SQU Journal for Science, 2019, 24(1), 1-10 DOI: 10.24200/squjs.vol24iss1pp1-10
Sultan Qaboos University

Assessment of Heavy Metal Contamination in Soil in and around Sohar Industrial Port Area, Oman

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ABSTRACT: The increase in the number of heavy metal emitting sources in industrial areas is a serious issue in pollution science. Sohar Industrial Port (SIP) area is located in the northern part of Oman where different industrial activities like petrochemical production, metal processing, and waste disposal are prevalent. This study comprehensively identified the presence and quantities of heavy metals in the soils of Sohar Industrial Port area and traced their origin to geogenic or anthropogenic sources. Bulk geochemical and mineralogical analyses were carried out on all samples. Environmentally available and bioavailable heavy metals were extracted by diethylenetriaminepentaacetic acid (DTPA) and were finally analyzed using Inductively Coupled Plasma-Optical Emission spectrometry (ICP-OES). The environmentally available metals that showed higher concentrations when compared to international standards were Ni and Cd. The geochemical evidence showed a strong geochemical signature of the ophiolite rocks in the soils as indicated by the significant correlation between Cr and Ni ($P< 0.05$). In addition, the Cd content showed significant correlations with Ni and Cr ($P< 0.05$). Other metals like Pb and Zn, possibly also were geogenic in origin, but with significantly elevated concentrations in samples close to a national highway ($P< 0.05$). The present study demonstrated the significance of understanding the geological framework of an industrial area, which is already imposing high background concentrations of Cr, Ni and Cd, and also the possible anthropogenic impacts in the cases of Pb and Cd that exceeded internationally permissible limits.

Keywords: Heavy metals; Spatial distribution; Sohar Industrial Port; Oman.

مقدار تلوث التربة بالمعادن الثقيلة حول ميناء صحار الصناعي في سلطنة عمان

مها غارب الجابري، أدانيل موريتس وريجنالد فكتور

الملخص: ان ازدياد معدلات إنبعاث الكثير من المعادن الثقيلة في المناطق الصناعية يعتبر موضوع خطير في علم التلوث. تقع منطقة ميناء صحار الصناعي في شمال سلطنة عمان حيث أن هنالك العديد من الأنشطة الصناعية كانتاج البتروكيماويات،معالجة المعادن والتخلص من النفاياتز تهدف هذه الدراسة الشاملة لتحديد أنواع وكميات المعادن الثقيلة في التربة المحيطة بميناء صحار الصناعي وتتبع المنشا الجيلوجي والبشري الصناعي و لقد تم تحليل كل العينات جيوكميائيا ومعدنيا. ان المعادن المتاحة بيئيا وبيولوجيا تم استخلاصها بواسطة حامض وطريقة DATPA وتم تحليلها بواسطة استقراء البلازما وطيف الإنبعاثات الضوئية. لقد وجدنا تركيز النيكل والكادميم في عينات المعادن البيئية بانها كانت عالية بالمفارنة مع المعايير الدولية. ان الأدلة الجيوكميائية أظهرت وجود صخورأفيوليت في التربة والذي دل على ذلك الإرتباط الكبير بين الكروميم والنيكل (0.05P less than). أما بالنسبة لمعدني الرصاص والزنكل فربما لديهم منشأ جيولوجي ولكن بمقدار كثافة عالية في بعض العينات التي اخذت بالقرب من الطريق السريع القومي. (P less than 0.05). أظهرت الدراسة الحالية اهمية فهم الإطار الجيولوجي بمنطقة صناعية تفرض خلفية عالية من تركيز الكروميم والنيكل والكادميم وتظهر احتمال اثر المنشأ البشري الصناعي في حالة الرصاص والكادميم االلذان فاق تركيزها المستوى الدولي المسموح به.

الكلمات المفتاحية: معادن ثقيلة، التوزيع المكاني، ميناء صحار الصناعي، سلطنة عمان.

1. Introduction

Soil is an interface for earth, water and air and is a key component of the ecosystem, and is exposed to several pollutants including toxic heavy metals generated by various natural and anthropogenic activities. This makes soil a source of pollution to living organisms, surface and groundwater, sediments and oceans. Heavy metals can affect soil microbes and their associated activities, which play a significant role in the recycling of plant nutrients, detoxification of noxious chemicals, and the control of plant pests and plant growth [1,2]. Among different contaminants, heavy metals are categorized as the most hazardous class of anthropogenic pollutants because of their persistence and toxicity [3,4]. The heavy metals of importance in soil with reference to potential hazards are cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), aluminium (Al), nickel (Ni), cadmium (Cd), arsenic (As) and zinc (Zn) [5,6]. Heavy metals in soil originate from natural sources like parent rocks, and anthropogenic activities including mining, other industrial activities, energy production, agriculture, vehicle exhausts, waste disposal, and coal combustion [7-13].

Industrial activities are increasing rapidly all over the world. Many studies have been conducted to assess heavy metal contamination in and around industrial areas, especially in the most industrialized countries [3,10]. The occurrence of heavy metals in soil at industrial sites depends on the type of the industry. Metals contaminate soils through dust, spillage of raw materials, wastes, final products, fuel ash, accidents and fires [14].

In the last few years, industrialization in Oman, especially in the north, has increased rapidly. Sohar lies in the center of Al-Batinah region, in north Oman. Sohar Industrial Port (SIP), Sohar Free Zone together with Sohar Airport and the upcoming Gulf Cooperation Council (GCC) rail network are prime areas for investment. SIP in particular accommodates various types of highly polluting industries including metal processing, petrochemicals, power plants and a sewage treatment plant. In addition, it has high vehicular activity during working days. Heavy metals generally are expected in the soil of such areas.

