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# Heavy Metal Pollution of Soil and Crops in Rural Gujarat, Next to an Industrial Area: A Correlation Study

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## ABSTRACT

Heavy metal contamination is one of the significant concerns of environmental pollution. The present study was conducted to find out the correlation between soil and crop/food matrices grown at the exact location for Al, As, Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Ni, Na, P, Zn, and Pb elements near the industrial areas of Narol, Changodar, Vatva, Makarpura, Nandesari, and Ankleshwar in Gujarat, India. Soil samples were collected from 64 sampling sites in an industrial area. Twenty of these sites contained crop/food matrices used for the correlation study. The ranges of concentration of Cr (17-74.4 $mg.kg^{-1}$), Cu (9.6-82.4 $mg.kg^{-1}$), Ni (10.6-55.9 $mg.kg^{-1}$), Pb (4.5- 20.7 $mg.kg^{-1}$), Zn (21.5-112.4 $mg.kg^{-1}$), and Al (7075-44557.5 $mg.kg^{-1}$) for Soil and for crop Cr (0.3-0.6 $mg.kg^{-1}$), Cu (0.3-8.6 $mg.kg^{-1}$), Zn (1.1-43.5 $mg.kg^{-1}$), Fe (12.6-69.4 $mg.kg^{-1}$), and Al (5.8-102.2 $mg.kg^{-1}$). According to the study, there is a strong correlation between the soil and crop/food matrices at the different locations, like 0.97 for Fe and Ni, 0.94 for Mg, 0.95 for Mn, and 0.55 for Pb and Zn, and very little correlation between K, P, and Ca, while a negative correlation between Al, Cr, Cu, and Na. The DTPA extractable method was used for the elemental analysis, and analysis was done using the ICP-OES instrument following microwave-assisted digestion. The results show that metal contamination transforms from soil to crop/food matrices, which represents a serious concern and requires action to address the metal contamination by industrialization.

## INTRODUCTION

The two most important natural resources on the Earth's surface are soil and water, affecting all terrestrial life. Modern technology development and rapid industrialization aggravate environmental pollution. Heavy metals, one of the most prevalent environmental pollutants, pose long-term health concerns to both people and the ecosystem (Lin et al. 2007, Antli & Canli 2008, Manyin & Rowe 2009, Perianez 2009). Regularly using heavy metal-contaminated water in agricultural regions leads to soil contamination and heavy metal enrichment (Lokhande & Kelkar 1999). Soil pollutants like heavy metals can leak into underlying groundwater with enough surface water infiltration. Depending on the kind of soil, heavy metals can affect groundwater in various ways (Kumar et al. 2013). The toxicity of heavy metals in animals varies depending on the animal type, the metal, the concentration, the chemical form, the composition of the groundwater, and the period of exposure. Heavy metals such as cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg) are highly toxic to metal-sensitive enzymes, resulting in organism death and growth suppression (Huang et al. 2012, Li & Zhang 2012, Matache et al. 2009). Heavy metals, including Pb, Hg, and nickel (Ni), are trace elements that are not needed. These are very hazardous elements because they are persistent, bioaccumulative, and challenging to break down or metabolize in the environment. Heavy metals, including Pb, Hg, and Ni, accumulate in the ecological food chain after being taken up by primary producers and consumed by consumers (Lenoble et al. 2013, Dupler 2001). Heavy metals can enter the human body through food, water, air, and skin absorption in modern agriculture, industrial, and residential environments. Humans are exposed to heavy metals such as Cd, Pb, and As. Heavy metals are also known to cause cancer. Arsenic poisoning is caused by contaminated drinking water. Heavy metal vapors, such as Cd, Pb, and As, mix with water in the atmosphere to generate aerosols, which can cause health issues (Bruins et al. 2000, Zenglu 1992,

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Burkat et al. 1999). Some heavy metals, such as Hg and Pb, can cause autoimmunity, a condition in which a person's immune system destroys their cells. Heavy metals are among the contaminants introduced into soils by industrial processes such as moving scrap metal and raw materials, forging metal, producing alkaline batteries, and creating synthetic organic compounds (Lokeshwari & Chandrappa 2006).

