Plant at Dadri in India

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ABSTRACT

Coal fired thermal power plant (TPP) serves as point source releasing hazardous heavy metals in the environment contributed from burning of coal for electricity generation. This causes altered physicochemical properties of soil. Arsenic (As) is highly toxic in nature which gets transferred to the soil environment by varied pathways. The present study attempts to measure the physicochemical properties and arsenic contamination in soil around a coal fired thermal power plant in India for two consecutive years (2017-19). The soil pH, moisture, conductivity, water holding capacity, nitrogen, phosphate, potassium, manganese, iron and arsenic were measured in six villages located within 0-10km around TPP. Results suggest soil from the villages to be slightly alkaline with good water holding capacity and soil moisture. The soil was manganese deficient however the levels of nitrate, phosphate and potassium were similar to that of agricultural soil suggesting negligible impact of TPP on soil quality in the region. Low arsenic contamination (though within permissible limits), at site 4 (Piyawali) located within 0-5 km and in windward direction from TPP was noted. Traces of as was also measured at site 2 (Jarcha) and site 3 (Khatana) which were within 5-10 km of TPP and in the windward direction. Results indicate that arsenic from the emissions migrate with the wind to Jarcha and Khatana whereas it directly falls and retains at Piyawali which is in the leeward direction. Thus, a significant relation between movement of arsenic and the position of the village, distance and direction of wind with respect to TPP is evident. The soil pollution index (Pi) for arsenic revealed the Pi values to be <1 in all seasons suggesting that though arsenic is present in the soils of the villages near the thermal power plant, it may not be contributing largely towards the pollution in the soil. Application of zinc to bind arsenic electrostatically in the soil matrix is therefore recommended to mitigate arsenic or growing of non-edible or energy rich crops will be helpful. Moreover, power plants be geared for arsenic containment measures to minimize input of arsenic in soil environment.

Keywords- Arsenic; Coal; Soil; Thermal Power Plant.

I. INTRODUCTION

India has a large fleet of 267 coal-fired thermal power plants (CEA, 2020). Figure 1 shows the major thermal power plants in India. Of these, 19 are located in the state of Uttar Pradesh alone totalling to a capacity of 22409 MW.

Figure 1: Map showing major thermal power plants in India. (Source: Maps of India, 2020).

With the growth and development of the country, increasing demand for power generation from coal is there, from both supercritical and subcritical plants. It is the thermal efficiency of the power plant which decides the amount of KWh of electricity produced. Owing to lower efficiency of coal-fired power plants in India as compared with those in United States (Cropper et al., 2012), the gap between the energy demand and supply in India continues to exist. The nation strives towards renovation and modernization of old units or retiring the old less efficient power plants in addition to introducing newer advanced technologies with an aim to reduce national carbon growth. Moreover, the country continues to urbanize and develop the manufacturing sector in the fast-growing economy fulfilled by various energy sources however coal still

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remains the foremost source of energy supply, India's coal reserves are the second-largest in the world after China (Figure 2).

