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Original Research

Distribution of Heavy Metals in Irrigated Vertisol Profiles in Semiarid Region of Turkey

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Abstract

Vertisols with swell-shrink properties comprise most of the arable land in northwestern Turkey. These soils are important for agricultural activities. Seven sites were selected to represent Vertisols irrigated with polluted water from the Ayvali Canal. The soils occur on flat to gently sloping plains of the region. The soils were formed on marl parent material under thermic temperature and xeric moisture regimes in the western Bursa plain, Turkey. Some agricultural lands in the plain were irrigated with heavily polluted water from the Ayvali Canal. This is a unique surface water source for irrigation in the studied area. The morphology, physico-chemical properties and DTPA-extractable Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were determined in this research. The heavy metal concentrations were found in high levels in the upper horizon and decreased gradually throughout all the profiles studied. The results showed that accumulation of heavy metals in the upper horizon is due to long periods of irrigation with polluted surface water. Soil characterization was determined to provide useful information to understand the behavior of the heavy metal distribution throughout the soil profiles in the semiarid region with under intensive irrigation with polluted water.

Keywords: heavy metals, irrigation, polluted water, vertisols, semiarid region

Introduction

The problem of heavy metal contamination of the biosphere has been an issue of global concern for many decades. The quest for global industrialization and a wide range of other human activities has resulted in the release of significant amounts of various pollutants, including toxic heavy metals into the environment [1]. The behavior of some heavy metals in soils does not only depend on the level of contamination as expressed by total concentration, but also on the forms and origin of the metals and the properties of the soils themselves. Soil pH, texture and organic matter contents are properties mainly important with regards to the forms of the heavy metals and their bioavailability [2]. Sequential extraction of metals from solid media is a common analytical tool used in environmental and exploration geochemistry [3] to understand the forms of these metals in soils, hence their behavior (e.g. bioavailability, toxicity and distribution) in the environment.

Soil is a long-term sink for the group of potentially toxic elements often referred to as heavy metals, including zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), chromium (Cr) and cadmium (Cd). Whilst these elements display a range of properties in soils, including differences in mobility and bioavailability, leaching losses and plant uptake are usually relatively small compared to the total quantities entering the soil from different agricultural sources. As a consequence, these potentially toxic elements slowly accumulate in the soil profile over long periods of time. This could have long-term implications for the quality of agricultural soils, including phytotoxicity at high concentrations, the maintenance of soil microbial processes, and the transfer of zootoxic elements to the human diet from increased crop uptake or soil ingestion by grazing livestock. Therefore, reducing heavy metal inputs to soil is a strategic aim of developing soil protection policies in the UK and EU [4, 5]. However, information on the significance and extent of soil contamination with heavy metals from different sources is required so that appropriate actions can be effectively targeted to reduce inputs to soil.

The studied soils are under intensive agricultural activities in the Bursa plain of northwestern Turkey. Vertisols in some parts of the region were irrigated for valuable crops with limited surface water sources. The water sources were polluted with industrial and city sewage effluents due to industrialization and urbanization in the plain. These activities have caused serious soil and water pollution in some parts of fertile Bursa plain. The research area was located

Table 1. The morphological features of the irrigated profiles.