So far, limited investigations have been conducted on the heavy metal concentrations in the soils of the SIP area. Al-Rashdi and Sulaiman [15] studied the heavy metal accumulation in the soils of farms west of the Sohar industrial area and their results showed that the heavy metal concentrations in the soil were in the order of iron (Fe) > aluminium (Al) > nickel (Ni) > zinc (Zn) > chromium (Cr) > cobalt (Co) > copper (Cu) > lead (Pb). Heavy metals in the surface sediments north and south of Sohar industrial area studied by Al-Suely *et al.* [16] showed that the concentrations of chromium (Cr), manganese (Mn) and vanadium (V) were high in several areas while other elements were low.

The present study is the first to investigate the heavy metals of the soil inside the SIP area. Its main objective is to identify the content of heavy metals in the soils around SIP area and trace their origin. In addition to providing the baseline data on the soil concentrations of heavy metals in the SIP area, this study is expected to provide a descriptive model for the investigation of heavy metals in the soils of other industrial areas in Oman.

2. Materials and Methods

Sohar Industrial Port (SIP) area, one of the most rapidly growing areas in Sohar City, Sultanate of Oman, is approximately 240 km from Muscat (Figure1). It covers a total area of 123 km^2 and has three main clusters of activities: (a) petrochemical production, (b) metal processing, and (c) logistics such as power production and water supply. Other activities include wastewater processing, water-cooling and cargo handling.

The geology of the study area is comprised mainly of the allochthonous ophiolite nappe, like dunites and gabbro (seen in the west part of Figure 1) and the quaternary deposits which cover most of the area. Structurally, the ophiolite nappe has been covered by thick quaternary sediments. The quaternary deposits are mainly gravels and sands (either cemented or not) towards inland and sand and silt along with sabkha deposits in the coastal area downstream. The area is carved by numerous wedian supplying clastic material to coastal areas [17].

The study area was divided into a grid of 15 cells and each cell was 1.62 ×0.75 km in area around the port (Figure 2). Twenty-four surface soil samples were taken from the industrial area within the grid (Sh1 - Sh24) and two from residential areas (Sh25, Sh26). In addition, two surface samples (B1, B2) were taken from the beach at the eastern and western limits of the port and two surface samples (C1, C2) were taken as controls at a distance of 2-5 km from the port. C1, C2 are considered to be the control areas because of their upstream position from Sohar port and their similarity to the study area in the geochemical signature of the soils (mainly clasts from ophiolite nappe). Five subsurface samples were also taken from selected locations (Sh5, Sh8, Sh15, Sh16, Sh17) within the grid where surface samples were collected. The total number of soil samples collected were 35. The surface samples were taken at a depth of 0-10 cm using a spade and subsurface samples were taken by an auger at a depth of 60-80 cm. The surface samples were taken from three locations within a radius of 5 m within a cell and were mixed together to make up a composite sample. All samples were packed in labelled polyethylene bags.

Samples were transferred to the laboratory and then dried in the open air for about 72 h. The dried samples were sifted through a 2-mm sieve to remove large gravel, plant roots and other waste materials. Then parts of the samples were ground using a Pulverisette-5 planetary mill (FRITSCH, Germany). The ground samples were sieved using a 315-μm sieve and stored in labelled polyethylene bags.

The electrical conductivity and pH were measured in a water to soil ratio of 2:1. The organic matter content was measured by the potassium dichromate method and the bulk chemistry was determined using X-Ray Fluorescence

(XRF) with Nilton XL3 from Thermo Scientific. The grain size distribution was measured by the Bouyoucos method [18].