Gujarat is India's metropolis and the center of many multinational industries. Industries have come up in the last three decades around the cities of Gujarat. Ankleshwar, Makarpura, Vatva, Nandesari, Changodar, and Narol GIDC (Gujarat Industrial Development Corporation) area was selected for the study to cover the majority of industries of Gujarat. Sample extraction was performed using DTPA (diethylenetriaminepentaacetic acid) metal extraction method. For quantification, Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) technique was used to achieve a lower detection level. Pearson's correlation was used to determine the correlation between soil and crop/food matrices. ICP-OES provides an advanced technique for very low-level metal detection following the advanced micro-assisted digestion system. This study's primary objectives were to assess the soil's quality and determine the levels of heavy metals present in the soil and the association between those levels and the crop/food matrices planted nearby.

## MATERIALS AND METHODS

### Study Area

In this study, samples were obtained from nearby farming areas of all possible directions with increasing distances of 100 m, 200 m, 400 m, and 800 m of the industrial areas of Ahmedabad, Vadodara, and Ankleshwar in Gujarat. 64 soil samples were obtained, with 20 containing crop/food samples used in correlation analysis. These locations were selected based on the total industrial area, the total number of industries, and the types of manufacturing. Numerous industrial operations in this area serve as the primary source of hazardous waste, which includes medicines, medications, metal, paint, packaging, machinery, and chemicals.

### Sampling

### Soil Sample Collection

For soil sample collection, the zigzag approach was used. To avoid unwanted interference, the surface was properly cleaned by removing herbs, and samples were collected after identifying the collection point from a farming region (Table 1). Samples were gathered from 4-5 zigzag points using a hand auger from 15 cm deep on both sides of the wall and combined into a single composite sample. Approximately 1 kg of the sample was collected from each zigzag point, and around 2 kg of samples were prepared for the study. Each sample was carefully sealed in a plastic bag after being collected, and a specific identification number was used to identify each sample.

### Crop/Food Sample Collection

Crop/food samples were gathered from all four sides of a designated industrial region at distances of 100 m, 200 m, 400 m, and 800 m depending upon availability. Crop samples such as wheat, pearl millet, rice, pulses, and fodder crops were collected from various locations, as were food samples such as brinjal, bottle gourd, and cauliflower. All crop/food samples were collected according to their type, such as 2-3 whole pieces of bottled gourd and cauliflower collected from the same place in vegetable samples and 10-12 bunch of grain of different points collected from the same site in crop samples. Every sample was defined by its location, sides, distance, and industrial sector.

### Sample Preparation

Soil samples were dried in the shade for two to three days before being conserved after passing through a 2 mm sieve. The samples were then crushed to pass through a 0.25 mm filter for heavy metal analysis. 4 mL $HNO_3$, 1 mL HCl, and 0.5 mL $H_2O_2$ were added to a 0.2 gm sample in a micro oven vessel for analysis, and the samples were digested in a micro oven digestion machine. After digestion, the samples were made up to 50 mL with type-1 water and analyzed using an ICP-OES instrument (Kebata-Pendias 2000). To avoid contamination, vegetable plant samples were cleaned (dirt removed) using shaking and a dry pre-cleaned vinyl brush. The entire vegetable plant body was then separated into distinct segments, and non-edible components were removed in accordance with standard home norms. To eliminate airborne contaminants, the edible sections of the vegetable samples were rinsed multiple times with tap water before being immersed in 0.01 N HCl acid for 5 minutes and thoroughly washed in distilled and deionized water. Crop/food samples were crushed and homogenized in a stone mortar pistol to avoid metal contamination. 1 g of samples were taken for analysis in a micro oven vessel, and 5 mL

Table 1: Sampling location.

| Name of Industrial area | City area | Location |
|---|---|---|
| Narol GIDC | Ahmedabad | 23.0906° N,72.6714° E |
| Vatva GIDC | Ahmedabad | 22.9738° N,72.6479° E |
| Changodar GIDC | Ahmedabad | 22.9272° N,72.4484° E |
| Makarpura GIDC | Vadodara | 22.2503° N,73.1895° E |
| Nandesari GIDC | Vadodara | 22.4130° N,73.0951° E |
| Ankleshwar GIDC | Ankleshwar | 21.6174° N,73.0283° E |

$HNO_3$, 1 mL HCl and 0.5 mL $H_2O_2$ were added, and samples were digested in a micro oven digestion machine. After digestion, the samples were made up to 50 mL with type-1 water and analyzed by an ICP-OES system.

### Chemicals

Sigma-Aldrich in the United States provided the entire Standard. Merck, USA, provided laboratory-grade nitric acid ($HNO_3$), hydrochloric acid (HCl), and Hydrogen peroxide ($H_2O_2$). Type-1 water was obtained from the Elga water purification system.