Horizon (FAO/UNESCO)	Depth (cm)	Munsell Colour (moist)	Texture	Structure	Consistency (moist)	Roots	Boundary
Profile 1							
Ap	0-25	10 YR 2/3	C	2f, sbk	f	c, f	g
Bw	25-50	10 YR 3/2	C	3m, abk	f	f, f	s
Ck	50-75	10 Y 8/1	SC	1c, sbk	fr	-	s
Profile 2							
Ap	0-30	10 YR 2/2	C	2f, sbk	f	c, m	g
Bw	30-60	10 YR 3/1	C	3m, abk	f	f, f	s
Ck	60-80	10 Y 8/1	SC	1c, sbk	fr	-	w
Profile 3							
Ap	0-20	10 YR 3/3	C	2f, sbk	f	c, f	g
Bw	20-55	10 YR 3/2	C	3m, abk	f	f, f	s
Ck	55-85	10 Y 8/2	SCL	1c, sbk	fr	-	w
Profile 4							
Ap	0-35	10 YR 3/3	C	2m, sbk	f	f, m	g
Bw	35-75	10 YR 3/4	C	3m, abk	f	f, f	w
Ck	75-95	10 Y 8/1	SCL	1c, sbk	fr		w
Profile 5							
Ap	0-30	10 YR 3/1	C	2f, sbk	f	f, m	s
Bw	30-65	10 YR 3/2	C	3m, abk	f	f, f	w
Ck	65-110	10 Y 8/2	SCL	1c, sbk	fr	-	w
Profile 6							
Ap	0-25	10 YR 3/2	C	2f, sbk	f	c, m	g
Bw1	25-55	10 YR 3/3	C	3m, abk	f	c, f	w
Bw2	55-80	10 YR 3/4	C	3m, abk	f	-	w
Ck	80-100	10 Y 8/2	SCL	1c, sbk	fr	-	i
Profile 7							
Ap	0-20	10 YR 3/3	C	2m, sbk	f	c, m	g
Bw1	20-60	10 YR 3/3	C	2m, abk	f	f, f	w
Bw2	60-90	10 YR 3/4	C	3m, abk	f	-	w
Ck	90-120	10 Y 8/2	SCL	1c, sbk	fr	-	i

Structure: 1 = weak, 2 = moderate, 3 = strong.
Type: f = fine, m = medium, c = coarse.
Class: abk = angular blocky, sbk = subangular blocky
Consistency: f = firm, fr = friable.
Roots; abundance: f = few, c = common.
Thickness: f = fine, m = medium,
Boundary: g = gradual, s = smooth, w = wavy, i = irregular

on the pollution-affected side of the plain. The physical, chemical, morphological features and DTPA-extractable Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were determined in this research. The soils were also classified according to FAO/UNESCO [6] and USDA Soil Taxonomy [7]. The aim of this research was to determine the characteristics of the soils, to classify them and to assess the irrigation effects of heavy metal distribution in the Vertisol profiles.

Experimental Procedure

The study area was located on the western side of the Bursa plain in northwestern Turkey. The mean annual precipitation and temperature are 713.1 mm and 14.4ºC in the plain. The soil temperature and moisture regimes are thermic and xeric, respectively.

Seven soil profiles were chosen for this research. Soil pits dig down to parent material and samples were collected according to different horizons. The morphology of the soils was described according to the Soil Survey Manual [8]. Soil samples collected from different horizons were air dried and passed through a 2 mm sieve. Laboratory analyses were determined by the hydrometer method for particle-size distribution [9], pH in a 1:2 soil:water ratio [10], organic carbon [11], total nitrogen [12], calcium carbonate [13], CEC [14], exchangeable cations [15], available phosphorus [16] and DTPA-extractable Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn [17]. The concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were determined by ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer). Horizon nomenclature and classification of the soils were carried out according to FAO/UNESCO [6] and USDA Soil Taxonomy [7].

Results and Discussion

These soils are formed on marl parent material. The research area was slowly drained and cultivated for various types of crops.

Soil Morphology and Classification

The morphological features of the profiles are presented in Table 1. The colour of all the Ap and Bw horizons is 10YR hue with value 2 to 3 and chroma 1 to 4 in the profiles. The surface horizons had a moderate subangular blocky structure, which changed strong angular blocky with depth in the Bw horizons. Ck horizons had a weak coarse subangular blocky structure in all soil profiles. Wide cracks were observed, with 2 to 5 cm spacing to depths of 30 to 90 cm during the dry season in the soils. The cracking feature was not observed in the Ck horizons. Frequent slickensides were also observed between 30 to 90 cm depths, and self-mulching characteristics were also exhibited in all the soils studied. The soils developed on more gently sloping landscape positions with slightly surface runoff, those developed from calcareous rich parent material of marl. These soils were classified according to the FAO/UNESCO [6] and USDA Soil Taxonomy [7] as Eutric Vertisols and Typic Haploxererts, respectively, based on their morphological, physical, and chemical properties. The soils are dominated by the influence of climate and showed similar pedogenic processes. The location of profiles has caused some differences between the formations of these soils.

