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# Distribution and source identification of heavy metals in the soil surrounding Kermanshah Refinery, Iran

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## ABSTRACT

Oil products are considered to be life-threatening factors in the ecosystem due to their contents of organic compounds, sulfide, sulfur, heavy metals, and various circular hydrocarbons, organic solvents, aromatic compounds, linear formaldehyde, fats, and grease. The present study aimed to investigate the soil surrounding Kermanshah Refinery, Iran and estimate the density of various heavy metals and their pollution sources, including arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni), zinc (Zn), lead (Pb), copper (Cu), scandium (Sc), and vanadium (V). The geoaccumulation index indicated that the intensity of the refinery soil had variable degrees of pollution, ranging from no pollution to average pollution with chromium and nickel. In addition, the enrichment index showed average enrichment for cadmium (station 14), copper (stations two, 11, 13, and 14), lead (stations six and 13), zinc (stations two, six, 11, and 13), and chromium (stations 6-15). On the other hand, the pollution bar index of chromium, copper, nickel, zinc, and lead was estimated to be higher than one, which confirmed unacceptable soil quality and the presence of soil pollution in the region. According to the results of Pearson's correlation-coefficient, nickel pollution was significantly correlated with chromium and scandium pollution, while cobalt pollution was associated with vanadium and chromium pollution. Moreover, a significant correlation was observed between zinc and copper pollution, which indicated the equal pollution source or similar geochemical behaviors of these elements toward each other. Since vanadium is considered to be an oil pollution index, it could be concluded that high pollution with this element and chromium may arise from petroleum in the studied region.

**Keywords:** Heavy metals, Pollution bar, Kermanshah Refinery, Soil, Pollution index

## Introduction

Heavy metal pollution directly affects the physical and chemical properties of soil, while reducing biological activities and access to soil nutrients. Furthermore, heavy metal pollution is considered to be severe threat to human health. These elements could enter the food chain or penetrate into underground water sources.[1]

Soil pollution by heavy metals differs from water or air pollution since these elements remain in soil considerably longer than the other parts of the biosphere.[2] Unlike organic components, these inorganic pollutants are not biodegradable; as such, heavy metals are considered to be one of the most hazardous environmental pollutants.[3] Iran has rich sources of oil, which is mainly extracted in the southern regions and refined in other places every year. The extraction, transmission, and refinery of oil lead to soil pollution.[4]

Some sources of soil pollutants are caused by oil discovery, production, saving, transmission, and distribution, as well as the final waste burial. As such, the associated industries are considered to be a major cause of pollution.[5]

Increased soil pollution with heavy metals has been the subject of extensive research. In a

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study, Gitipour *et al.*[6] assessed the rate of soil pollution in the vicinity of refineries through conducting cross-country and laboratory experiments. In the mentioned study, the comparison of soil pollution with the acceptable pollution limits indicated that some parts of the soil in Azimabad region (Iran) were polluted with oil compounds. According to Khoshnam *et al.*,[7]determining some parameters and group statistical features of data (e.g., mean and deviation, especially deviation from the normal range) is the first step toward recognizing the nature of the obtained data. Moreover, the geochemical studies of sediments could be effective in verifying the source of sediments, as well as the transmittal patterns of elements and environmental assessment of the regional status in this regard.[8]

The present study aimed to investigate the distribution of heavy metals in the soil surrounding Kermanshah Refinery, Iran based on pollution indices and statistical analyses and assess the rate of environmental pollution.

## Materials and Methods

Kermanshah Refinery (34º20-34º21΄ N, 47º 06΄-47º06΄ E) is built on alluvial terraces and has fans of new low foothills, inceptisols, and vertisols. In total, 15 samples were collected from the soil surrounding the refinery from the depth of 15-25 centimeters. The density of heavy metals in the samples was determined and analyzed using the ICP-MS method and Agilent Series 4500 machine (USA). The samples were ground to sizes less than four millimeters using a crusher and powdered to the size of 75 microns (200 mesh) using a disc mill.[9] The samples were weighed using Teflon pipes in digest 4 acid, and hydrochloric, perchloric, nitric, and chloridric acids were added to the samples equally. All the samples were preserved in a Hot Box case. After complete digest operations, the samples were preserved in a cold environment, and the required volume was achieved using distilled water.