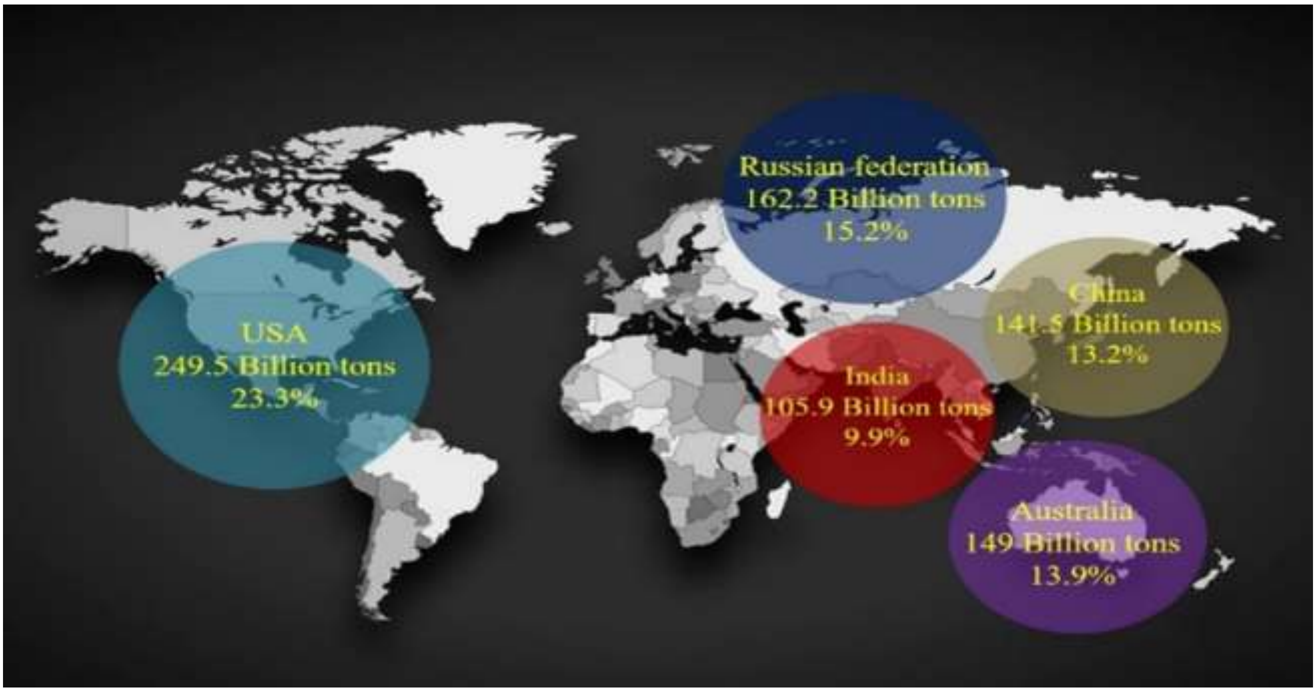

Figure 2. Coal reserves of major countries across the globe (Source: IEA, 2019).

Greater connection to the electricity grid for the rural population, industrial growth, and the government's massive infrastructure program have contributed to higher coal growth in the last two years (2017 and 2018). IEA India ranks as the second-largest coal producer in the world on a volumetric basis (IEA, 2020). The majority of Indian coal deposits are of drift origin, belonging to the lower Gondwana period. It is the eastern and southern parts of the country that has coal reserves. Geologically, formed from ancient vegetation by the process of "coalification" (Coal Directory of India, 2017-18). Coal occurs as layers or seams, ranging in thickness from millimeters to many tens of meters. The composition of coal is largely of carbon (50–98%), hydrogen (3–13%) and oxygen, with little amount of sulfur, nitrogen and other elements. The liberation characteristics of Indian coals, specifically non-coking coals, are very poor and come under the category of problematic washability characteristics. The total coal reserve in India is 253 billion tons. The of which around 15% of the total reserve is coking coal and the rest 85% is non-coking coal. Non-coking coal is fall under F-grade coal, which with nearly 40% ash content (Dwari and Rao, 2007). The climatic conditions at Dadri are tropical with an average temperature of 32 degree celsius and average annual rainfall of 1100 mm. The soil is largely alluvial and the main crops are rice and wheat. Thermal power plant at Dadri is the primary electricity source for Delhi and Uttar Pradesh consuming over 21,03,722MT of coal in the year 2016-17 for power generation (CERC, 2018). NTPC Dadri runs in a hybrid mode as it has coal based thermal power plant and gas based thermal plant of 1820MW and 817MW, respectively (CEA, 2020).

II. MATERIALS AND METHODS

Sample collection

The samples were collected through random sampling technique from the agricultural fields at 6 different sites (Table 1) [Chauna (site1)], [Jarcha (site 2)], [Khatana (site 3)], [Piyawali (site 4)], [Ranauli (site 5)] and [Sidhipur (site 6)] villages located at varying distance within 01 to 10 km of the thermal power plant at Dadri. The soil samples were collected thrice a year during post monsoon (Oct to Jan), pre monsoon (Feb to May) and monsoon (June to September) seasons for the years 2017-18 and 2018-19 from a depth of 25cm and stored separately in labelled plastic bags. Fresh weight, pH and conductivity of the samples were noted soil sample were kept for oven drying for 2-3 days at 70^0C. Dry weight of the samples were recorded. Soil physico-chemical parameters were analysed as accepted by Indian Standards. Table 2 shows standard analytical methods used for soil physico-chemical parameters analysed using the standard protocols as accepted by Indian Standards and Procedures.