### Analysis and Determination of the Heavy Metal Concentrations in Samples

The soil sample digests were analyzed for Aluminium (Al), As, Calcium (Ca), Cd, Chromium (Cr), Copper (Cu), Iron (Fe), Hg, Potassium (K), Manganese (Mg), Magnesium (Mn), Nickel (Ni), Sodium (Na), Phosphorous (P), Zinc (Zn) and Pb using the Inductively coupled plasma optical emission spectroscopy (ICP-OES) equipment (Agilent Technology, Model 5110). For each metal, calibration curves were created by running different concentrations of standard solutions. To adjust for reagent impurities and other sources of errors from the environment, a blank reagent sample was taken through the technique, evaluated, and subtracted from the samples. Each determination was based on the average of three replicates.

## RESULTS AND DISCUSSION

### Heavy Metal Concentrations in Soil

The data showing the distribution of selected heavy metals in terms of concentration, along with statistical parameters, is presented in Table 2. From Table 2, Al and Fe contents of the soil samples were very high, in the majority of the location ranging from 7075 $mg.kg^{-1}$ to 44558 $mg.kg^{-1}$ for Al with a median value of 15279 $mg.kg^{-1}$ and Fe range from 8128 $mg.kg^{-1}$ to 40320 $mg.kg^{-1}$ with median value 16300 $mg.kg^{-1}$. Heavy metals like As higher at Ankleshwar and Makarpura locations was 5.7 $mg.kg^{-1,}$ and Pb higher at Vatva and Makarpura locations were 20 $mg.kg^{-1}$ and 20.7 $mg.kg^{-1,}$ respectively. Chromium slightly to moderately higher at Changodar, Ankleshwar, and Makarpura locations from were 48.6 $mg.kg^{-1}$ to 74.4 $mg.kg^{-1}$, which shows the level of contamination of heavy metal in these areas, and Cu was present in the range from 9.6 $mg.kg^{-1}$ to 82.4 $mg.kg^{-1}$ with median value 24.3 $mg.kg^{-1}$. Heavy metals like Ni at a higher level at Vatva and Ankleshwar locations were 49.2 mg.kg-1, 55.9 mg.kg-1, respectively, and metals like Cd and Hg were absent at most locations except Hg at the Vatva location at 4.9 $mg.kg^{-1}$. Other analytes like Ca, K, Mg, Mn, Na, and P were present in the range from 2118 $mg.kg^{-1}$ to 43033 $mg.kg^{-1}$g with median value 4156 $mg.kg^{-1}$, 1246 $mg.kg^{-1}$ to 6323 $mg.kg^{-1}$ with median value 1883 $mg.kg^{-1}$, 1892 to 8844 $mg.kg^{-1}$ with median 4391 $mg.kg^{-1}$, 156 $mg.kg^{-1}$ to 879 $mg.kg^{-1}$ with median 280 $mg.kg^{-1}$, 285 $mg.kg^{-1}$ to 1452 $mg.kg^{-1}$ with median 625 $mg.kg^{-1}$, and 866 $mg.kg^{-1}$ to 6423 $mg.kg^{-1}$ with median 1564 $mg.kg^{-1}$ respectively. Zinc (Zn) present in a soil sample ranged from 22 $mg.kg^{-1}$ to 112 $mg.kg^{-1}$ with a median value of 51 $mg.kg^{-1,}$ and the highest concentration was observed at Naroda and Makarmpura industrial areas. The order of metals present in the soil in decreasing order was as Fe> Al> Ca> Mg> K> P> Na> Mn> Zn> Cr> Cu> Ni> Pb> As> Hg> Cd.