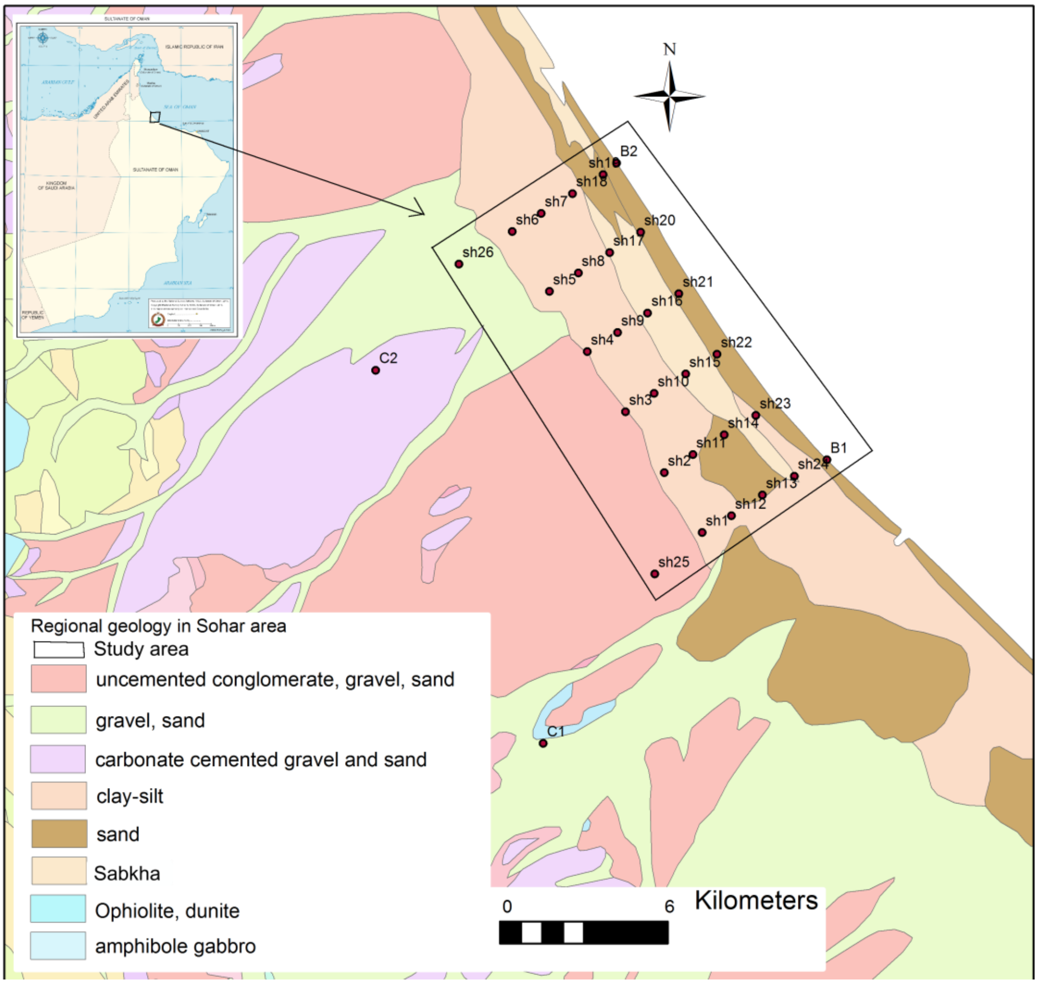


Figure 1. Study area geological map with sampling locations in and around Sohar Industrial Port, "Sh" refers to samples collected from industrial and residential areas, C refers to control and B to samples collected from the beach. The geological map was modified after Bishimetal Exploration Co. LTD. [31] and the Arabian Peninsula map was supplied by the National Survey Authority Oman (Oman 2015).

Heavy metals were extracted using the US Environmental Protection Agency (EPA) 3050 extraction method [19] and were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (Varian 710-ES, USA). The analysis was done in triplicate and one spiked sample was analyzed for quality assurance. Micronutrients were extracted using diethylenetriaminepentaacetic acid (DTPA) and the extracts were analyzed for heavy metals using ICP-OES [20]. The results obtained from EPA 3050 extraction methods were classified using cluster analysis based on similarity measures.

3. Results

The geology of the area is characterized by different sized loose sediments as shown in Figure 1. Sabkha, coastal sediments of clay and sand cover a large area. There are outcrops of ophiolite close to sites C1 and C2. The physical and chemical parameters along with the results of the grain size distribution are given in table 1. The XRF analysis showed that soils have a significantly positive correlation ($P < 0.05$) for Cr and Ni and significantly negative correlation ($P < 05$) for MgO and K_2O (Figure 2 A,B).

The organic material was relatively low (<1%) in most of the samples except for those samples collected from sabkha deposits with vegetation cover as in Sh14, Sh18, and Sh19 and a plantation of trees as in Sh10. The samples with high organic content did not show correspondingly high heavy metal contents. The pH and electrical conductivity range from 7.78 to 8.99 and 50 µS/cm to 23 mS/cm respectively. The grain size was considered mainly fine in most of the samples except at the beach sites B1 and B2, where it was sandy.

The concentrations of the environmentally available metals were extracted through EPA 3050 procedure and the recommended international guidelines for soil quality are presented in table 2. The results of two factor ANOVA for zones and gradients showed no significant differences of specific heavy metals within zones ($F = 1.75 < F = 2.25$; $P = 0.13$) and within gradients ($F = 1.08 < F = 2.40$; $P = 0.38$). In general, most of the metal concentrations were below the maximum concentrations recommended by the international guidelines for soil except for Ni and Cd, which were higher. The same results from EPA 3050 procedure, fed into the cluster analysis showed that both Cd and Ni belong to the same cluster group along with Cr. In addition, other heavy metals cluster into two other groups of Pb, Zn, Cu, Mo and V, Al, Fe and Mn (Figure 3).

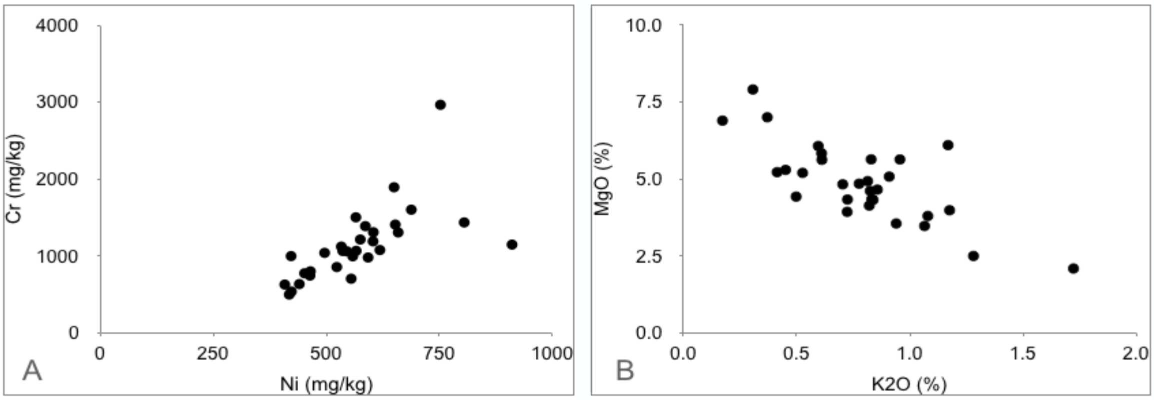
Table 1. pH, electrical conductivity (EC), organic matter and soil texture for all samples. Triplicates for organic matter and EC in 20% of the samples showed standard deviation less than 5% in the analysis.