Table 1: Sampling sites with coordinates within 0-10 km of coal fired Thermal Power Plant (TPP) at Dadri along with prevailing wind direction

Sampling Sites	Name of village and distance from TPP (km)	Wind direction	Coordinates
Site 1	Chauna (0-4.5)	Leeward	28°, 60', 80", N; 77°, 33', 51", E
Site 2	Jarcha (0-5)	Windward	28°, 34', 02", N; 77°, 39', 22", E
Site 3	Khatana (0-5.5)	Windward	28°, 32', 55", N; 77°, 34', 54", E
Site 4	Piyawali (0-3.5)	Leeward	28°, 36', 33", N; 77°, 34', 39", E
Site 5	Ranauli (0-6)	Leeward	28°, 34', 4", N; 77°, 35', 20", E
Site 6	Siddhipur (0-10)	Leeward	28°, 38', 57", N ; 77°, 36', 07", E

Table 2: List of standard analytical method used for soil sample analysis as accepted by Indian Standards and Procedures

S. No.	Parameters	Unit	Method of analysis
1.	Total water holding capacity	%	IS.2720.2.1973
2.	pH	1-14	pH meter
3.	Conductivity	µS/cm	Potentiometric
4.	Nitrogen	mg/kg	Kjeldahl method (1883)
5.	Available Phosphorous	mg/kg	Olsen et al. (1954)
6.	Potassium	mg/kg	Flame photometer
7.	Iron	mg/kg	Atomic absorption spectrophotometer
8.	Manganese	mg/kg	Atomic absorption spectrophotometer
9.	Arsenic	mg/kg	Atomic absorption spectrophotometer
10.	Soil Pollution Index (Pi)	--	Ge et al. (2016)

Water holding capacity

Veihmeyer and Hendrickson (1931) defined the field capacity or the water holding capacity (WHC) as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially ceased. The stage of field capacity is attained in the field after 48–72 hours of saturation. It is the upper limit of plant-available soil moisture. Uniform plots of dimension 5 m × 5 m were selected. Weeds, pebbles, etc., around the plots were removed. Plots were filled with sufficient water to saturate the soil completely. Plot area was covered with a polyethylene sheet in order to check evaporation. A soil sample from the center of the plot was taken from 25-30 cm deep after 24 hours of saturation and the moisture content was determined daily until the values of successive days are nearly equal. The weight was recorded as:

Weight of empty moisture box = X;
Weight of moisture box + moist soil = Y;
Weight of moisture box + oven-dry soil = Z;

Repeat the above on the next day and so on until a constant Z value is reached. Daily readings were plotted on a graph, the lowest reading taken as the value of field capacity of the soil.

III. CALCULATION

Percentage of moisture in soil (1st day) = $\frac{Y-Z}{Z-X} \times 100 = a$

Where,
Moisture content in soil = $Y - Z$
Weight of oven-dry soil = $Z - X$

Soil pH

The soil pH is the negative logarithm of the active hydrogen ion (H^+) concentration in the soil solution. It is the measure of soil alkalinity, acidity or neutrality.10 g of soil sample was placed into a 100 ml beaker and 20 ml of water was added to it. Soil was allowed to absorb water without stirring and then was stirred thoroughly for 10 seconds using a glass rod. The suspension was shaken for 30 minutes and the pH was recorded on a calibrated pH meter. pH of soil samples was measured through electrodes using portable microprocessor-based water and soil testing kits.

Electrical Conductivity

Electrical conductivity (EC) is considered to be a measure of the dissolved salts in a solution. The EC reading is a measure of the soluble salt content in the extract, and an indication of salinity status of the soil sample. For estimating EC, 1:1 soil/water suspension

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was used. 40 g of soil was placed in a 250 ml Erlenmeyer flask, and 40 ml of distilled water was added. The flask was stoppered and shaken on a reciprocating shaker for one hour and filtered through No. 1 filter paper. The conductivity electrode of the microprocessor-based water and soil testing kit (Universal Bio, Germany) was calibrated and readings were noted down.