### *Statistical analyses*

Data analysis was performed in SPSS version 18. Data were analyzed in terms of the interactions of the elements and their origin using descriptive statistics, Pearson's correlation-coefficient, Pearson cluster analysis, and the analysis of the main constituents.

## Results and Discussion

### *Pollution assessment*

Due to the changes in the density of the elements in the soil of the studied region and presence of petroleum compounds, we selected some heavy metals for further evaluation, including arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), scandium (Sc), vanadium (V), and zinc (Zn). Table 1 shows the results of the ICP-MS analysis of the collected soil samples (n=15) on the levels of arsenic, cadmium, cobalt, chromium, nickel, zinc, lead, copper, scandium, and vanadium.

Comparison of the density of the elements indicated that the process of the changes in the heavy metals present in the soil surrounding Kermanshah Refinery showed the following: Cr>Zn>Ni>V>Cu>Pb>Co>Sc>As>Cd (Table 2). According to the obtained results, chromium and cadmium had the highest and lowest density compared to the other elements, respectively.

In the present study, the enrichment factor, geoaccumulation index, and pollution bar index were used to determine and analyze the level of soil pollution in the collected regional samples. The geoaccumulation index is considered to be an important geochemical factor to describe the density of heavy metals in various regions,[10] which could be calculated by Eq. 1.

$$\text{Igeo}=\text{Log2}\left(\frac{\text{Cn}}{1.5\ \text{Bn}}\right) \qquad (1)$$

Table 3 shows the findings regarding the soil samples collected from the sampling stations in the vicinity of Kermanshah Refinery based on the geoaccumulation index.

According to the results of the present study, the soil concentration of chromium in stations one, two, six, nine, 11, 12, 13, 14, and 15 ranged from no pollution to average pollution

(Igeo value: 0-1), while an average range was observed in stations seven, eight, and 10. On the other hand, the range was indicative of no pollution in stations three, four, and five.

Table 1. ICP-MS analysis of soil samples in Kermanshah refinery (ppm)

| Station | Y(utm) | X(utm) | Zn | V | Sc | Pb | Ni | Cu | Cr | Co | Cd | As |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 141287 | 3808206 | 82 | 79 | 12.6 | 25 | 101 | 31 | 173 | 17.2 | 0.2 | 6.7 |
| 2 | 141258 | 3808168 | 220 | 93 | 14.7 | 40 | 95 | 149 | 174 | 19.2 | 0.3 | 7.8 |
| 3 | 141231 | 3808164 | 71 | 75 | 12.2 | 13 | 97 | 39 | 110 | 16.9 | 0.2 | 7.9 |
| 4 | 141149 | 3808153 | 69 | 94 | 13.7 | 12 | 61 | 23 | 115 | 16.2 | 0.2 | 7.3 |
| 5 | 141144 | 3808109 | 74 | 68 | 10.7 | 14 | 76 | 28 | 109 | 14.1 | 0.2 | 6.5 |
| 6 | 141184 | 3808147 | 174 | 91 | 11.5 | 56 | 100 | 71 | 185 | 14.9 | 0.3 | 6.2 |
| 7 | 141124 | 3808054 | 84 | 100 | 13.2 | 12 | 150 | 65 | 287 | 19.1 | 0.3 | 7.1 |
| 8 | 141162 | 3808020 | 97 | 123 | 15.6 | 12 | 133 | 76 | 281 | 22.1 | 0.4 | 7 |
| 9 | 141244 | 3807959 | 99 | 84 | 9.2 | 24 | 98 | 57 | 146 | 13.4 | 0.3 | 8.7 |
| 10 | 141215 | 3808045 | 107 | 133 | 15.4 | 25 | 133 | 60 | 340 | 19.2 | 0.3 | 6.4 |
| 11 | 141422 | 3808312 | 157 | 96 | 9.4 | 26 | 96 | 109 | 181 | 15.2 | 0.3 | 7.9 |
| 12 | 141391 | 3808281 | 76 | 106 | 9 | 14 | 115 | 60 | 238 | 16.2 | 0.3 | 6.3 |
| 13 | 141427 | 3808231 | 171 | 102 | 8.8 | 29 | 103 | 63 | 156 | 14.6 | 0.3 | 7.7 |
| 14 | 141527 | 3808304 | 92 | 84 | 7 | 21 | 80 | 59 | 146 | 12.6 | 0.4 | 6.3 |
| 15 | 141524 | 3808361 | 92 | 98 | 9.7 | 26 | 98 | 61 | 150 | 14.8 | 0.2 | 6.3 |

