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Spatial Assessment and Variability of Soil Properties on the Saiq Plateau, Oman

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Abstract

The Al-Hajar mountain range is a special environment in northeastern Oman and possesses a number of threatened plant and animal species. Recent development projects and other human activities have the potential of causing serious disturbance to the natural environment. Fundamental to conserving this region is maintaining a healthy soil environment. This study examined spatial variability of soil properties in the Saiq Plateau of Oman by collecting a total of 45 samples at different sites. These sites were divided into agricultural and non-agricultural (such as Natural, Dam and Wadi) locations. Soil samples were analyzed for particle size, pH, EC, water-soluble content of Na, Ca, Mg, K, Fe, B, Zn, Cu, Mn, Ni, Cd, Pb, V, Cl, NO_3, PO_4, and SO_4, and total content was measured for Ca, Mg, Na, K, Al, Fe, Mn, Zn, Cu, Ni, Cd, Pb, V, and Cr. No Fe, B, Zn, Cu, Mn, Ni, Cd, V, and P occurred in the water-soluble fraction. The results indicate that soil EC and NO_3 are highest next to dams with a positive correlation between NO_3 and Cl. Factor analysis suggests chloride, and sulfate salts as a source of soil salinity. Heavy metals were found in normal concentrations and factor analysis indicates that lithogenic processes control their presence and variability in soils.

1. Introduction

In many parts of the world, it is often said that mountains serve as the water reservoirs from which large quantities of water flow via many paths supplying vast communities with their needs of water [1]. However, it can also be said that mountains have been providing the surrounding areas with large amounts of soils. The variability in soil properties, laterally and vertically, results from the impact of the soil-forming factors such as climate, vegetation, topographic setting, parent material, and the time [2, 3, 4]. These soils, depending on the parent rocks from which they form, differ greatly in their physical and chemical characteristics and make soils one of the most valuable resources in terms of sustaining plants, animals, and humans. Such attributes exert decisive influence on soil development processes and the way water flows in landscape [4]. Further, the direction of the slope aspect of topography influences the amount and intensity of solar radiation to which a location is exposed and subsequently the temperature regime, which affects soil's biological and chemical processes as well as evaporation [5].

However, because of the many pressures on this vital resource soils are highly vulnerable to changes and degradation. The vertical nature of mountains with steep slopes and plateaus makes surfaces very unstable. In addition, pressures from human activities, especially those disturbing protective plant cover, such as overgrazing, increased housing development and road building, pollution, tourism, and inappropriate farming practices result in erosion and loss of fertility, hence increasing the fragility of mountain soils [6,7,8,]. Therefore, conservation measures have to be adopted and implemented to sustain this vital natural resource [9]. Such management can only be achieved by first investigating the current chemical and physical parameters of topsoils in the mountains. The Al-Hajar mountain range is a special environment in northeastern Oman and possesses a number of threatened plant and animal species. Recent development projects and other human activities have the potential of causing serious disturbance to the natural environment [1, 10,11, 12]. Over the past, few decades there are limited studies that have been conducted related to the soilresources of Al-Jabal Al-Akhdar Mountain region of Oman.

Thus, the objective of study was to investigate the spatial variability of surface soil properties focused on their physical and chemical nature and the information generated from this study would contribute towards proper planning as well as to assess appropriately human activities on the plateau.

1.1. Study Area and the Environment

Al-Hajar mountain range, divided as Al-Hajar al Gharbi (Western Al-Hajar) and Al-Hajar Al-Sharqi (Eastern Al-Hajar), stretches north-west to South-East, paralleling the coast of the Sea of Oman, for over 700 km from Musandam to Ras Al-Hadd. Its width varies between about 30 to 70 km. Between the Al-Hajar al Gharbi and the Al-Hajar Al-Sharqi is the high ridge known as Al-Jabal Al-Akhdar(Latitude:23.05 and Longitude: 57.65) rising to more than 3000 m above sea level with an average elevation of about 1200 m (Figure 1).

Figure 1: Map showing the location of Al-Jabal Al-Akdhar Mountain region, Oman.