Physical and Chemical Soil Properties

The physical and chemical properties of the profiles are shown in Table 2. Laboratory analyses support field observations. Texture of profiles range between clay and sandy clay loam. Clay contents ranged from 26.7% to 64.7% and highest at the Bw horizons. Maximum clay content for soils occurred between 20 and 90 cm depth. pH varies from 7.6 to 8.2 and increases with depth as a result of accumulation of free $CaCO_3$ in the soils. The organic C and total N contents are low and decrease gradually with depth, and the decrease is abrupt between the Ap and Ck horizons. The CEC values range between 38.2 to 53.5 mg kg^{-1} and high CEC values are contributed largely by 2:1 swelling clays. Ca and Mg are the dominant cations in the soils due to dissolution of carbonates and possible weathering of marl. Ca values range from 30.2 to 46.1 mg kg^{-1} and increase to Bw horizons. Mg values vary from 3.4 to 4.6 mg kg^{-1} and steadily increase with depth throughout the profiles. K values range from 1.8 to 2.6 mg kg^{-1}. Na values vary from 1.8 to 2.5 mg kg^{-1}, and increase slightly. The base saturation values are 100% in all the profiles. $CaCO_3$ varies from 1.4% to 7.1% and gradually increase with depth. Available phosphorus values ranges from 2.56 to 19.56 ppm and decrease with depth. The values are highest in the upper horizon and lowest in the Ck horizon.

DTPA extractable Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn are shown in Table 3.

The concentration of all these elements is at high levels in the upper horizons and increases gradually throughout the profiles. The limited previous study indicated that Cd, Cu, Fe, Mn and Zn were accumulated in the upper horizons of Vertisols [18]. In Greek soils, extractable Cd ranged from 0.03 up to 1.5 mg kg^{-1}, and Cu from 0.1 up to 8 mg kg^{-1} [19]. The soils, which appeared from the spatial trends to be polluted with Cu, exceeded this upper limit while for Cd the ranges observed were similar. Daniel et al. [20] have studied Co, Cr, Cu, Ni, Pb and Zn concentrations in the Vertisol of the Akaki soils in Ethiopia. Apparently, irrigation with wastewater for the last few decades has contributed to the observed higher concentrations of the above elements in the Vertisol when compared to uncontaminated Vertisol. For a similar wastewater application, the soil variables influence the status and the distribution of the associated heavy metals among the different soil fractions in these soils. Among heavy metals that presented relatively elevated levels and with potential mobility could pose a health threat through their introduction into the food chain in the wastewater irrigated soils. Itanna et al. [21] have determined the effects of the application of industrial liquid

Table 2. The physical and chemical properties of the soils.