Table 2. Comparison of standard density of heavy metals in soil in studied region[11]

|  | Zn | V | Sc | Pb | Ni | Cu | Cr | Co | Cd | As |
|---|---|---|---|---|---|---|---|---|---|---|
| World Shale | 95 | 130 | 13 | 20 | 68 | 45 | 90 | 19 | 0.3 | 13 |
| Unpolluted soil | 62 | 60 | 9.5 | 25 | 18 | 14 | 42 | 6.9 | 1.1 | 4.7 |
| Studied soil | 111 | 95.6 | 51.11 | 23.26 | 102.4 | 62.8 | 186.6 | 16.38 | 0.28 | 7.13 |

With regard to copper, average pollution was reported in station two, while the concentration of this element ranged from no pollution to average pollution in stations six, eight, and 11, and no pollution was observed in the other stations. As for nickel, the concentration ranged from no pollution to average pollution in stations seven, eight, 10, 12, and 13, while no nickel pollution was reported in the other stations. With the exception of stations two and six where the range of no pollution to average pollution was observed, no lead pollution was reported in the other stations. With regard to zinc, the concentration of this element ranged from no pollution to average pollution in stations seven, eight, 10, 12, and 13, while no zinc pollution was observed in the other stations.

Based on the geoaccumulation index and shale, the mean concentrations of chromium and nickel were in category one, in which the pollution intensity ranged from no pollution to average pollution. In addition, the concentration of the other elements was in the range of no pollution. Table 4 shows the mean values of geoaccumulation index in the studied samples.

Since the pollution factor could be used to describe environmental pollution with a specific element,[12] the Hakanson method was used to calculate the pollution factor of the samples, that is presented as Eq. 2.[11]

$$Cf=\frac{C0}{Cn} \qquad (2)$$

Table 5 shows the findings based on the pollution factor and shale mean in the studied stations. Accordingly, low pollution with arsenic was observed in all the sampling regions.

According to the findings of the current research, the soil concentration of cadmium ranged from no pollution in stations 1-5 and 15, while average pollution with this element was reported in the other stations. Moreover, the soil concentration of cobalt indicated average pollution in stations two, seven, eight, and 10, while low pollution with this element was reported in the other stations.

Table 3. Findings based on geoaccumulation index in soil of Kermanshah Refinery, Iran