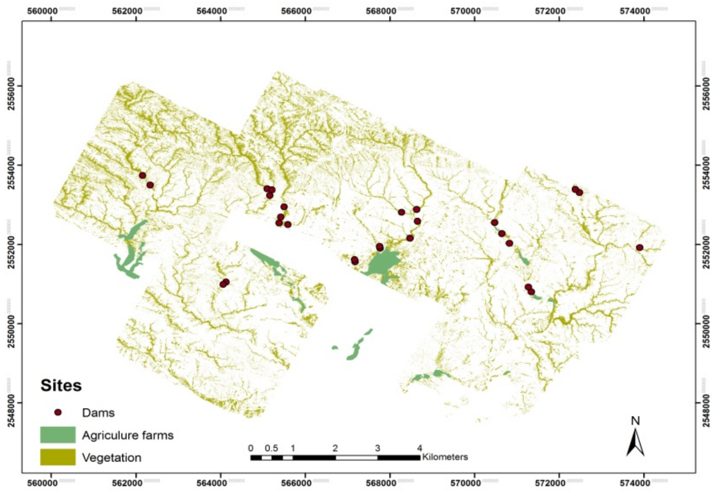

Figure 2: Map showing soil sample collected sites in the Al-Jabal Al-Akdhar Mountain region, Oman.

Geologically, the range is comprised mostly of thin-bedded Cretaceous limestone but also included are metamorphic and igneous rocks that include the distinctive crystalline grey-brown ophiolites [13]. Runoff from these mountains has provided large amounts of gravelly soils to the surrounding waterways and alluvial fans. The most evident example is the fertile Batinah plain [14]. Soils on the Al-Jabal Al-Akhdar are identified as Torriorthents [15] which are calcareous; with some soils having more than 35% $CaCO_3$ [16]. Most soils are very gravelly loamy to sandy soils with a shallow depth to rock. These soils occur on very steep hills, which make them poorly anchored, highly unstable, and consequently susceptible to erosion and loss of fertility through leaching of nutrients. With an average annual rainfall of about 330 mm [17], the risk of soil erosion in the Al-Jabal Al-Akhdar can be high.

Until recently these mountain ranges have been relatively undisturbed by humans and are well preserved landscapes; however, the pressure from human activities on these fragile environments is rising rapidly [1, 17]. A study carried out to assess the global soil degradation shows that the primary factor contributing to soil degradation in the Al-Hajar Mountains is loss of topsoil through water erosion where 25-50% of the area is affected by moderate degree of degradation [18] and the secondary factor is human induced salinization [17].

2. Materials and Methods

2.1Soil Sampling

In the winter season of year 2008, a total of 45, agricultural (n=13) and non-agricultural (n=32) sites were sampled. Non-agricultural soils were collected from three areas and these were next to natural vegetation (n=16), wadis (n=8), and reservoir dams (n=8). To obtain a representative composite sample for each site 3-4 sub samples were collected from surface soil to an average depth of 5cm for non-agricultural sites and 15cm for agricultural sites.

2.2 *Analytical Methods*

Soil samples were air-dried and crushed to pass through a 2 mm sieve. Extracts were analyzed by Optical Emission Spectrometry using an Inductively Coupled Plasma (ICP-OES) equipped with a cross-flow nebulizer in addition to an ultrasonic nebulizer (Perkin Elmer 3300DV) and an Ion Chromatograph oven (Dionex IC25). Soils were digested in a Milestone 1200 MDR Ethos Plus Microwave Lab station fitted with 10 Teflon vessels.

2.3. Water Soluble Extraction Procedure
Two hundred grams of each soil sample were weighed in a plastic container. Distilled water was added to the soil with stirring until near saturation. The saturated soil paste was allowed to stand for 4 hours and then transferred to Buchner filter funnel fitted with a filter paper, vacuum was applied, and filtrate was collected in a bottle. The water soluble variables analyzed were pH, EC, Na, Ca, Mg, K, Fe, B, Zn, Cu, Mn, Ni, Cd, Pb,V, Cl, NO_3, PO_4, and SO_4.