### Heavy Metal Concentrations in Crop/Food Matrices

DTPA-extractable Al, As, Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Ni, Na, P, Zn, and Pb contents in crop/food samples are presented in Table 3. The highest concentration of Al was found at Naroda, Vatva, and Changodar in crop/food matrix was 102.2 $mg.kg^{-1}$, 46.3 $mg.kg^{-1,}$ and 57.6 $mg.kg^{-1}$ respectively, with the range from 5.8 $mg.kg^{-1}$ to 102.2 $mg.kg^{-1}$ and 25.3 $mg.kg^{-1}$ median value. Copper was found at the highest level at Makarpura and Nandesari locations, 8.6 $mg.kg^{-1}$ and 8.0 $mg.kg^{-1,}$ respectively, with a range from 0.3 $mg.kg^{-1}$ to 8.6 $mg.kg^{-1}$ and a median value of 2.8 $mg.kg^{-1}$ and Iron found higher side from 69.4 $mg.kg^{-1}$ to 49.3 $mg.kg^{-1}$ at Changodar and Nandesari location respectively with range 13 $mg.kg^{-1}$ to 69 $mg.kg^{-1}$ and median value 32 $mg.kg^{-1}$ showing the contamination level of the soil of farming area nearby the industrial areas. Heavy metals like As, Cd, and Hg were absent in all the locations, and Pb was present at a few locations at a very low level. Other metals like Ca, Cr, Cu, K, Mg, Mn, Na, Ni, P, and Zn highest concentrations were 1632, 0.6, 8.6, 2670, 1496, 30, 962, 1.8, 3995, and 44 $mg.kg^{-1}$ respectively with the range 136 to 1632, 0.2 to 0.6, 0.3 to 8.6, 421 to 2670, 71 to 1496, 0.7 to 30, 92 to 962, 0 to 1.8, 212 to 3995 and 1.1 to 44 $mg.kg^{-1}$ respectively. The median values for Ca, Cr, Cu, K, Mg, Mn, Na, Ni, P, and Zn were 376, 2.8, 32, 1039, 345, 3.5, 130, 0.3, 750, and 7.6 $mg.kg^{-1,}$ respectively. The order of metals present in crop/food matrices in decreasing order was as P> Mg> Ca> Na> Fe> Al> Zn> Mn> Cu> Ni> Cr> Pb.

From Table 3, Al was found at Muthiya of Naroda, Changodar gam of Changodar and Vinzol of Vatva location very high and Fe very high at Vinzol of Vatva, respectively Changodar gam of Changodar and Koili of Nandesari location. The contamination levels of Al, Fe, Zn, and Cu in crop/food were above the level suggested by WHO, showing the quality of cop/food gowned in the metal-contaminated soil and not healthy for human consumption.

Table 2: Determination of soil samples from different villages in surrounding areas of Naroda, Vatva, Changodar, Ankleshwar, Makarpura, and Nandedari GIDC.