| Station | Zn | V | Sc | Pb | Ni | Cu | Cr | Co | Cd | As |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -0.8 | -1.3 | -0.63 | -0.26 | -0.01 | -1.17 | 0.36 | -0.73 | -1.17 | -1.36 |
| 2 | 0.63 | -1.17 | -0.41 | 0.42 | -0. | 1.14 | 0.37 | -0.58 | -0.58 | -1.32 |
| 3 | -1.01 | -1.38 | -0.68 | -1.17 | -0.07 | -1.17 | -0.3 | -0.75 | -1.17 | -1.3 |
| 4 | -1.05 | -1.05 | -0.51 | -1.32 | -0.74 | -1.55 | -0.23 | -0.8 | -1.17 | -1.42 |
| 5 | -0.95 | -1.52 | -0.87 | -1.1 | -0.43 | -1.27 | -0.31 | -1.2 | -1.17 | -1.58 |
| 6 | 0.29 | -1.1 | -0.76 | 0.9 | -0.03 | 0.07 | 0.45 | -0.9 | -0.58 | -1.65 |
| 7 | -0.76 | -0.96 | -0.56 | -1.32 | 0.56 | -0.05 | 1.09 | -0.58 | -0.58 | -1.46 |
| 8 | -0.58 | -0.66 | -0.32 | -1.32 | 0.38 | 0.17 | 1.06 | -0.4 | -0.17 | -1.48 |
| 9 | -0.53 | -1.17 | -1.08 | -0.32 | -0.06 | -0.24 | 0.11 | -1.02 | -0.58 | -1.16 |
| 10 | -0.41 | -0.58 | -0.34 | -0.26 | 0.38 | -0.17 | 1.33 | -0.58 | -0.58 | -1.61 |
| 11 | 0.14 | -1.02 | -1.05 | -0.21 | -0.09 | 0.69 | 0.42 | -0.91 | -0.58 | -1.34 |
| 12 | -0.91 | -0.88 | -1.12 | -1.1 | 0.17 | -0.17 | 0.82 | -0.81 | -0.58 | -1.63 |
| 13 | 0.26 | -0.93 | -1.15 | -0.05 | 0.01 | -0.1 | 0.21 | -0.96 | -0.58 | -1.34 |
| 14 | -0.63 | -1.22 | -1.48 | -0.51 | -0.35 | -0.19 | 0.11 | -1.18 | -0.17 | -1.63 |
| 15 | -0.63 | -0.99 | -1.01 | -0.21 | -0.06 | -0.15 | 0.15 | -0.95 | -1.17 | -1.63 |

Table 4. Mean geoaccumulation index in samples collected from Kermanshah Refinery, Iran

| As | Cd | Co | Cr | Cu | Ni | Pb | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|
| -1.5 | -0.6 | -0.7 | 0.4 | -0.1 | 0.5 | -0.3 | -0.7 | -1.3 | -0.3 |

According to the obtained results, the rate of chromium pollution was high in stations seven, eight, and 10, while average pollution was observed in the other stations. Furthermore, the rate of copper pollution was reported to be high in station two, average in stations 6-15, and low in stations one, three, four, and five. With the exception of station two where the rate of nickel pollution was low, the rate of pollution with this element was observed to be average in the other stations.

According to the findings, the rate of pollution with lead was low in stations three, four, five, seven, eight, and 12 and average in the other regions. On the other hand, average pollution with scandium was observed in stations two, four, seven, eight, and 10, and the other stations had no scandium pollution. With the exception of station 10 where there was average vanadium pollution, the rate of vanadium pollution was reported to be low in the other stations.

According to the results of the present study, the rate of zinc pollution was average in stations two, six, eight, nine, 10, 11, and 13, while the other stations had low zinc pollution. Based on the calculated mean density of the studied heavy metals in the soil surrounding the refinery and comparison with the global shale, the rates of pollution with arsenic, cadmium, cobalt, scandium, and vanadium were low, while average pollution with the other elements was reported (Table 6).