2.4. Total Digestion procedure
Three separate 0.5 g aliquotes of air-dried soil samples were weighed in teflon vessels. Six milliliters of aqua regia (HCl-HNO_3, 3-1) were added to each sample. The samples were then heated in a programmable microwave from room temperature to 220°C over a 5-min period, then held at 220°C for another 20-min. The Teflon vessels were allowed to cool down to room temperature. The acid mixtures were carefully transferred to 25 ml volumetric flask. The vessels were then rinsed twice with 5 ml of deionized distilled water (DDW), and the washings added to the volumetric flask. The final volume was made up to 25 ml with DDW, followed by analysis with ICP-OES. Elements analyzed include Ca, Mg, Na, K, Al, Fe, Mn, Zn, Cu, Ni, Cd, Pb, V, and Cr.

2.5. Particle Size Analysis
The Hydrometer method described was used to identify textures of soil samples collected [19]. This method quantitatively determines the physical proportions of three sizes of primary soil particles as determined by their settling rates in an aqueous solution using a hydrometer.
2.6. Statistical Analyses
Statistical analyses were performed using Minitab 14.1 [20]. Multiple comparisons of means among sites and their significance was determined for each of the soil variables using one way analysis of variance (ANOVA) and Tukey's method. Pearson correlation coefficients were estimated for all pairs of soil variables for each site. The variables were analyzed for presence of any underlying patterns using factor analysis with the varimax rotation technique. Because of high levels of elements in some sampled soils, data were highly skewed to right and a natural log transformation was applied to the data of each element to attain normality. Average pH values reported are calculated from the average of H^+ concentrations in soils. All tests were done at a probability level of $\alpha = 0.05$.

3. Results and Discussion

3.1. Soil Texture
Preliminary observations suggest that ophiolitic and carbonitic geologies of the mountains are the dominant parent materials for soils. In general, soils forming on ophiolites are gravelly and coarse in texture whereas the texture of carbonitic soils tends to be finer. These properties strongly influence the susceptibility of soils to erosion and their water holding abilities. Table 1 shows the range of soil textures found for the 4 sites in the study area of Al-Jabal Al-Akhdar.

Table 1: Number of samples (x) and soil textural classification at 4 sites

Site	Soil Texture
Natural	Loamy Sand(3), Sandy Loam(5), Sandy Clay Loam(4), Loam(1), Clay Loam(1), Silt Loam (1), Silty Clay Loam(1)
Dam	Loamy Sand(1), Sandy Loam(2), Sandy Clay Loam(3), Loam(1), Clay Loam(1)
Agriculture	Loam(7), Clay Loam(6)
Wadi	Sandy Loam(3), Loam(4), Silt Loam(1)

3.2. Water Soluble Elemental Composition
Soil chemical variables were analyzed for their water soluble and total content. Table 2 provide average pH and Electrical Conductivity values for the 4 sites sampled. The pH values observed were expected to be alkaline, since geologically most of the rock formation in the Al-Jabal Al-Akhdar is carbonitic in nature. However, some agricultural soils were found to have pH values above what should be expected for these soils (ranged from

6.90-8.48). This could be an indication of lower use of chemical fertilizers on these farms. Electrical Conductivity (EC) values of some soils around dams had higher EC values than other sites, which is clearly shown by their higher average EC value of 1488 µS/cm compared to less than 1000 µS/cm for the other sites. Average water-soluble elemental composition of soil samples data given in Table 3. No Fe, B, Zn, Cu, Mn, Ni, Cd, V, and P were detected in the water-soluble fraction.