Sampling Code	pH	EC (uS/cm)	% soil organic matter	% silt	% clay	% sand	Soil Texture
Sh1	8.82	116	0.33	23.6	7.2	69.2	Sandy loam
Sh2	8.87	46	0.87	29.6	5.2	65.2	Sandy loam
Sh3	8.54	208	0.13	31.2	5.2	63.6	Sandy loam
Sh4	8.13	7019	0.73	21.2	7.2	71.6	Sandy loam
Sh5	7.78	6710	1.73	41.2	3.2	55.6	Sandy loam
Sh6	8.55	138	0.73	35.2	7.6	57.2	Sandy loam
Sh7	8.50	117	0.93	35.2	5.6	59.2	Sandy loam
Sh8	7.88	6718	1.33	51.2	3.6	45.2	Silt loam
Sh9	8.25	1094	1.27	33.2	5.6	61.2	Sandy loam
Sh10	8.52	113	2.00	45.2	13.6	41.2	Loam
Sh11	8.30	439	0.80	21.2	7.6	71.2	Sandy loam
Sh12	8.68	72	1.27	25.2	7.6	67.2	Sandy loam
Sh13	8.53	727	0.87	31.2	9.2	59.6	Sandy loam
Sh14	7.87	23882	2.07	31.2	13.2	55.6	Sandy loam
Sh15	7.90	4101	0.93	35.2	11.2	53.6	Sandy loam
Sh16	7.97	6966	0.47	21.2	7.2	71.6	Sandy loam
Sh17	7.97	8907	0.76	27.2	11.2	61.6	Sandy loam
Sh18	8.70	13833	1.60	67.2	5.2	27.6	Silt loam
Sh19	8.44	20112	2.07	71.2	15.2	13.6	Silt loam
Sh20	7.86	2725	1.07	45.2	15.2	39.6	Loam
Sh21	8.70	128	0.13	15.2	5.2	79.6	Loamy sand
Sh22	7.91	2097	0.20	21.2	5.2	73.6	Sandy loam
Sh23	7.95	7007	0.47	19.2	5.2	75.6	Clay
Sh24	8.26	10890	0.93	51.6	23.6	24.8	Loamy sand
Sh25	8.93	86	0.53	33.6	5.6	60.8	Sandy loam
Sh26	8.17	2618	0.20	35.6	11.6	52.8	Loam

C1	8.07	224	0.67	29.6	5.6	64.8	Sandy loam
C2	8.99	50	0.27	13.6	2.6	83.8	Loamy sand
B1	8.32	2889	0.13	1.6	1.6	96.8	Sand
B2	8.66	3103	0.47	1.6	1.6	96.8	Sand

Table 2. Summary of heavy metal concentration (mg/kg) with minimum, maximum, and mean ± standard deviation and international limits of heavy metals in soil (Zhao *et al.*, 2014). The small letters above the value in some results represent the first letter of international limits and mean that values exceed the limit .

Parameters	Al	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn
Minimum	5339	1.7 Ch,G	52	9	11629	239	0.5	256.7 D,Ch,Cn,Eu,G	0.7	17	24
Maximum	10399	2.0 Ch,G	103 G,Cn	99 Cn	15289	378	1.4	569 D,Ch,Cn,Eu,G	8.0	33	405 Ch,Cn,Eu,G
Mean	8343± 1333	1.8± 0.1 Ch,G	70± 13	31± 18	13068± 939	339± 35	0.8± 0.2	397± 66 D,Ch,Cn,Eu,G	2.2± 1.4	25± 3	56± 68
Dutch soil guidelines D	-	12	380	190	-	-	200	210	530	-	720
Chinese guidelines Ch	-	0.3	200	100	-	-	-	50	300	-	250
Canada guidelines Cn		22	87	91	-	-	-	50	600	-	360
EURS Eu	-	3.0		140	-		-	75	-	300	300
Germany G	-	1.0	100	100	-	-	5.0	60	100	50	300



Figures 2 (A,B). A. XRF analysis - Correlation between Cr and Ni (R^2=0.43; df = 33; P<0.05), **B.** Correlation between Mg and K_2O (R^2=0.50; df =33; P <0.01).