Table 5. Findings based on pollution factor in studied stations

| Station | Zn | V | Sc | Pb | Ni | Cu | Cr | Co | Cd | As |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.86 | 0.61 | 0.97 | 1.25 | 1.49 | 0.67 | 1.92 | 0.91 | 0.67 | 0.58 |
| 2 | 3.32 | 0.72 | 1.13 | 2 | 1.4 | 3.31 | 1.93 | 1.01 | 1 | 0.6 |
| 3 | 0.75 | 0.58 | 0.94 | 0.67 | 1.43 | 0.67 | 1.22 | 0.89 | 0.67 | 0.67 |
| 4 | 0.73 | 0.72 | 1.01 | 0.6 | 0.9 | 0.51 | 1.28 | 0.85 | 0.67 | 0.58 |
| 5 | 0.78 | 0.52 | 0.82 | 0.7 | 1.12 | 0.67 | 1.21 | 0.74 | 0.67 | 0.5 |
| 6 | 1.83 | 0.7 | 0.88 | 2.8 | 1.47 | 1.58 | 2.06 | 0.78 | 1 | 0.48 |
| 7 | 0.88 | 0.77 | 1.01 | 0.6 | 2.21 | 1.44 | 3.19 | 1.01 | 1 | 0.58 |
| 8 | 1.01 | 0.95 | 0.5 | 0.6 | 1.96 | 1.69 | 3.12 | 1.16 | 1.32 | 0.58 |
| 9 | 1.01 | 0.67 | 0.71 | 1.2 | 1.44 | 1.27 | 1.62 | 0.71 | 1 | 0.67 |
| 10 | 1.13 | 1.01 | 1.18 | 1.25 | 1.95 | 1.33 | 3.78 | 1.01 | 1 | 0.48 |
| 11 | 1.65 | 0.74 | 0.72 | 1.3 | 1.41 | 2.42 | 2.01 | 0.8 | 1 | 0.61 |
| 12 | 0.8 | 0.82 | 0.67 | 0.7 | 1.69 | 1.33 | 2.64 | 0.85 | 1 | 0.48 |
| 13 | 1.8 | 0.78 | 0.67 | 1.45 | 1.51 | 1.4 | 1.73 | 0.77 | 1 | 0.58 |
| 14 | 0.97 | 0.67 | 0.58 | 1.01 | 1.18 | 1.31 | 1.62 | 0.67 | 1.33 | 0.48 |
| 15 | 0.97 | 0.75 | 0.75 | 1.3 | 1.44 | 1.36 | 1.67 | 0.78 | 0.67 | 0.48 |

Table 6. Mean values based on pollution factor for potential toxic elements in soil samples collected from Kermanshah Refinery, Iran

| As | Cd | Co | Cr | Cu | Ni | Pb | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 0.93 | 0.86 | 2.06 | 1.39 | 1.5 | 1.16 | 0.88 | 0.73 | 1.16 |

The pollution bar index is another essential parameter in the assessment and estimation of the intensity of soil pollution intensity, which was calculated based on the density value of each of the elements in soil and dividing the density of each element to its density in the reference sample.[13] As a geometric mean value for the intensity of heavy metals, the pollution bar index was calculated for a set of pollutant metals. In addition, the total rate of heavy metal pollution was determined using the Eq. 3.[14]

$$P.L.I=\frac{(CF1\times CF2\times CF3\times \ldots\ldots\times CFn)1}{n} \qquad (3)$$

Table 7 shows the findings of the current research based on the pollution bar index. Accordingly, the soil in the studied area was polluted with chromium, copper, nickel, lead, and zinc and had an inappropriate quality despite the appropriate density of the other elements.

Table 7. Pollution bar index of refinery soil (P.L.I)

| $PLI_{Zn}$ | $PLI_{V}$ | $PLI_{Sc}$ | $PLI_{Pb}$ | $PLI_{Ni}$ | $PLI_{Cu}$ | $PLI_{Cr}$ | $PLI_{Co}$ | $PLI_{Cd}$ | $PLI_{As}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1.14 | 0.6 | 0.8 | 1.06 | 1.75 | 1.4 | 2.75 | 0.77 | 0.85 | 0.4 |

The normalized enrichment factor is used to assess anthropogenic effects on soil and is a common method for the calculation of the higher metal density compared to standard levels.[15] In the present study, scandium was selected as the reference heavy metal considering its inanimate properties and having the least changes compared to the other samples. Moreover, the mean density based on the global shale was considered as the reference environment in the calculations based on the pollution factor. The enrichment index was determined using the Eq. 4.[16]

$$EF=\frac{Cn(sample).Cref(sample)}{Bn(backgroung).Bref(backgroung)} \qquad (4)$$

Table 8 shows the findings based on the calculations of the enrichment factor (EF) in the measurement of the heavy metals in the soil samples. Accordingly, the mean value of EF was <2 for arsenic, cobalt, and vanadium, confirming that the studied region showed no enrichment for aforesaid elements.

According to the obtained results, the EF values for cadmium (station 14), chromium (stations 6-15), copper (stations two, 11, 13, and 14), nickel (stations seven, nine, 12, 13, and 14), lead (stations 6 and 13), and zinc (stations two, six, 11, and 13) were within the range of 2-5, indicating the average enrichment of these elements compared to the other heavy metals. Since the EF values of these samples was >2, it could be concluded the pollution in these samples was of an anthropogenic source.