Table 2: Range and average pH and EC of soil samples at the 4 sites

Site/Variable	pH	EC(µS/cm)
Natural	8.00 (7.52-8.32)	713 ± 461 (310-1602)
Dam	7.66 (7.30-8.34)	1488 ± 1219 (444-3540)
Agriculture	7.81 (6.90-8.48)	965 ± 181 (726-1357)
Wadi	8.16 (7.93-8.32)	766 ± 199 (430-1070)

Table 3: Range and average water soluble elemental content (mg/kg) of soil samples at the 4 sites

Site	Na	Ca	Mg	K	Pb	Cl	SO_4	NO_3
Natural	4.1 ± 3.7 (1.3 -14.6)	26.4 ± 20.1 (6.7-57.2)	3.3 ± 3.7 (0.6-12.6)	2.9 ± 4.5 (0.4-14.5)	0.00 ± 0.01 (0-0.02)	11.9 ± 18.1 (1.1-69.8)	7.2 ± 9.1 (0-30.4)	13.5±16.5 (0-55.4)
Dam	4.3 ± 3.9 (1.9-13.0)	14.2 ± 7.8 (7.2-29.0)	1.5 ± 1.0 (0.6-3.6)	1.1 ± 0.7 (0.4-2.1)	0.00 ± 0.00 (0-0)	6.0 ± 8.3 (1.0-24.1)	37.3 ± 66 (2.0-182)	89.6±114 (0.3-319)
Agriculture	4.5 ± 1.4 (3.1-6.7)	22.7 ± 6.8 (10.9-32.9)	9.3 ± 2.6 (5.4-14.3)	2.9 ± 3.8 (0.7-13.5)	0.18 ± 0.20 (0-0.6)	28.9 ± 12.4 (9.0-49.9)	9.2 ± 4.5 (1.2-20.3)	20.9±33.0 (0.8-95.1)
Wadi	3.1 ± 1.1 (1.5-4.8)	19.4 ± 7.3 (9.0-29.5)	4.8 ± 1.5 (2.1-6.9)	0.7 ± 0.3 (0.3-1.2)	0.16 ± 0.19 (0-0.4)	27.2 ± 7.5 (12.6-35.0)	8.6 ± 4.2 (4.2-14.0)	47.6±57.9 (2.9-167)

Nitrate levels, a major concern to environmental pollution and water quality degradation, were found in very high levels around some dams. Wadis had the second highest levels of nitrates. This accumulation of nitrates next to dams and wadis might indicate NO_3- leaching from various sources into water streams. Statistically, however, and because of large variation in the levels observed, there are no significant differences in nitrate levels among the 4 sites. Table 4 shows the comparisons between means for all elements and ions detected except Pb. Only Mg, K, and Cl had significantly different concentrations between sites.

Table 4: Analysis of geometric means of water-soluble elements among the 4 sites (values are in mg/kg)

Site/Variable	Na	Ca	Mg	K	Cl	SO_4	NO_3
Natural	3.0a	19.1a	2.1a	1.5a	5.2a	4.6a	7.6a
Dam	3.4a	12.7a	1.3a	1.0ab	3.4a	10.5a	24.8a
Agriculture	4.3a	21.6a	9.0b	1.7a	26.2b	7.9a	5.7a
Wadi	2.9a	18.0a	4.5c	0.6b	26.0b	7.7a	23.4a

Tables 5 provides analysis data on Pearson correlation coefficients for all pairs of soil variables for each of the sites sampled. Only significant correlations are shown. Two important relationships that can be noticed from the correlation tables are the high and significant correlations between NO_3 and Cl in Natural (r= 0.70) and Dam sites (r= 0.88) and the strong positive correlation between Pb and Cl (r= 0.99) in Agricultural sites. The high correlation of NO_3 and Cl could be indication of common origin of these two elements. It is not known exactly what might be this common origin and further studies need to be carried out to study the possible sources. However, it is known that with increasing salinity, chloride ions suppress the uptake of NO_3 by plants from soils [21, 22], hence increasing the potential of NO_3 remaining in soils. This could be inferred from the high and significant correlations of Cl and NO_3 with elevated values of EC. Other studies carried out on groundwater contamination indicated that correlation values above 0.35 is evidence of contamination by municipal or domestic wastes [23, 24]. This might explain the high correlation between NO_3 and Cl in soils next to Dams resulting from the possible contamination of water.