Horizon (FAO/ UNESCO)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH 1:2 soil water	Org. C (%)	Total N (%)	C/N	$CaCO_3$ (%)	Available P, ppm	CEC	Exchangeable cations				BS (%)
													Ca	Mg	K	Na	
												mg kg^{-1}					
Profile 1																	
Ap	0-25	18.3	33.4	47.3	C	7.8	1.9	0.13	14.6	1.5	18.40	44.8	37.2	4.0	2.5	2.2	100
Bw	25-50	19.6	26.2	53.5	C	7.9	1.3	0.10	13.0	2.8	15.25	46.1	38.5	4.2	2.2	2.3	100
Ck	50-75	50.1	11.2	38.2	SC	8.0	0.0	0.0	0.0	5.9	5.56	42.4	34.0	4.6	2.2	2.3	100
Profile 2																	
Ap	0-30	23.3	30.2	45.2	C	7.6	1.4	0.11	12.7	1.8	14.62	43.5	36.3	3.8	2.2	2.0	100
Bw	30-60	22.7	25.4	51.0	C	7.7	1.0	0.08	12.5	2.5	11.74	47.0	39.8	3.9	2.1	2.1	100
Ck	60-80	54.1	8.6	36.7	SC	7.9	0.0	0.0	0.0	6.3	6.80	39.2	32.1	4.3	2.0	2.2	100
Profile 3																	
Ap	0-20	22.2	26.0	49.8	C	7.9	1.7	0.12	14.2	2.0	16.87	46.9	39.7	3.6	2.6	1.9	100
Bw	20-55	19.8	23.7	55.3	C	8.0	1.5	0.11	13.6	2.9	10.53	48.7	41.5	4.0	2.0	2.1	100
Ck	55-85	52.5	18.4	28.1	SCL	8.1	0.0	0.0	0.0	6.0	4.18	43.0	35.3	4.3	2.0	2.1	100
Profile 4																	
Ap	0-35	17.8	28.2	52.5	C	7.8	1.8	0.13	13.8	1.4	10.84	49.4	42.5	3.4	2.1	2.3	100
Bw	35-75	16.9	24.5	57.8	C	7.9	1.5	0.11	13.6	2.5	8.32	53.5	46.1	3.8	1.9	2.4	100
Ck	75-95	57.2	11.9	30.4	SCL	8.0	0.0	0.0	0.0	6.8	5.17	46.8	39.2	4.0	1.9	2.5	100
Profile 5																	
Ap	0-30	24.7	30.6	43.4	C	7.8	1.7	0.12	14.2	2.8	19.56	44.0	37.0	3.6	2.2	1.8	100
Bw	30-65	18.3	28.1	52.9	C	7.9	1.2	0.09	13.3	3.9	16.44	48.2	41.5	3.9	1.8	1.9	100
Ck	65-110	55.1	17.9	26.7	SCL	8.2	0.0	0.0	0.0	5.7	7.32	41.5	34.4	4.4	1.9	2.0	100
Profile 6																	
Ap	0-25	22.9	27.3	48.0	C	7.8	1.6	0.12	13.3	2.3	12.69	41.2	33.5	3.8	2.3	2.1	100
Bw1	25-55	18.6	24.0	56.2	C	7.9	1.1	0.09	12.2	3.0	9.01	43.8	35.8	4.2	2.2	2.3	100
Bw2	55-80	14.9	22.8	61.5	C	7.9	0.8	0.07	11.4	3.8	7.55	46.0	37.6	4.4	2.2	2.4	100
Ck	80-100	60.3	10.1	29.1	SCL	8.1	0.0	0.0	0.0	6.5	3.28	38.2	30.2	4.4	2.0	2.4	100
Profile 7																	
Ap	0-20	20.4	26.7	51.4	C	7.6	1.8	0.13	13.8	2.5	17.81	42.5	35.2	3.8	2.2	2.0	100
Bw1	20-60	17.2	23.5	58.3	C	7.8	1.4	0.11	12.7	3.2	13.92	46.1	38.6	4.1	2.0	2.1	100
Bw2	60-90	13.6	20.9	64.7	C	7.8	0.7	0.06	11.7	4.3	6.03	49.0	41.3	4.3	2.0	2.1	100
Ck	90-120	53.5	12.3	33.6	SCL	8.0	0.0	0.0	0.0	7.1	2.56	38.8	31.0	4.5	1.9	2.2	100

waste from a textile factory on the distribution of DTPA extractable metals in a Pelli-Eutric Vertisol at Akaki in Ethiopia, classified according to the FAO-UNESCO Soil Classification System. Application of the industrial liquid waste modified and increased levels of DTPA metals in the treated Akaki soils compared to natural levels in the background soils. These metals generally decreased consistently with depth in the Vertisols. Li et al. [22] also have studied physicochemical properties, total and DTPA Cu, Zn, Pb and Cd contents, microbial biomass carbon content and the organic C mineralization rate of the soils in a long-term trace metal-contaminated paddy region of Guangdong, China, which were determined to assess the sensitivity of microbial indices to moderately metal-contaminated paddy soils. DTPA extractable metals were correlated positively and significantly with total metals, CEC, and organic C (except for DTPA-extractable Cd), while they were negatively and highly significantly correlated with pH, total Fe and Mn. Ortega-Larrocea et al. [23] sampled the topsoil of the Vertisols in fields irrigated for 5, 35, 65 and 95 years in the Valley. They measured the concentrations of Zn, Pb, Cu and Cd, all of which appeared to have increased linearly with time. The longtime irrigation caused Zn, Pb, Cu and Cd accumulation that was observed in this current study. Therefore, Golia et al. [24] have researched the state of Cd, Cu, Ni, Zn, Pb, and Cr pollution at different soil profiles in Thessaly, an intensely cultivated region in Central Greece. The concentrations of all the metals studied were higher in

Table 3. DTPA extractable some metal concentrations of irrigated Vertisols.