Table 8. Findings based on enrichment factor in soil samples of Kermanshah Refinery, Iran

| Station | $EF_{Zn}$ | $EF_{V}$ | $EF_{Sc}$ | $EF_{Pb}$ | $EF_{Ni}$ | $EF_{Cu}$ | $EF_{Cr}$ | $EF_{Co}$ | $EF_{Cd}$ | $EF_{As}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.89 | 0.63 | 1 | 1.29 | 1.53 | 0.71 | 1.98 | 0.93 | 0.69 | 0.53 |
| 2 | 2.05 | 0.63 | 1 | 1.77 | 1.24 | 2.93 | 1.71 | 0.89 | 0.89 | 0.65 |
| 3 | 0.8 | 0.61 | 1 | 0.69 | 1.52 | 0.71 | 1.3 | 0.95 | 0.71 | 0.53 |
| 4 | 0.68 | 0.69 | 1 | 0.53 | 0.85 | 0.49 | 1.2 | 0.8 | 0.63 | 0.63 |
| 5 | 0.95 | 0.64 | 1 | 0.85 | 1.36 | 0.76 | 1.5 | 0.9 | 0.81 | 0.53 |
| 6 | 2.7 | 0.79 | 1 | 3.16 | 1.66 | 1.78 | 2.32 | 0.89 | 1.13 | 0.53 |
| 7 | 0.87 | 0.76 | 1 | 0.59 | 2.17 | 1.42 | 3.14 | 0.99 | 0.99 | 0.45 |
| 8 | 0.85 | 0.79 | 1 | 0.53 | 1.63 | 1.41 | 2.6 | 0.97 | 1.11 | 0.95 |
| 9 | 1.47 | 0.91 | 1 | 1.69 | 2.04 | 1.79 | 2.3 | 1 | 1.42 | 0.42 |
| 10 | 0.95 | 0.86 | 1 | 1.05 | 1.65 | 1.13 | 3.2 | 0.85 | 0.85 | 0.84 |
| 11 | 2.28 | 1.02 | 1 | 1.8 | 1.95 | 3.35 | 2.8 | 1.11 | 1.39 | 0.7 |
| 12 | 1.16 | 1.18 | 1 | 1.01 | 2.44 | 1.93 | 3.82 | 1.23 | 1.45 | 0.88 |
| 13 | 2.66 | 1.16 | 1 | 2.14 | 2.44 | 2.07 | 2.56 | 1.14 | 1.48 | 0.9 |
| 14 | 1.8 | 1.2 | 1 | 1.95 | 2.19 | 2.44 | 3.01 | 1.23 | 2.48 | 0.63 |
| 15 | 1.3 | 1.01 | 1 | 1.74 | 1.93 | 1.82 | 2.23 | 1.05 | 0.9 | 0.63 |

### *Zonation of heavy metal pollution in the refinery soil*

Today, geostatic methods, geographic information systems, normal Kriging logs, and common Kriging are used to map elements such as copper, arsenic, mercury, and lead, which could be used to determine the endangered areas with heavy metal pollution, providing useful data for planners to select appropriate regions for various applications.[17-19]

In the present study, the raster layers of each element were combined in ArcGIS software version 10.2,[15] and a single map was developed based on all the maps of spatial distribution in order to determine the rates of heavy metal pollution (Fig. 1). Accordingly, the maximum pollution was observed in stations seven, eight, 10, and 11, which are near petroleum storage tanks. Furthermore, the maximum density of heavy metals was observed in station two, which is near the installations and petroleum refinery units.