Table 5: Significant (α= 0.05) correlation coefficients (r) for all pairs of soluble soil variables (a= Agriculture, d= Dam, n= Natural, w= Wadi)

	Na	Ca	Mg	K	Cl	SO_4	NO_3	pH
Ca	0.69w							
Mg	0.94w	0.66n, 0.96d, 0.89a, 0.72w						
K	0.65a	0.70w	0.80n, 0.81d, 0.65w					
pb			-0.84a		0.99a			
Cl			0.75n	0.87n				
SO_4	0.93w	0.85d, 0.69w	0.83d,0.90w					
NO_3					0.70n, 0.88d			
pH						-0.58n	-0.56n	
EC	0.62n, 0.73a	0.74n, 0.85d	0.68n, 0.61a	0.89n	0.88d	-0.66n	0.76w, 0.67w	0.67w

As for Pb and Cl, excess chlorides complex with and solubilize many heavy metals in soils [25]. Other studies have also shown similar correlations between Pb and Cl where the apparent vertical migration and solubilization of Pb is linked to complexation with Cl [26, 27]. However, the soluble Pb correlates negatively with % clay in agricultural soils (r= -0.90). This indicates larger adsorption and complexation of soil Pb with the soil clay fraction as % clay increases in soils.

The pattern of associations between water-soluble elements was determined by factor analysis (Table 6). Only loadings above 0.5 are shown. Based on Eigenvalues, 4 main factors explained 82.4% of the total variance. The first factor, explaining 27.9% of total variance, grouped Mg, Ca, Cl, and EC, which could be suggestive of soil salinization from chloride salts. The second factor groups Na, K, SO_4, and EC and explains 20.8% of total variance. This could also suggest salinization but from sulfate salts. The high loadings of K and Clay in factor 3 could be of geochemical nature, while factor 4 could represent the influence of soil texture on total variance.

Table 6: Factor loadings for soil variables- water soluble elements

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Mg	0.889			
Ca	0.856			
Cl	0.743			
EC	0.692	-0.624		
SO_4		-0.764		
K		-0.687	0.529	
pH		0.672		
Na		-0.645		
Clay			0.832	
NO_3			-0.714	
Silt				0.953
Sand				-0.859
% Var	0.279	0.208	0.179	0.158

3.3. Total Elemental Composition

Trace elements are present in very small concentrations, less than 0.1%, in rocks of the earth's crust. Many of these elements are essential for life in lower concentrations but become toxic in higher concentrations. The trace element content of soils depends mainly on the parent rock type from which these soils were derived and on the geochemical and pedochemical weathering processes. However, anthropogenic inputs may add to, and at times exceed, those from natural geological sources. Average total elemental composition of soil samples is shown in Tables 7 and 8.

Table 9 shows Pearson correlation coefficients for all pairs of soil variables for each of the sites sampled. Only significant, correlations are shown. Generally, concentrations of all elements fall within the natural limits in all 4 sites.

Table 7: Average total elemental content (mg/kg) and standard deviation of soil samples at the 4 sites.