| Industrial Area | Village (location) | Distance (meter) | Al | As | Ca | Cd | Cr | Cu | Fe | Hg | K | Mg | Mn | Na | Ni | P | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Naroda | Ranasan (northeast) | 800 | 14637.8 | 2.1 | 2854.9 | ND | 32.2 | 14.0 | 14352.9 | 0.6 | 1700.4 | 3531.3 | 252.2 | 784.1 | 20.2 | 944.4 | 6.3 | 30.6 |
| | Muthiya (east) | 100 | 17563.3 | 2.0 | 5887.3 | ND | 39.9 | 29.6 | 13553.9 | 2.5 | 2513.9 | 4458.8 | 251.9 | 735.5 | 20.8 | 2613.6 | 11.5 | 111.2 |
| | Ranasan (north east) | 400 | 10049.3 | 1.4 | 2360.6 | ND | 26.7 | 9.9 | 10000.4 | 0.6 | 1245.7 | 2339.6 | 201.9 | 414.4 | 13.7 | 866.3 | 4.5 | 23.2 |
| | Nana chiloda (west) | 800 | 10101.0 | 1.9 | 2439.3 | ND | 24.2 | 9.6 | 10144.0 | 0.5 | 1454.0 | 2360.3 | 184.9 | 468.9 | 13.0 | 872.4 | 4.6 | 21.5 |
| Vatva | Vinzol (south east) | 200 | 44557.5 | 6.4 | 4444.9 | 0.3 | 74.0 | 36.3 | 40320.2 | 0.0 | 6322.7 | 8011.1 | 491.9 | 1069.1 | 49.2 | 1122.0 | 20.0 | 80.8 |
| | Vinzol (south west) | 400 | 9153.9 | 1.4 | 3957.9 | ND | 25.0 | 10.1 | 9541.0 | 0.5 | 1319.5 | 2887.3 | 189.2 | 1095.3 | 13.6 | 972.2 | 6.0 | 26.8 |
| | Vinzol (north east) | 400 | 7075.0 | 0.9 | 2849.9 | ND | 17.0 | 12.5 | 8127.7 | 4.9 | 1386.1 | 1891.5 | 155.8 | 285.3 | 10.6 | 1815.9 | 6.7 | 29.0 |
| Changodar | Changodar gam (Northwest) | 400 | 10454.2 | 2.7 | 2117.7 | ND | 22.7 | 14.2 | 10723.1 | 1.5 | 2720.2 | 2850.5 | 170.2 | 686.5 | 12.2 | 1850.5 | 7.6 | 42.6 |
| | Changodar gam (Northeast) | 400 | 30812.9 | 5.7 | 6934.2 | ND | 48.6 | 32.0 | 25973.0 | 1.9 | 4694.4 | 7124.1 | 410.6 | 1451.7 | 35.9 | 1558.7 | 14.7 | 63.2 |
| | Changodar gam (Southeast) | 400 | 27352.0 | 4.1 | 6182.0 | 0.1 | 50.9 | 24.5 | 21862.2 | ND | 3044.9 | 6725.7 | 297.5 | 1105.8 | 28.6 | 1309.8 | 10.4 | 50.3 |
| Ankleshwar | Ankleshwar gam (west) | 100 | 42298.3 | 4.6 | 6443.7 | ND | 74.4 | 60.4 | 35623.6 | ND | 1638.1 | 7799.8 | 879.2 | 431.5 | 55.9 | 947.8 | 9.6 | 46.1 |
| | Jitali (east) | 200 | 38283.6 | 4.9 | 12231.0 | 0.3 | 69.8 | 71.3 | 35307.4 | ND | 1911.6 | 8844.4 | 724.3 | 458.3 | 55.0 | 1457.3 | 11.7 | 53.8 |
| | jitali (east) | 400 | 36975.3 | 4.9 | 11350.4 | ND | 65.9 | 65.6 | 33617.0 | ND | 1904.3 | 8687.3 | 777.8 | 552.7 | 53.7 | 1568.7 | 11.9 | 51.1 |
| Makarpura | Omkar chokadi (North) | 400 | 12812.5 | 3.1 | 2312.3 | ND | 27.9 | 24.0 | 14677.2 | 0.7 | 1638.7 | 4323.9 | 230.2 | 640.6 | 18.7 | 3103.3 | 9.6 | 51.6 |
| | Omkar chokadi (North) | 800 | 16931.1 | 3.2 | 4353.6 | 0.1 | 35.4 | 34.1 | 18158.5 | ND | 2240.5 | 6767.3 | 335.0 | 895.9 | 23.9 | 6422.8 | 13.9 | 78.7 |
| | Talodara (west) | 100 | 28922.1 | 5.7 | 6386.3 | 0.5 | 70.5 | 82.4 | 30213.2 | 0.6 | 2758.8 | 6693.8 | 468.5 | 604.9 | 46.2 | 2226.6 | 20.7 | 112.4 |
| | Talodara (west) | 400 | 24989.0 | 4.3 | 43033.1 | ND | 45.0 | 47.9 | 27022.3 | ND | 2616.0 | 7496.3 | 508.8 | 610.2 | 39.3 | 2139.5 | 10.6 | 52.1 |
| Nandesari | Dashrath (Karachiya) | 400 | 14147.5 | 2.3 | 3381.6 | 0.2 | 34.7 | 22.3 | 15617.9 | ND | 1658.1 | 3780.3 | 212.6 | 594.3 | 19.9 | 1929.9 | 7.3 | 47.3 |
| | Koili (southwest) | 400 | 15279.1 | 2.9 | 3942.2 | 0.2 | 34.4 | 23.6 | 16273.6 | ND | 1861.7 | 4157.7 | 263.0 | 667.7 | 20.7 | 1987.9 | 8.5 | 50.3 |
| | Koili (north west) | 400 | 13793.1 | 2.7 | 2805.9 | 0.2 | 35.2 | 21.9 | 16326.8 | ND | 1552.0 | 3872.3 | 296.1 | 530.1 | 21.8 | 1534.9 | 6.8 | 54.5 |

All the above results are in $mg.kg^{-1}$, ND- Not detected

Table 3: Determination of crop/Food samples from different villages in the surrounding area of Naroda, Vatva, Changodar, Ankleshwar, Makarpura, and Nandedari GIDC.