Nitrogen

Total N includes all forms of inorganic N, such as NH_4^{+}, NO_3^{-} and NH_2^{-}, and the organic N compounds such as proteins, amino acids and other derivatives. While organic N materials can be converted into simple inorganic ammoniacal salt by digestion with sulphuric acid, for reducing nitrates into ammoniacal form, the modified Kjeldahl method (1883) is adopted with the use of salicylic acid. At the end of digestion, all organic and inorganic salts are converted into ammonium form, which is distilled and estimated by using standard acid.

Available Phosphorus

The available Phosphorus (P) in soil sample was estimated by Olsen et al. (1954) for neutral and alkali soils.

Potassium

The Potassium (K) present in the soil samples was extracted with neutral ammonium acetate of 1 molarity and estimated with the help of a flame photometer following (Toth and Prince, 1949).

Iron and Manganese

The estimation of elements in the extract is done with the help of an Atomic Absorption Spectrophotometer (AAS) (Shimadzu, AA-6880, Japan) with DTPA-extractable micronutrient elements as proposed by Lindsay and Norvell (1978).

Arsenic

The arsenic in soil samples was estimated using Atomic Absorption spectroscopy (Shimadzu, AA-6880, Japan). An element-specific hollow cathode lamp was selected and was mounted on the AAS and the flame was started.

Soil Pollution Index

The permissible limit for arsenic is between 5 to 20 mg/kg (FAO/WHO, 2007). The Soil Pollution Index (Pi) was calculated to assess the environmental risks associated with soil contaminated with arsenic as given by Ge et al. (2016) with certain modifications (Khan et al. 2021). The threshold limit for arsenic was taken as 20 mg/kg. The Pi was calculated using the formula Pi= Ci/Si, where, Pi- Pollution index, Ci- Arsenic concentration in soil sample (mg/kg) and Si- Threshold limit of As in soil (mg/kg). The Pi calculated for the two consecutive years in the soil samples from six villages during the pre-monsoon, monsoon and post-monsoon periods were then compared to understand the suitability of soil for agricultural purposes.

IV. RESULTS AND DISCUSSION

The soil samples were collected from the six villages lying within 0-10 km from the thermal power plant. Random soil sampling was carried out thrice a year for post-monsoon (October to January), pre-monsoon (February to May) and monsoon (June to September) seasons for two consecutive years (2017-18 and 2018-19),from the agricultural fields at a depth of 25 cm. The soil samples were analysed for pH, soil moisture, conductivity, nitrate, phosphate and potassium and other elements as Fe, Mn and as using standard protocols.

The soil pH 3 was noted to be in the range from 7.4-9.1 suggesting that the soil in all the sites studied herein varied from neutral to alkaline in nature (Figure 3a). This variation in soil pH could be due to the fly ash properties of Indian coal from the thermal power plant (Adriano et al., 1980; Warren, 1992; Ghodrati et al., 1994) which gets transported and settles on the soil surface. The soil moisture (Figure 3b) was from 39.3%-59.0 % suggesting optimum soil moisture conditions in the villages supporting healthy growth and development of plants. Similarly, the soil conductivity was found in the range 30-161.3 µS/cm in all the six villages (Figure 3c).

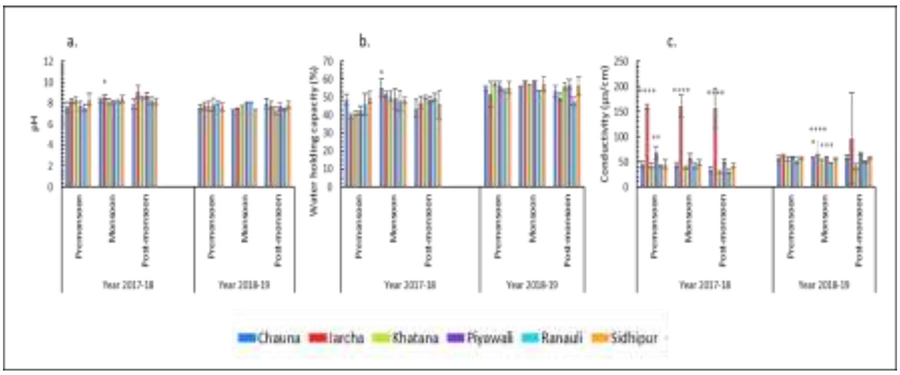

Figure 3: Soil physicochemical properties a. pH; b. soil moisture (%) and c. conductivity (µs/cm) in the six villages near the thermal power plant at Dadri in 2017-18 and 2018-19 for pre monsoon, monsoon and post monsoon periods. Values are mean of three replicates ± SD and mean difference is significant at 0.1 level.