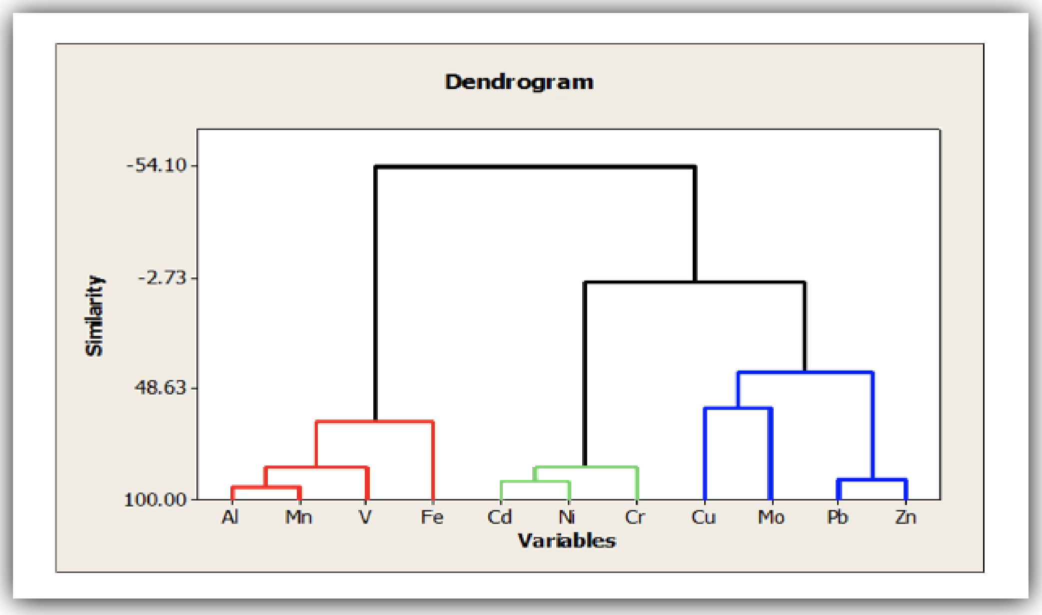


Figure 3. Dendrogram showing the clustering derived from the results of the environmentally available metals with EPA 3050 method.

The DTPA extraction was done for selected samples. At least one sample from each zone and gradient was chosen for analysis. The extraction was done for four metals, copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) which are important as micronutrients for plants. The concentration of metals among different samples was close to each other except for Sh 25 where the concentration of Zn was high. This also was shown in EPA extraction. The results of DTPA extraction are presented in Table 3.

Table 3. Concentration of Cu, Fe, Mn and Zn in (mg/kg) extracted by DTPA for selected samples.

Sample code	Cu	Fe	Mn	Zn
Sh1	0.546± 0.005	1.532± 0.015	0.594± 0.005	3.063± 0.027
Sh3	0.548± 0.004	3.036± 0.042	0.811± 0.011	1.770± 0.020
Sh5	0.633± 0.009	1.455± 0.022	6.482± 0.036	1.828± 0.022
Sh9	0.488± 0.011	1.558± 0.020	2.115± 0.031	0.743± 0.010
Sh11	1.224± 0.019	2.949± 0.029	0.827± 0.009	1.511± 0.025
Sh13	0.335± 0.001	1.893± 0.013	0.977± 0.008	1.071± 0.014
Sh15	0.454± 0.007	1.895± 0.014	0.517± 0.004	0.622± 0.009
Sh17	0.376± 0.003	3.220± 0.031	1.300± 0.008	0.982± 0.001
Sh19	0.654± 0.004	0.189± 0.002	0.322± 0.002	0.856± 0.010
Sh23	0.183± 0.002	1.934± 0.014	0.632± 0.003	0.567± 0.004
Sh25	2.372± 0.008	2.910± 0.017	1.620± 0.002	31.679± 0.059
Sh26	1.346± 0.003	2.535± 0.013	0.884± 0.005	0.490± 0.003
C1	0.948± 0.002	2.012± 0.012	0.938± 0.007	1.239± 0.001
C2	0.432± 0.004	1.034± 0.004	0.482± 0.003	0.693± 0.002
B1	0.241± 0.002	5.070± 0.046	1.828± 0.017	0.164± 0.002

The spatial distribution of heavy metal concentration is shown in figures 5 A-D. The iso-concentration map of each metal is presented for the study area. The map has coordinates and contours. Each contour indicates a different concentration displayed arranged in a different color as presented in the legend on the right side of the maps. The spatial distribution of Cr and Ni had similar trends. Their concentration increased towards the coastline where there is industrial activity. In contrast, Pb and Zn decreased towards the coastline.

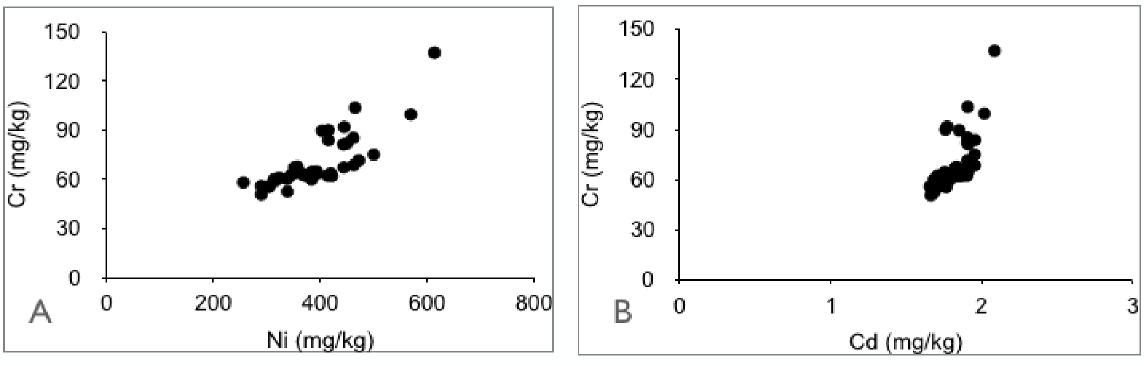
4. Discussion

The bulk chemical and physical analyses reflect the dry soil environment with low organic matter content and the lithology of the fine sediment alluvial fans. The low organic content is expected in the current climatic conditions. The high salinity and the high pH of several soil samples are attributed to the presence of sabkha deposits and the current coastline deposits such as those in samples Sh14 to Sh19. The absence of significant correlations between environmentally available metals and organic matter concentrations show that organic matter has little influence on the heavy metal contents in soils.