| Industrial Area | Village (location) | Distance (meter) | Al | As | Ca | Cd | Cr | Cu | Fe | Hg | K | Mg | Mn | Na | Ni | P | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Naroda | Ranasan (northeast) | 800 | 15.8 | ND | 182.1 | ND | 0.3 | 0.8 | 19.0 | ND | 494.5 | 121.2 | 1.3 | 208.0 | ND | 289.9 | 0.2 | 1.9 |
| | Muthiya (east) | 100 | 102.2 | ND | 166.2 | ND | 0.6 | 1.0 | 62.5 | ND | 893.5 | 148.8 | 1.4 | 143.5 | 0.0 | 315.0 | 0.2 | 3.2 |
| | Ranasan (north east) | 400 | 9.2 | ND | 164.4 | ND | 0.2 | 0.9 | 12.6 | ND | 961.8 | 181.6 | 1.6 | 104.0 | ND | 344.0 | 0.1 | 2.3 |
| | Nana chiloda (west) | 800 | 29.4 | ND | 230.0 | ND | 0.4 | 0.9 | 32.3 | ND | 447.3 | 91.5 | 1.3 | 110.7 | 0.1 | 245.3 | 0.3 | 2.5 |
| Vatva | Vinzol (south east) | 200 | 29.6 | ND | 444.2 | ND | 0.4 | 4.6 | 55.4 | ND | 1694.6 | 1052.4 | 29.5 | 503.0 | 0.1 | 3109.6 | 0.1 | 23.4 |
| | Vinzol (south west) | 400 | 29.3 | ND | 373.8 | ND | 0.3 | 4.0 | 50.0 | ND | 1381.5 | 946.1 | 26.4 | 275.5 | 0.1 | 2698.1 | 0.1 | 17.4 |
| | Vinzol (north east) | 400 | 46.3 | ND | 540.4 | ND | 0.5 | 4.4 | 66.2 | ND | 1847.0 | 1091.6 | 24.6 | 962.0 | 0.1 | 2755.0 | 0.2 | 26.8 |
| Changodar | Changodar gam (northwest) | 400 | 31.5 | ND | 370.4 | ND | 0.6 | 5.0 | 33.2 | ND | 1945.1 | 314.5 | 3.4 | 133.5 | 1.5 | 1378.5 | ND | 12.7 |
| | Changodar gam (northeast) | 400 | 24.1 | ND | 457.8 | ND | 0.3 | 1.7 | 28.1 | ND | 1023.2 | 297.7 | 2.8 | 104.1 | 0.4 | 604.5 | ND | 4.9 |
| | Changodar gam (southeast) | 200 | 57.6 | ND | 407.0 | ND | 0.3 | 4.9 | 69.4 | ND | 1240.6 | 764.4 | 22.4 | 170.3 | 0.1 | 1674.7 | 0.1 | 43.5 |
| Ankleshwar | Ankleshwar gam (west) | 100 | 18.0 | ND | 162.9 | ND | 0.3 | 0.6 | 20.1 | ND | 420.5 | 70.6 | 0.7 | 93.3 | 0.0 | 211.8 | 0.2 | 1.9 |
| | Jitali (east) | 200 | 11.4 | ND | 378.4 | ND | 0.4 | 2.8 | 17.2 | ND | 1054.7 | 375.9 | 3.8 | 116.7 | 0.3 | 812.6 | ND | 8.5 |
| | jitali (east) | 400 | 14.0 | ND | 450.7 | ND | 0.2 | 2.7 | 17.4 | ND | 922.9 | 398.7 | 3.6 | 92.1 | 0.3 | 687.0 | ND | 6.6 |
| Makarpura | Omkar chokadi (north) | 400 | 11.9 | ND | 147.9 | ND | 0.3 | 0.8 | 12.7 | ND | 666.1 | 124.7 | 0.9 | 115.2 | ND | 248.7 | ND | 1.1 |
| | Omkar chokadi (north) | 800 | 12.0 | ND | 159.5 | ND | 0.2 | 0.3 | 13.8 | ND | 906.0 | 153.9 | 1.2 | 498.9 | ND | 382.7 | ND | 4.5 |
| | Talodara (west) | 100 | 26.7 | ND | 640.2 | ND | 0.3 | 4.2 | 30.8 | ND | 1875.3 | 424.9 | 4.6 | 151.4 | 0.6 | 1022.9 | 0.2 | 12.3 |
| | Talodara (west) | 400 | 26.6 | ND | 1631.5 | ND | 0.3 | 8.6 | 42.2 | ND | 1620.6 | 1336.3 | 12.0 | 211.3 | 1.2 | 3443.5 | ND | 39.7 |
| Nandesari | Dashrath (Karachiya) | 400 | 13.2 | ND | 136.4 | ND | 0.3 | 0.9 | 15.0 | ND | 791.6 | 141.6 | 1.3 | 96.6 | ND | 321.7 | ND | 1.7 |
| | Koili (southwest) | 400 | 32.1 | ND | 1469.3 | ND | 0.2 | 8.0 | 37.1 | ND | 1763.4 | 1490.9 | 9.4 | 111.9 | 1.8 | 3973.3 | ND | 33.3 |
| | Koili (north west) | 400 | 5.8 | ND | 1497.7 | ND | 0.3 | 6.5 | 49.3 | ND | 2670.3 | 1496.3 | 12.4 | 126.7 | 1.2 | 3994.6 | ND | 37.0 |