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Typically, soil with conductivity below 1000 µS/cm is categorized as non-saline (USDA-NRCS 1998). The pH value of the saline soil is always less than 8.2 and more often near neutrality (Abrol et al., 1980). In our dataset the pH reflected non-saline nature of the soil at all the sites except for during post-monsoon season of the year 2017-18 where despite of the conductivity being very low, the pH was raised to 8.5, 8.7 and 9.1 at Khatana, Piyawali and Jarcha, respectively.

The levels of nitrate, phosphate, potassium, iron, manganese and arsenic in the soil samples from the six villages during pre-monsoon, monsoon and post-monsoon for the year 2017-2019 is shown as Figure 4 (a, b, c, d, e, & f) respectively. In our study, the nitrate (Figure 4a) concentrations in the soil were found to be ranging between 300.33 mg/kg to as high as 1019 mg/kg, whereas, the desired concentration of nitrates in the soil were 10-50 mg/kg (Pattison et al., 2010). Nitrates in agricultural fields are predominantly a result of application of commercial mineral fertilizers in the farms (Roy et al., 2006). Soil pH is also known to have effects on the nitrate concentrations in soil. as a higher pH (6-8) promotes nitrification. Surprisingly Jarcha and Khatana had lower nitrate levels in soils in all the seasons as compared to the rest of the villages. Any possibility of dilution due to rainfall is ruled out as the similar levels of nitrate were noted during all the three seasons (Figure 4a). Therefore, it appears that the lower nitrate levels in Jarcha and Khatana may be due to the location of these two villages near ponds and water bodies that are enriched with nitrate through agricultural run-off as these water bodies were observed to be under eutrophication.

Phosphate (Figure 4b) levels 2 in the soil samples were found to be ranging from 1.65-4.60 mg/kg, with lower phosphate concentrations in monsoon and post monsoon seasons during the first year of study. Lowered phosphate concentrations could be due to rigorous agricultural practices and the application of fertilizers observed in the area. Available phosphates (P) were found to be appropriate for healthy crop growth. The desired concentration of the potassium in agricultural soils is in 80-250 mg/kg (Shinde et al., 2018). However a low concentration *i.e* 3-7 mg/kg (Figure 4c) of potassium was noted in soils in the villages during 2 years of study period. The Sufficient limits for iron in soil are 9-18 mg/kg (Wani et al., 2013). Iron (Figure 4d) in the soil of Jarcha during 2017-18 was found to be sufficient. The Fe form that is predominantly taken up by plants is Fe^{2+}. The uptake of Fe is inhibited by phosphate levels resulting from the formation of insoluble iron phosphate (Loeppert and Hallmark, 1985). The levels of phosphate were sufficient or low in the soil which might be contributing towards proper Fe uptake in the soils near the Thermal Power Plant.

Manganese (Figure 4e) was found to be deficient in all of the soil samples at all times of study. The appropriate levels of manganese in soil to be able to promote healthy crop growth should be between 2.5-3.5 mg/kg (Wani et al., 2013). Chemically, Mn behaves in soil in the same way as Fe. It is taken up preferably by the plants as Mn^{2+} ions. Manganese and phosphate are mutually antagonistic (Moore et al., 1979). There can be varied reasons for manganese deficiency in the soil near thermal power plant. Firstly, because of the slightly alkaline nature of the soil and secondly due to calcareous nature of the alluvial soils that led to an increased phosphate levels.