Site / Variable	%Ca	%Mg	%Al	%Fe	K	Na	Pb	Cr	V	Cu	Ni	Cd	Mn	Zn
Normal	18.5±6.5	2.8±2.8	1.1±0.5	1.5±0.8	1579±1086	437±373	12.6±19.1	31.3±27.4	21.3±15.9	13.7±4.9	77.2±37.1	0.33±0.15	302±120	65.8±39.1
	(7.3-29.4)	(0.7-9.2)	(0.5-2.3)	(0.3-3.3)	(326-4870)	(80-1060)	(4.5-83.0)	(0-96.4)	(0-46.9)	(6.1-22.5)	(27-168)	(0.14-0.69)	(181-572)	(11-146)
Dam	13.8±1.8	3.7±1.9	1.1±0.3	1.2±0.9	1579±667	561±822	11.6±12.2	28.7±24.2	14.2±13.9	15.4±3.5	88.2±29.4	0.33±0.11	410±136	58.0±33.5
	(10.6-16.7)	(1.8-6.2)	(0.6-1.5)	(0-2.3)	(840-2910)	(92-2440)	(3.1-41.2)	(0-61.1)	(0-31.7)	(8.8-19.8)	(35.6-124)	(0.06-0.41)	(268-695)	(25.6-104)
Agr	13.9±3.3	2.7±1.1	0.7±0.4	0.8±0.4	1679±874	910±198	15.6±10.6	15.1±17.9	12.7±8.9	17.2±7.2	54.5±18.2	0.18±0.18	322±68	118±17.6
	(10.1-13.5)	(1.2-4.5)	(0-1.5)	(0-1.3)	(531-3230)	(671-1250)	(2.1-42.8)	(0-47.7)	(0-25.7)	(3.3-29.3)	(31.5-89.5)	(0-0.67)	(202-418)	(81.4-146)
Wadi	10.0±1.2	4.2±0.5	0.7±0.6	0.7±0.6	1203±443	689±153	11.1±6.8	24.0±19.3	7.7±8.0	16.9±14.5	72.2±19.7	0.08±0.15	337±70	94.5±38.9
	(7.8-11.9)	(3.4-4.8)	(0-1.4)	(0-1.3)	(707-1903)	(484-856)	(4.1-21.1)	(0.7-44.6)	(0-18.1)	(2.9-47.6)	(45.1-110)	(0-0.43)	(211-396)	(39.6-145)

Table 8: Analysis of geometric means of total elements among the 4 sites. Different letters indicate significantly different means at a site.

Site /variable	%Ca	%Mg	%Al	%Fe	K	Na	Pb	Cr	V	Cu	Ni	Cd	Mn	Zn
Normal	17.2a	1.9a	1.1a	1.5a	1437a	291a	8.6a	14.7a	12.6a	12.8a	68.7ab	0.33a	302a	66a
Dam	13.7ab	3.3b	1.1ab	1.2ab	1474a	265a	8.6a	13.7a	6.6a	14.9a	82.9b	0.33a	410a	58a
Agr	13.6b	2.5ab	0.7b	0.8b	1304a	891b	11.7a	5.7a	8.2a	15.3a	51.8a	0.18b	322a	118b
Wadi	10.0c	4.13b	0.7b	0.7b	1132a	673b	9.3a	10.3a	4.3a	11.6a	70.0ab	0.08b	337a	95b

Table 9: Significant (α= 0.05) correlation coefficients (r) for all pairs of total soil variables (a= Agriculture, d= Dam, n= Natural, w= Wadi)

Variable	Ca	Mg	Na	K	Fe	Al
Ca				0.53a		
Mg	-0.56a					
Na	0.71a	-0.51a		0.67a		
K	-0.73n		0.56n, 0.78d		0.91w	0.89w
Fe				0.77a		
Al	-0.59n		0.64w	0.67a	0.82n, 0.93a, 0.98w	
Cr	-0.64a	0.62a	-0.67n, -0.57a	0.75w	0.76n, 0.95w, 0.94w	0.72n, 0.57a
V	-0.61n		0.68d	0.59n, 0.89a, 0.92a, 0.89w	0.76n, 0.75d	0.76n, 0.80a
Cu	-0.76n			0.72n	0.59n, 0.71a	0.82n, 0.93d, 0.69a
Ni	-0.64n, -0.72a	0.89a	-0.56a	0.49n	0.63n	0.89n, 0.79d
Pb	0.58a		0.66n, 0.76d	0.88a	0.68a, 0.87w	0.54a, 0.83w
Cd	0.71a	-0.54a	0.63a	0.67a		
Mn	-0.66n, -0.60a	-0.83d	-0.62a	-0.51a		0.72n
Zn			0.87n, 0.86d, 0.69a, 0.74w	0.57n, 0.63d	0.75a, 0.89w	0.69a, 0.93w
pH			-0.55a	-0.67n		
EC				-0.71d		