All the above results are in $mg.kg^{-1}$, ND- Not detected

## Correlation Between Soil and Crop/Food Sample

The result of Table 4 was obtained by applying the correlation formula between soil and crop/food matrices data of industrial area for individual metals. Table 4 represents the correlation of metal between soil and crop/food matrices for particular industrial areas, shown in Table 4 as metal correlation at different industrial areas and correlation between the metal. The two variables for particular metal were a concentration in soil and the other was a concentration in crop/food matrices, obtained results of Table 2 and Table 3 and the correlation between parallel metal concentrations. From the correlation Table 4 Al at Naroda, Ankleshwar, Makarpura, and Nandesari showing the negative correlation between soil and crop/food sample were -0.46; for Cr showing negative correlation values were seen as -0.22, -0.05 and -0.53. Further, Mg, Mn, and Ni showing the highest correlation with respect to Al were 0.94, 0.95, and 0.97, respectively. P has a negative correlation with most elements, except for K and Na, and Fe has a high correlation of 0.97 with Al. Other

Table 4: Correlation between metal concentrations in soil vs. metal concentration in crop/food sample.

| | Al | Ca | Cr | Cu | Fe | K | Mg | Mn | Na | Ni | P | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil vs. Crop | -0.46 | 0.01 | -0.22 | -0.23 | -0.48 | 0.43 | -0.33 | -0.31 | 0.28 | -0.20 | 0.01 | 0.01 | 0.02 |
| Al | - | -0.31 | -0.05 | -0.21 | 0.97 | 0.04 | 0.94 | 0.95 | -0.20 | 0.97 | -0.13 | 0.51 | 0.04 |
| Ca | - | - | -0.53 | -0.14 | -0.63 | -0.27 | -0.32 | -0.37 | -0.13 | 0.08 | -0.35 | 0.55 | -0.27 |
| Cr | - | - | - | -0.23 | -0.55 | -0.38 | -0.31 | -0.23 | -0.21 | -0.22 | -0.35 | 0.41 | -0.35 |
| Cu | - | - | - | - | -0.73 | -0.40 | -0.34 | -0.40 | -0.28 | -0.04 | -0.39 | 0.59 | -0.39 |
| Fe | - | - | - | - | - | -0.27 | -0.21 | -0.14 | -0.12 | -0.17 | -0.25 | 0.35 | -0.23 |
| K | - | - | - | - | - | - | 0.20 | 0.61 | 0.47 | -0.15 | 0.24 | -0.93 | 0.53 |
| Mg | - | - | - | - | - | - | - | -0.27 | -0.24 | -0.08 | -0.36 | 0.31 | -0.25 |
| Mn | - | - | - | - | - | - | - | - | -0.27 | -0.23 | -0.40 | 0.51 | -0.44 |
| Na | - | - | - | - | - | - | - | - | - | 0.02 | 0.21 | -0.96 | 0.55 |
| Ni | - | - | - | - | - | - | - | - | - | - | -0.35 | 0.45 | -0.36 |
| P | - | - | - | - | - | - | - | - | - | - | - | 0.29 | 0.12 |
| Pb | - | - | - | - | - | - | - | - | - | - | - | - | 0.16 |
| Zn | - | - | - | - | - | - | - | - | - | - | - | - | - |