Arsenic (Figure 4f) levels were high in the soil samples from village Piyawali throughout the study period, whereas in the villages Jarcha, Khatana and Ranauli, though the arsenic content in soil was lower during pre monsoon period it could not be detected in post-monsoon during 2017-18. On closer investigation of weather data, it was found that monsoon season of the year 2018 experienced nearly 160% more rainfall (175 mm) when compared to monsoon of 2017 (290 mm) (https://www.worldweatheronline.com/dadri-weather/haryana/in.aspx) suggesting that iron, arsenic and magnesium may experience dilution during the monsoon season of 2018 hence, their contribution in the soil may not be from the parent rock material alone, but from the coal combustion residues. As Piyawali (site 4) lies closest to TPP as compared with sites 2 and 3 it is more likely that higher arsenic levels be observed in soil samples from villages falling in the leeward direction of TPP (outside the impact zone of dominant winds) which was also observed at Piyawali (site 4) in our case. The observed concentrations of Arsenic, however lowered at site 2 (Jarcha) and 3 (Khatana) suggesting that the travel distance of as along with the wind flow from TPP is one of the major decisive factors among others for As movement in soil. Since varied arsenic contamination was noted in villages in the leeward direction from the TPP, it is possible that the impact zone of dominant winds and plume behaviour might have led to changes in the movement of arsenic and its atmospheric deposition in the soil.

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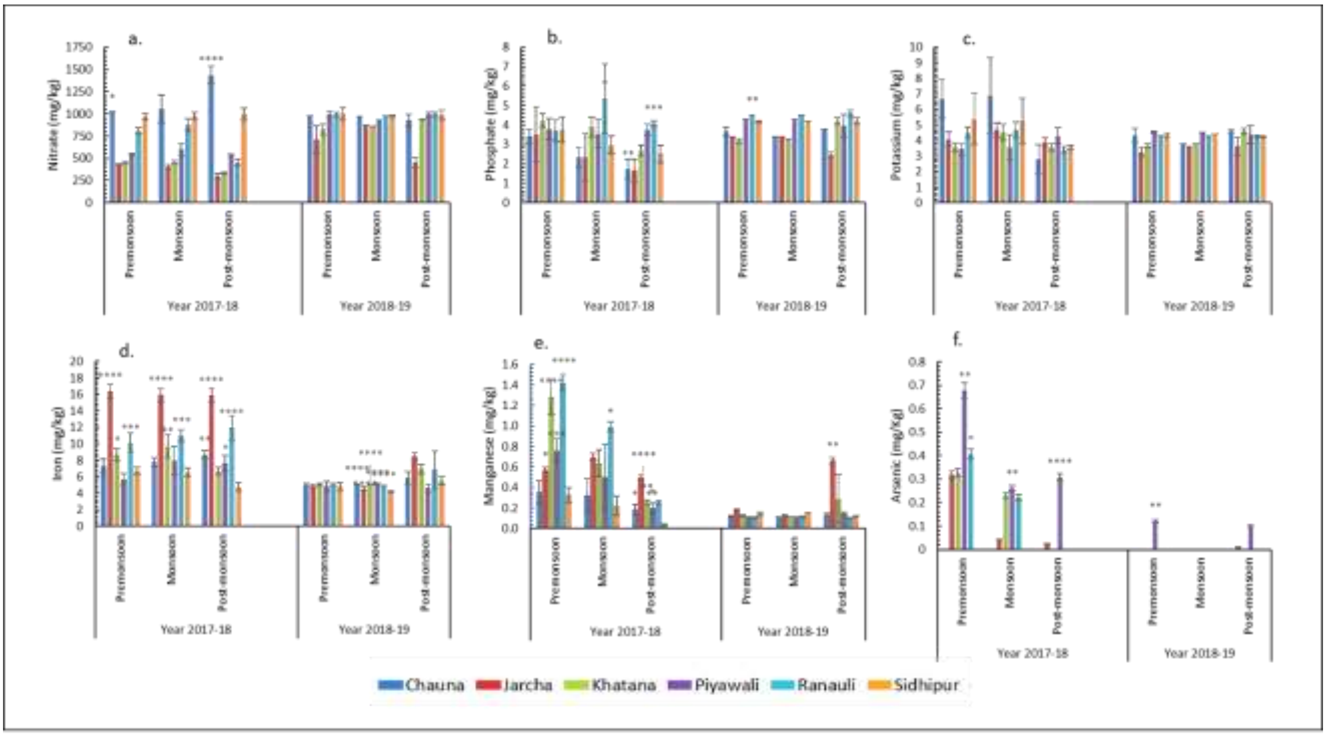

Figure 4: Levels of different elements in mg/kg in the six villages near the thermal power plant at Dadri in 2017-18 and 2018-19 for pre monsoon, monsoon and post monsoon periods. a. nitrate; b. phosphate; c. potassium; d. iron; e. manganese; f. arsenic. Values are mean of three replicates ± SD and mean difference is significant at 0.1 level.