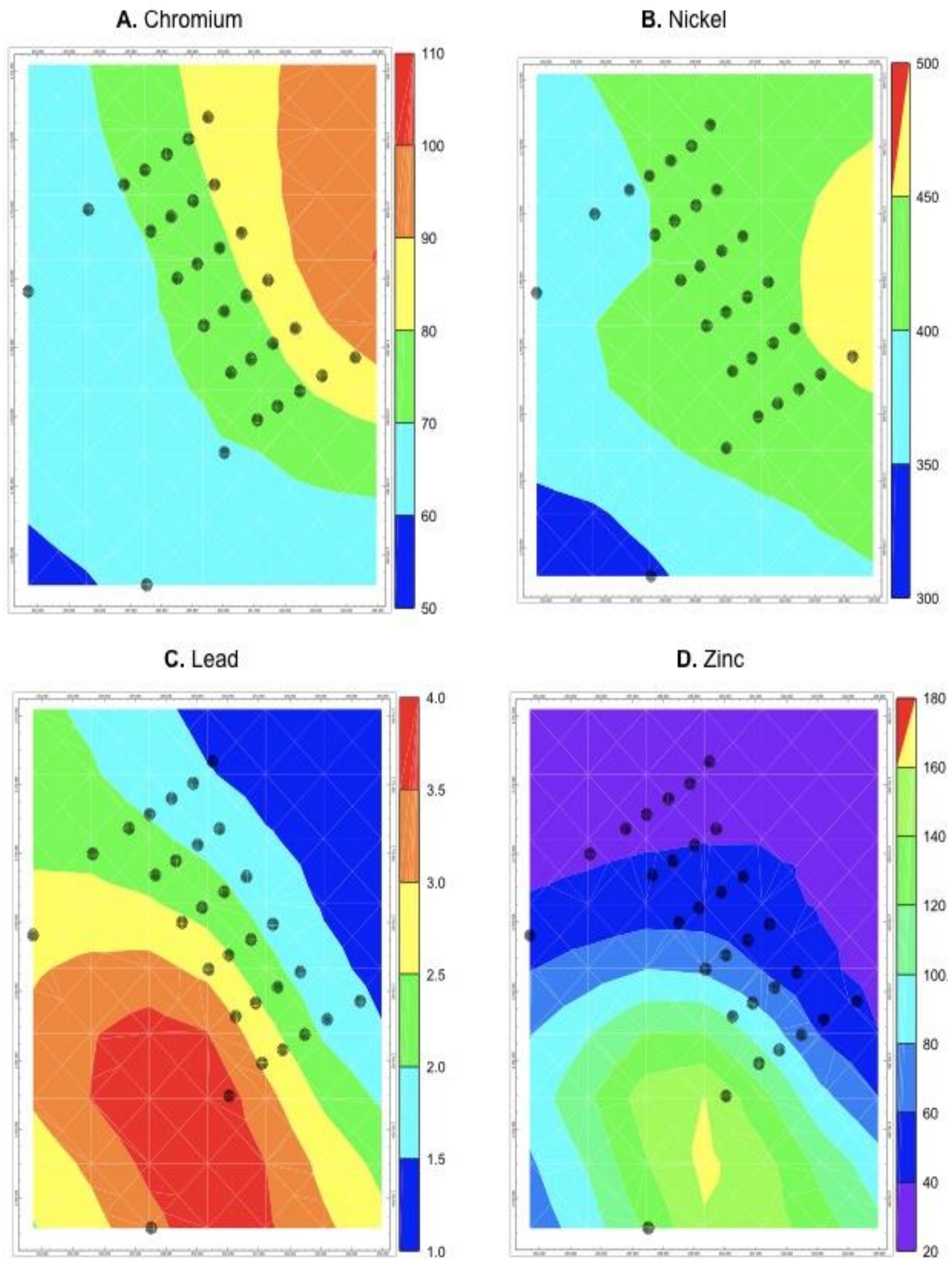
Eleven heavy metals were detected, namely Al, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, V and Zn. The mean concentrations of these heavy metals were compared with the international standards for industrial and agricultural soil quality of different countries because there are no national limits in Oman for heavy metals in soil. The mean concentration of Cd exceeded Chinese and German limits and the mean concentration of Ni exceeded all limits (Dutch, Chinese, Canadian, European and German guidelines). Zn and Cr had mean concentrations below the standard limits, but the maximum concentrations were above several international standards. Metal concentrations in soils below the standard limits usually indicate no influence of pollution on the soil environment and therefore can be ignored; concentrations above limits are deleterious to the environment [21]. The values of Pb, Zn and Cd reported in this study are much lesser than those reported for other industrial areas [22-24]. In Hong Kong, Li *et al.* [7] reported the concentrations of Cr, Ni, Pb, Zn and Cd in urban soils close to an industrial area as 23.10 ±10.10, 12.4 ± 4.8, 94.60 ± 61.0, 125.0 ± 89.1, 0.62 ± 0.82 mg/kg respectively. In comparison, this study reported higher concentrations for Cr, Ni and Cd, while Pb and Zn concentrations were lower.

The clustering of Cd, Ni and Cr in the same group (Figure 3) suggests a common source of geogenic and/or anthropogenic contamination. Correlation between Cr and Ni, (Figure 2A) was significant ($P< 0.05$). The high correlation between Cr and Ni in both XRF analysis (Figure 2A) and the EPA 3050 leaching (Figure 4A) suggest a significant geogenic origin such as in areas with ophiolite rocks [25, 26, 27]. The elevated concentration of the Ni and Cd when compared with most of the international guidelines could lead someone to conclude that this area is partly contaminated by anthropogenic activities. In addition, the negative correlation between MgO and K_2O (Figure 2B) confirms that the main factors controlling the geochemistry of the soils in SIP are erosion and deposition of mafic and ultramafic material. The clustering of Pb, Zn, Mo and Cu (Figure 3) is very common in areas rich in sulfides. Sulfide deposits are widespread in the ophiolite outcrops of the northeastern flanks of the Hajar Mountains. The high concentrations of Pb and Zn in sample Sh25 indicate anthropogenic impact due to the high number of vehicles plying the area.

Copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were extracted by the DTPA method because of their importance as micronutrients for plants. The metals estimated by the DTPA method are low when compared with the acid digestion method. This is because the DTPA method targets available cations in the soil via chelation. The acid digestion method targets all metal forms including the available cations and those in compound forms. The results showed high concentrations of Zn, and similar results were observed in EPA 3050 extraction. The highest concentration of Zn (31.679 ± 0.059 mg/kg) in Sh 25 could be due the high vehicular traffic at this site. Anyakora *et al.* [28] reported that Zn in the soil adjacent to roads in Africa was due to its release from car tires and lubricant oils.



Figures 4 (A,B). A. Correlation between Cr and Ni, **B.** Cr and Cd derived from the soil acid digestion (EPA3050). Cr and Ni correlation has an $R^2=0.53$ and for Mg and K_2O is $R^2=0.50$



Figures 5 (A,B,C,D). Spatial distribution of Cr, Ni, Pb and Zn concentration (mg/kg) presented as iso-concentration map with legend of different concentrations classified by colour codes.

Spatial distribution of heavy metals provides a simple and effective presentation of results in pollution investigations [29]. In addition, it is used to assess the origin of the possible sources and points of high metal concentrations [11]. The iso-concentration maps of Cr and Ni (Figure 5) were generally similar suggesting that they originated from the same source, which is the ophiolite rocks as already demonstrated by the geochemical results. Similarly, Pb and Zn showed an increase outside the SIP towards a national highway thus indicating the contribution of heavy traffic (Figure 5). However, within the SIP, only Sh 25 which has a lot of heavy vehicular traffic using diesel registered the highest concentration of Pb and Zn. Many earlier studies have shown that Pb and Zn could originate from traffic emissions [7, 21, 23, 30], but these metals could also be released from the parent rocks.

This study should prompt the decision makers to establish the baseline limits for heavy metals in the soils of industrial areas in Oman. Soil quality analysis for heavy metals should be an integral part of the environmental impact assessment (EIA) protocols needed for establishing new industries. Especially in the case of Oman, heavy metals like Cr, Ni and Cd should be considered in legislative and risk assessment studies because of their high concentrations in the natural environment. Metals like Pb, Zn and Cu could be released from geogenic sources, but extreme values, especially close to the roads should be carefully assessed for the anthropogenic impact.

5. Conclusion

The investigation of heavy metal content in SIP soils showed that the concentrations of heavy metals are low when compared to international guidelines and standards except for Ni and Cd. However, the correlations of Cr, Ni and Cd showed the geogenic origin of those heavy metals from the ophiolite. Pb and Zn fall in the same group with Cu and Mo and denote the possible geogenic origin from the erosion of sulfides deposits. The higher concentrations of Pb and Zn outside the SIP, especially in sample Sh25 towards a national highway, need further study on the roadside sediments to verify whether these are the products of anthropogenic soil impact or just the extreme outliers of the existing lithology.

Acknowledgement

We would like to thank Sohar Port for their support during the collection of soil samples. Departments of Biology and Earth Sciences, Sultan Qaboos University provided the facilities.