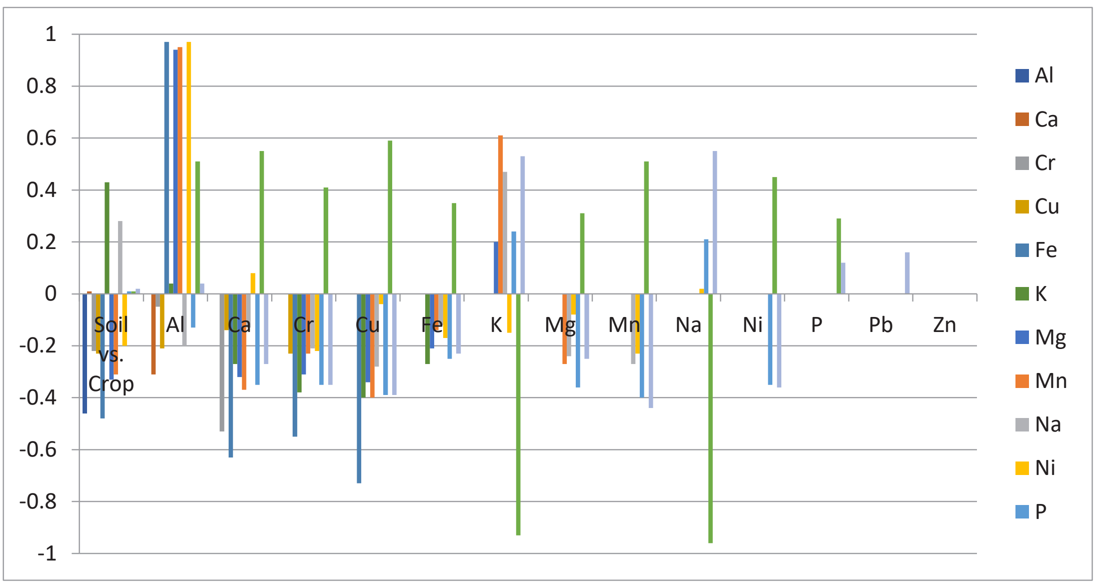


Fig. 1: Correlation chart of metal contamination for soil and crop/food matrices.

elements, such as Mg and Mn, view negative correlation with all elements except with respect to Al ranging value from -0.20 to -0.34 and -0.14 to -0.4, respectively. Some elements have a weak to strong positive correlation, like Zn and Pb, with the range 0.02 to 0.16 and 0.01 to 0.24 with different elements, respectively. P shows a negative correlation with the remaining elements. Pb exhibits a strongly negative correlation with K and Na of -0.93 and -0.96, respectively. The nutrients like Ca, P, K, and Na showed low to moderately negative correlations ranging from 0.01 to -0.31, 0.01 to -0.4, 0.04 to -0.4, and 0.47 to -0.27. Data showed that metals like Fe, Mg, Mn, Ni, Pb, and Zn changed from the soil to the matrix of crops and foods. From Table 4, results observed that the correlation at Ankleshwar and Makarpura industrial places was very high for most metals.

The statistical parameters for the elements, as given in Table 4, have high skewness and kurtosis. Pearson's correlation analysis for DTPA extractable metal Al, As, Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Ni, Na, P, Zn, and Pb were performed between all variables of soil sample and crop/food sample. Fig. 1 represents the correlation of metal contamination between soil and crop/food matrices and metal. Table 4 shows that all elements are significant at the p 0.01 level. The presence of high and significant correlations between these samples suggests that contaminants also move from soil to crop/food matrices. From the above-presented correlation matrix, we observe a high correlation between soil and crop/food matrix for Al, Fe, Mg, Mn, and Ni exhibit four different places and Ca, Cu, and Na showing moderate correlation with respect to other metals and for Cr, Cu, Na, and P showing negative correlation with respect to other metals. Between soil and crop/food matrices, Na and Pb show a very modest association, but Cr, Ni, and K show a little high correlation. Table 2 and Table 3 showed that higher contamination of Fe, Ni, and Pb transformed through the soil into a crop grown at the same place, and high contamination of Fe in soil was transforming into a crop which represents that metal contamination was transferring from soil to crop. The study shows a strong correlation between the soil and crop/food matrices at the different locations, and metals like Fe, Mg, Mn, and Ni show high correlations of 0.97, 0.94, 0.95, and 0.97 with respect to Al. Cr and Cu show very little correlation with most metals, and P shows a negative correlation with most elements.

## CONCLUSION

According to the findings, heavy metal content is introduced through various sources and human activities, including industrial operations. Heavy metal contamination in soil may be caused primarily by atmospheric deposition of contaminated dust and industrial discharge. Heavy metals in the field were also present in significant concentrations in the form of Al, Fe, Mg, Mn, and Ni in soil, and the same was transferred into crop/food matrices through its natural process resulting in negative impacts on the soil. The results of correlation research for metal between soil and crop/food matrices cultivated in the same location show a substantial connection between them. It is indicated that increased heavy metal concentration in the soil may damage soil quality and study locations, which is unsuitable for soil health. Crops and food commodities that grow in polluted accessible soil are likewise exposed due to their growth mechanisms, as evidenced by correlation research between soil and crop/food matrices.

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