### *Correlation-coefficients between the Elements*

Table 9 shows the findings regarding the correlation-coefficients of heavy metals in the soil of Kermanshah Refinery. Significant correlations were observed between chromium and cobalt (r=0.683; P>0.05), nickel with chromium (r=0.653; P>0.05) and cobalt(r=0.884; P>0.01), vanadium with cobalt (r=0.601; P>0.05), chromium (r=0.843; P>0.01), and nickel (r=0.653; P>0.05), scandium with cobalt (r=0.880; P>0.01), and zinc with copper (r=0.819; P>0.01) and lead (r=0.797; P>0.01), indicating the same origin or same geochemical behaviors of the elements toward each other. It is also notable that arsenic had an insignificant correlation with the other elements, which demonstrated that the density of the heavy metals did not depend on arsenic.

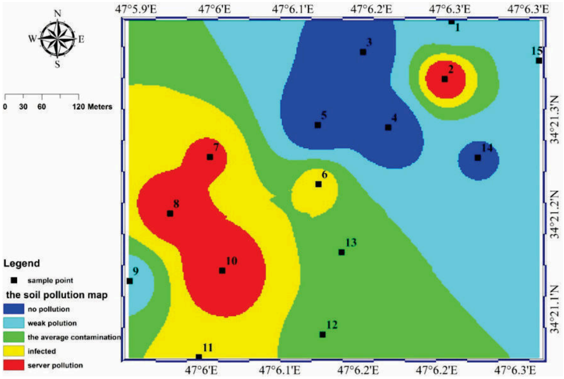

Fig. 1. General map of heavy metal pollution in the soil of the study area

Table 9. Pearson's correlation-coefficients of studied elements

| | As | Cd | Co | Cr | Cu | Ni | Pb | Sc | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| As | 1 | | | | | | | | | |
| Cd | -0.122 | 1 | | | | | | | | |
| Co | 0.020 | 0.189 | 1 | | | | | | | |
| Cr | -0.297 | 0.497 | 0.683* | 1 | | | | | | |
| Cu | 0.166 | 0.489 | 0.278 | 0.267 | 1 | | | | | |
| Ni | -0.101 | 0.401 | 0.653* | 0.884** | 0.224 | 1 | | | | |
| Pb | -0.060 | 0.111 | 0.185 | -0.051 | 0.495 | -0.093 | 1 | | | |
| Sc | 0.041 | -0.070 | 0.880** | 0.485 | 0.123 | 0.381 | -0.049 | 1 | | |
| V | -0.269 | 0.484 | 0.601* | 0.843** | 0.300 | 0.653* | -0.022 | 0.4310 | 1 | |
| Zn | 0.203 | 0.305 | 0.047 | 0.028 | 0.819** | 0.003 | 0.797** | 0.048 | 0.1370 | 1 |

**Correlation is significant at the 0. 1 level *Correlation is significant at the 0.05 level

Vanadium is considered to be an oil index, and high pollution rates with this element along with chromium could be attributed to petroleum.[20-21] Furthermore, considering the least significant effect of anthropogenic factors on scandium,[22] its significant correlation with cobalt confirmed the land-made pollution with these elements.

### *Principal component analysis*

Table 10 shows the findings regarding the factor analysis of various chemical compounds in the soil samples. This table provides useful data on the analysis of the controlling factors of heavy metal density in the soil of the studied region. The findings propose 10 factors, the first three of which could explain 79% of the total variance. The first factor also explained 40.1% of the total variance and is considered to be the most significant influential factor in the density of soil elements. In addition, this factor was observed to have a significant, positive correlation with vanadium, nickel, chromium, cobalt, and scandium, demonstrating that the density of these metals had the same origin as the petroleum of the regional soil. On the other hand, the second factor could explain 24.8% of the total variance and had significant correlations with copper, zinc, and lead, indicating the same origin of density for these elements.

Table 10. Analysis of compounds and factor analysis of elements in studied region

| Component | Initial eigenvalues | | | Extraction sums of squared loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 4.011 | 40.107 | 40.107 | 4.011 | 40.107 | 40.107 |
| 2 | 2.481 | 24.811 | 64.918 | 2.481 | 24.811 | 64.918 |
| 3 | 1.394 | 13.941 | 78.859 | 1.394 | 13.941 | 78.859 |
| 4 | 0.940 | 9.397 | 88.255 | | | |
| 5 | 0.466 | 4.664 | 92.919 | | | |
| 6 | 0.301 | 3.007 | 95.927 | | | |
| 7 | 0.270 | 2.700 | 98.627 | | | |
| 8 | 0.076 | 0.759 | 99.385 | | | |
| 9 | 0.044 | 0.436 | 99.821 | | | |
| 10 | 0.018 | 0.179 | 100.000 | | | |

In the present study, the third factor could explain 13.9% of the total variance and had significant correlations with arsenic and scandium, while it had the least significant influence on the increased density due to external factors, with scandium marking the land-made density (Table 11).