Table 9. Continued

Variable	Cr	V	Cu	Ni	Pb	Cd	Mn	Zn	pH
Ca			-0.71d	-0.69w				-0.60a	
Mg						-0.72w		0.85a	
Na	0.62w	0.53a			0.51a				0.73w
K		0.79w	0.59a		0.80w				
Fe									
Al									
Cr									
V	0.89w		0.54a						
Cu	0.49n	0.63n		0.81d				0.72w	
Ni	0.71n, 0.73d 0.77a, 0.64w	0.53n		0.84n				0.91d	
Pb	0.86w	0.78d		0.59a	0.67n				
Cd		0.49n		-0.59a		-0.66w		0.51a	
Mn	0.52n		0.73n	0.85n,0.79a					0.56a
Zn	0.73d,0.94w	0.80d	0.87a	0.63w	0.61n				
pH					-0.75d				0.76w
EC							-0.66n		

Most of trace and heavy metals correlated highly with Al, Fe, Ca, and Mg, indicating that rock forming minerals are the main source of these metals. The results show significant correlations (α= 0.05) among Pb, Cd, and Zn at the natural and agricultural sites and this could indicate the presence of a common source of these elements in soils. The minerals, Pb, Cd, and Zn sulfides, are known to contain different concentrations of these three elements [28]. In the Wadi and Dam sites, Cd does not correlate significantly with Pb and Zn. Cadmium is known to become more mobile and bioavailable under changing moisture conditions when its ore mineral undergoes oxidation. This requires further investigation since Cd is a toxic element in high concentration and the possible solubilization and mobility of Cd could cause environmental and health hazards.

The pattern of associations between total elements was determined by factor analysis and results are provided in Table 10. Based on Eigenvalues, 6 main factors explained 89.2% of the total variance. Factors 1 and 2 explaining 37.7% of total variance, grouped K, V, Na, Al, Cd and Cu, Cr, Zn, Al, and Fe, respectively.

Table 10: Factor loadings for soil variables- total elemental composition

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
K	0.883					
V	0.786					
pH	-0.777					
Na	0.614					
Cu		0.866				
Cr		0.778				
Zn		0.762				
Al	0.548	0.718				
Fe		0.704				
EC			0.853			
Mg			-0.823			
Clay			0.711			
Ca				-0.928		
Ni				0.713		
Pb					0.774	
Cd	0.529				0.713	
Mn				0.680	-0.682	
Silt						-0.924
Sand						0.852
% Var	0.200	0.177	0.148	0.131	0.122	0.114

Although these two factors include some of the heavy metals, the normal concentrations of these metals in soils indicate lack of human influence. On the other hand, V, Cu, Cr, and Zn can partially substitute for Al and Fe in clay minerals. In addition, Fe and Al oxides can adsorb and precipitate many heavy metals [28]. This suggests a geochemical nature of these two factors. Factor 3 explains 14.8% of total variance and includes high loadings of EC and Clay suggesting a source of salinity of pedogenic nature. Factor 4 groups Mn and Ni and explains 13.1% of the total variance. Manganese oxides are known to play secondary roles in adsorbing soil Ni [29]. Other studies have also shown the role of mineralogy in controlling the content of Ni and positive correlations between Mn and Ni [30]. Factor 5 explains 12.2% of the total variance and includes high loadings of Pb and Cd. Cadmium is highly mobile and toxic element and the presence of Pb and Cd in the same factor could suggest anthropogenic inputs, however, the measured concentrations seem normal and their sources need to be further investigated. Factor 6, explaining 11.4% of the total variance, is related to texture of soil.

Conclusions

Soils of Al-Jabal Al-Akhdar are very shallow, coarse, loosely anchored, and hence these soils are very susceptible to erosion. Results indicated that soil salinity seems to be an issue of concern since higher salinity levels were found next to dams compared to other sites. In addition, soils samples collected next to dams also exhibited a higher than normal nitrate levels. With regard to concentration of trace and heavy metals in soils, they were found in normal concentrations and their presence in soils was lithogenic in nature. However, presence of Pb in the soluble form in agricultural and wadi soils requires further investigation. More extensive sampling is required to reach firmer conclusions.

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