References

1. Olveira, A. and Pampulha, M.E. 2006. Effects of long-term heavy metal contamination on soil microbial characteristics. *Journal of bioscience and bioengineering,* **102**, 157-161.
2. Yuan-Peng, W., Ji-Yan, S., Qi, L., Xin-Cai, C. and Ying-Xu, C. 2007. Heavy metal availability and impact on activity of soil microorganisms along a Cu/Zn contamination gradient. *Journal of Environmental Sciences,* **19**, 848–853.
3. Alam, S.S., Osman, K.T. and Kibria, M.G. 2012. Heavy metal pollution of soil from industrial and municipal wastes in Chittagong, Bangladesh. *Archives of Agronomy and Soil Science*, **58**, 1427-1438.
4. Soodan, R.K., Pakade, Y.B., Nagpal, A. and Katnoria, J.K. 2014. Analytical techniques for estimation of heavy metals in soil ecosystem: a tabulated review. *Talanta,* **125**, 405-410.
5. Al-Khashman, O.A. and Shawabkeh, R.A. 2009. Metal distribution in urban soil around steel industry beside Queen Alia Airport, Jordan. *Environmental geochemistry and health,* **31**, 717-26.
6. Ali, I.H. and Ateeg, A.A. 2015. Study of soil pollutants in Omdurman Industrial Area, Sudan, Using X-ray Fluorescence. *International Journal of Environmental Research,* **9**, 291- 294.
7. Li, X., Lee, S.-L., Wong, S.-C., Shi, W. and Thornton, I. 2004. The study of metal contamination in urban soils of Hong Kong using a GIS-based approach. *Environmental pollution,* **43**, 129**,** 113-124.
8. Chen, T., Liu, X., Li, X., Zhao, K., Zhang, J., Xu, J., Shi, J. and Dahlgren, R.A. 2009. Heavy metal sources identification and sampling uncertainty analysis in a field-scale vegetable soil of Hangzhou, China. *Environmental pollution,* **157**, 1003-1010.
9. Li, J., Lu, Y., Yin, W., Gan, H., Zhang, C., Deng, X. and Lian, J. 2009. Distribution of heavy metals in agricultural soils near a petrochemical complex in Guangzhou, China. *Environmental Monitoring and Assessment*, **153**, 365-375.
10. Al-Khashman, O.A. 2012. Assessment of Heavy Metal Accumulation in Urban Soil around Potash Industrial Site in the East of the Dead Sea and their Environmental Risks. *Soil and Sediment Contamination,* **21**, 276-290.
11. Li, X., Liu, L., Wang, Y., Luo, G., Chen, X., Yang, X., Hall, M. H. P., Guo, R., Wang, H., Cui, J. and He, X. 2013. Heavy metal contamination of urban soil in an old industrial city (Shenyang) in Northeast China. *The Global Journal of Soil Science,* **192**, 50-58.
12. Haciyakupoglu, S., Esen, A.N., Erenturk, S., Okka, M., Genceli, M., Mercimek, M., Genceli, E., Yusan, S., Filiz, F.G., OlgenL, K., Camtakan, Z., Kiziltas, S. and Tanbay, T. 2014. Determining distribution of 42 heavy metal pollution in terms of ecological risk levels in soil of industrially intensive areas around Istanbul. *Toxicological and Environmental Chemistry*, **97**, 1-14.
13. Li, Z., Ma, Z., Vanderkuijp, T.J., Yuan, Z. and Huang, L. 2014. A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. *The Science of the total environment,* **468-469**, 843-853.
14. Alloway, B.J. 2013. Sources of heavy metals and metalloids in soils. *Environmental pollution,* **22**, 11-45.
15. Al-Rashdi, T.T. and Sulaiman, H. 2013. Bioconcentration of heavy metals in Alfalfa (Medicago sativa) from farm soils around Sohar industrial area in Oman. Proceeding at 5th International Conference on Environmental Science and Development, UAE. *Procedia APEBEE,* **5**, 271-278.
16. Al-Suely, W.Z.I., Al-Kindi, A., Al-Saidi, S., Khan, T., Marikar, F.A. and Al-Busaidi, M. 2009. Heavy metals content on beach sediments north and south of Sohar industrial area, Oman. *Journal of Environmental Science and Technology,* **2**, 73-79.
17. Kanda Nishiki-Cho and Chiyoda-Ku 1987. Geological map of Sohar sheet, NG, 40-14F-I scale 1:50,000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, Muscat.
18. Bouyoucos G.L. Hydrometer method improved for making particle size analysis of soils. Agronomy journal. 1962, **54**, 464-465.
19. Edgell, K. 1988. USEPA Method Study 37 - SW-846 Method 3050 Acid Digestion of Sediments, Sludges, and Soils. *In:* DEVELOPMENT, R.A. (ed.). US Environmental Protection Agency, Contract No. 68-03- 3254.

20. Lindsay, W.L. and Norvell, W.A. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal,* 1978, **42**, 421-428.
21. Zhao, L., Xu, Y., Hou, H., Shangguan, Y. and Li, F. Source identification and health risk assessment of metals in urban soils around the Tanggu chemical industrial district, Tianjin, China. *The Science of the total environment,* 2014, 468-469.
22. Velea, T., Gherghe, L., Predica, V. and Krebs, R. Heavy metal contamination in the vicinity of an industrial area near Bucharest. *Environmental science and pollution research international,* 2009, **16**, S27-S32.
23. Mtunzi, M.F. Evaluation of heavy metal pollution on soil in Vaderbijlpark, South Africa. *International Journal of Environmental Monitoring and Analysis,* 2015, **3**, 44-49.
24. Chabukdhara, M. and Nema, A.K. Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: probabilistic health risk approach. *Ecotoxicology and environmental safety,* 2013, **87**, 57-64.
25. Morrison, J.M., Goldhaber, M.B., Lee, L., Holloway, J.M., Wanty, R.B. A regional-scale study of chromium and nickel in soils of northern California, USA. Applied Geochemistry. 2009, **24**, 1500–1511.
26. Mills, C.T., Morrison, J.M., Goldhaber, M.B., Ellefsen, K.J. Chromium (VI) generation in vadose zone soils and alluvial sediments of the southwestern Sacramento Valley, California: a potential source of geogenic Cr (VI) to groundwater. Applied Geochemistry, 2011, **26(8)**, 1488-1501.
27. Moraetis D. Nikolaidis N.P., Karatzas G.P, Dokou Z, Kalogerakis N., Winkel L. Palaiogianni-Bellou A. Origin and mobility of hexavalent chromium in North-Eastern Attica, Greece. Applied Geochemistry, 2012, **27**, 1170-1178.
28. Anyakora, C., Ehianeta, T. and Umukoro, O. Heavy metal levels in soil samples from highly industrialized Lagos environment. *African Journal of Environmental Science and Technology,* 2013, **7**, 917-924.
29. Yan, W., Mahmood, Q., Peng, D., Fu, W., Chen, T., Wang, Y., Li, S., Chen, J. and Liu, D. The spatial distribution pattern of heavy metals and risk assessment of moso bamboo forest soil around lead–zinc mine in Southeastern China. *Soil and Tillage Research,* 2015, **153**, 120-130.
30. Imperato, M. Spatial distribution of heavy metals in urban soils of Naples city (Italy). *Environmental pollution,* 2003, **124**, 247-256.
31. Bishimetal Exploration CO LTD.1992b. Geological map of Sur sheet, NF, 40-14F-I, scale 1:50,000. Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, Muscat.

Received 8 March 2018
Accepted 8 October 2018