Table 11. Calculated factors before and after rotation

| | Component | | | | Component | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | 1 | 2 | 3 |
| As | 0.129 | 0.218 | -0.686 | As | -0.160 | 0.215 | 0.681 |
| Cd | 0.142 | 0.407 | 0.676 | Cd | 0.555 | 0.306 | -0.490 |
| Co | 0.968 | 0.015 | 0.029 | Co | 0.824 | -0.264 | 0.435 |
| Cr | 0.730 | 0.050 | 0.634 | Cr | 0.925 | -0.200 | -0.205 |
| Cu | 0.244 | 0.871 | 0.105 | Cu | 0.497 | 0.756 | 0.098 |
| Ni | 0.705 | 0.023 | 0.496 | Ni | 0.830 | -0.211 | -0.098 |
| Pb | -0.195 | 0.808 | 0.009 | Pb | 0.069 | 0.828 | -0.031 |
| Sc | 0.882 | -0.011 | -0.220 | Sc | 0.626 | -0.249 | 0.611 |
| V | 0.645 | 0.128 | 0.597 | V | 0.858 | -0.099 | -0.206 |
| Zn | 0.032 | 0.974 | -0.061 | Zn | 0.270 | 0.926 | 0.152 |
| Calculated factors after rotation | | | | Calculated factors before rotation | | | |

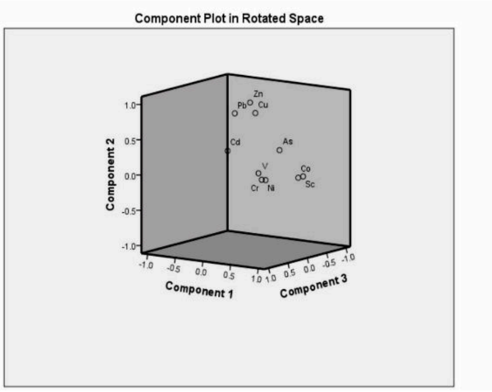

Fig. 2. Plot bar of effective components on density

Fig. 2 depicts the plot bar of the three main components based on the principal component analysis. As can be seen, the density of nickel, chromium, and vanadium was almost similar, confirming the findings of the factor analysis.

## Conclusion

According to the results, the soil surrounding Kermanshah Refinery is polluted with some heavy metals. Based on the geoaccumulation index values, the studied area was polluted with nickel and chromium. On the other hand, the EF values indicated the average enrichment of the soil with chromium and lead. In addition, the EF values of >2 for lead and copper confirmed the effects of the anthropogenic interference factors on the soil pollution in the studied region. The calculated values of the pollution bar for chromium, nickel, zinc, copper, and lead were >1, indicating soil pollution with these elements. Furthermore, the results of Pearson's correlation-coefficient showed significant correlations between vanadium, cobalt, chromium, and nickel, confirming their same origin. The zoning map of heavy metal density in the soil of the studied region demonstrated that the high density of the elements in some stations was due to proximity to petroleum production installations and storage tanks. In addition, cluster analysis indicated the division of the elements into seven categories, and the elements with structural correlations were in the subcategories. Categories six and seven confirmed the same origin of these elements. Since vanadium is derived from oil compounds, it could be concluded that chromium and nickel pollution have the same pollution origin as oil compounds. Finally, the factor analysis proposed three main factors, the first of which could explain 40.1% of the total variance and was considered to be the most significant influential factor in the density of the soil elements. Moreover, this factor had a significant, positive correlation with scandium, vanadium, nickel, chromium, and cobalt, confirming the same density origin as petroleum compounds.

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