Thermal power plants, have caused formation of anthropogenic landscapes like the ash disposal sites that in term have led to extreme heavy metal stress for plant survival (Pavlović et al., 2004). (Fiket et al., 2016) studied the impact of coal-fired TPP on the land surrounding in Croatia and reported that TPP affects the levels of rare earth elements in addition to heavy metals which actually lowers as the distance from TPP increases. These workers also demonstrated that the emissions of fly ash from the power plant is more intense in the direction of prevailing winds. Different researches have varied opinion upon the impact of heavy metals in soils in the nearby thermal power plant. Mandal and Sengupta (2006) in India and Goodarzi et al. (2006) in Canada analysed heavy metal contamination of flue gas, fly-ash, pond and soil near TPP and reported increased levels of the heavy metals in soil. Arsenic concentrations in the soil near the thermal power plant in Slovakia was reported to increase within a 5km radius of the TPP as compared to chromium, lead , zinc, copper, and cadmium (Keegan et al., 2006). Mehra et al. (1998) reported that a distance of 4km around TPP is more crucial to affect the soil quality, whereas Agrawal et al. (2010) determined and reported that the concentration of heavy metals is more significant between 2 and 4 km of the power plant, in the prevailing wind direction. Therefore, the soil pollution index(Pi) was calculated (Table 3) for arsenic which revealed the Pi values to be <1 in all seasons during 2017-18 and 2018-19 suggesting that though arsenic is present in the soils of the villages near the thermal power plant, it may not be contributing largely towards the pollution in the soil. Trace levels of arsenic in soil of these six villages could also be a consequence of over extraction of water for irrigation or due to geological factors (Nandi et al., 2016; Sharma et al., 2021).

Table 3: A comparison of Soil Pollution Index (Pi) for heavy metal Arsenic (As, mg/kg) in soil of six villages during pre-monsoon, monsoon and post monsoon periods near coal-fired thermal power plants during 2017-18 and 2018-19

		Pre-Monsoon				**Monsoon**				**Post-Monsoon**			
S. No.	Site	As 2017-18	As 2018-19	Pi 2017-18	Pi 2018-19	As 2017-18	As 2018-19	Pi 2017-18	Pi 2018-19	As 2017-18	As 2018-19	Pi 2017-18	Pi 2018-19
1	Chauna	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Jarcha	0.32	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.02	0.01	0.00	0.00

3	Khatana	0.33	0.00	0.02	0.00	0.23	0.00	0.01	0.00	0.00	0.00	0.00	0.00
4	Piyawali	0.68	0.12	0.03	0.01	0.26	0.00	0.01	0.00	0.1	0.31	0.01	0.02
5	Ranauli	0.00	0.00	0.02	0.00	0.22	0.00	0.01	0.00	0.00	0.00	0.00	0.00
6	Siddhipur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

In conclusion the soil physico-chemical properties in the villages near the coal fired thermal power plant in this study was almost similar to that of agricultural soil with alkaline pH, optimal level of soil moisture and concentration of nitrate, phosphate and potassium required essentially for growth of agricultural crops. A lowered manganese level with higher phosphate was noted. A slightly higher arsenic concentration at Piyawali though within the permissible limit was recorded. Statistical analysis of the data for two consecutive years suggests a direct correlation of the coal-fired TPP on arsenic contamination in the soils by emissions of TPP in these villages within 0-10 km radius. Low levels of arsenic observed at Piyawali which is situated at a distance of 3.5 km in the leeward direction from thermal power plant, appears to be a mixed consequence of both the distance and the direction from TPP. Though it is very unlikely that the arsenic enters the food chain from the crops grown in this belt as also supported by the obtained Pi values, yet the farmers in these villages may be suggested to apply zinc to mitigate arsenic or grow non-edible crops or energy rich crops. Das et al. (2016) reported a decrement of arsenic release in the soil solution of the given soils on application of zinc that tends to bind arsenic electrostatically in the soil matrix, thereby helping to mitigate the toxicity of arsenic to certain extent in the soil-plant system. Moreover, arsenic containment measures be made more robust by the power plant to minimize further input of arsenic in soil environment.

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