Horizon (FAO/UNESCO)	Depth (cm)	Fe	Mn	Zn	Cu	Cr	Ni	Co	Pb	Cd
		(mg·kg^{-1})								
Profile 1										
Ap	0-25	11.03	16.15	3.32	18.03	0.55	3.05	2.02	2.78	1.03
Bw	25-50	9.15	11.53	2.90	15.72	0.43	2.71	1.90	2.24	0.92
Ck	50-75	4.56	5.28	1.85	8.54	0.27	2.03	1.12	1.12	0.80
Profile 2										
Ap	0-30	13.89	14.81	3.66	19.87	0.52	3.21	1.31	3.04	0.99
Bw	30-60	10.43	10.04	2.25	13.05	0.48	2.95	1.20	2.52	0.78
Ck	60-80	3.71	3.78	1.93	6.23	0.33	2.53	1.03	2.05	0.66
Profile 3										
Ap	0-20	9.75	12.65	2.79	21.15	0.50	3.13	1.17	2.55	0.95
Bw	20-55	7.80	8.32	2.43	16.37	0.42	2.76	1.12	2.18	0.72
Ck	55-85	4.18	3.03	2.12	9.44	0.29	2.19	1.05	1.96	0.60
Profile 4										
Ap	0-35	15.58	17.51	3.75	14.28	0.53	2.68	1.42	2.92	0.85
Bw	35-75	11.04	13.27	2.10	10.81	0.46	2.17	1.18	2.47	0.62
Ck	75-95	3.92	2.74	1.78	7.07	0.39	2.00	1.14	2.19	0.50
Profile 5										
Ap	0-30	11.62	15.07	2.71	16.52	0.42	2.42	1.45	3.05	0.78
Bw	30-65	7.34	10.53	2.24	12.73	0.35	2.12	1.28	2.73	0.43
Ck	65-110	2.83	6.14	1.95	6.59	0.30	1.25	1.17	2.35	0.30
Profile 6										
Ap	0-25	12.90	16.18	3.18	19.90	0.40	3.75	1.42	2.97	0.81
Bw1	25-55	8.82	12.59	2.72	15.38	0.32	3.08	1.33	2.72	0.63
Bw2	55-80	5.17	6.53	2.34	9.75	0.28	2.81	1.25	2.55	0.55
Ck	80-100	2.66	3.04	2.10	5.08	0.25	2.25	1.20	2.30	0.51
Profile 7										
Ap	0-20	10.51	14.31	3.38	14.07	0.48	2.88	1.40	2.88	0.65
Bw1	20-60	8.47	9.70	2.54	10.26	0.40	2.60	1.32	2.62	0.52
Bw2	60-90	4.50	5.08	2.17	7.58	0.38	2.18	1.28	2.39	0.50
Ck	90-120	1.81	3.81	2.06	4.15	0.32	1.80	1.22	2.31	0.47

the topsoil (0-30 cm) and lower in the second soil layer (30-60 cm). Concentrations of 70-82% of Cd, 39-64% of Cu, 41-69% of Ni, 29-51% of Zn, 75-89% of Pb, and 52-87% of Cr were found in the exchangeable fraction. Cd appeared to be the most mobile of the metals studied, while Cu and Zn were found in forms associated with organic soil matter. Significant correlations were obtained between heavy metals fractions and soil physicochemical parameters. Grzebisz et al. [25] measured concentrations of cadmium, lead, copper and zinc in surface horizon and background soils were used to estimate the geochemical load indices and their spatial distribution in urban soils. It was found that concentrations of heavy metals were higher than geochemical background in 61% of the samples for cadmium, 47% of samples for lead, 49% of samples for copper, and 61% of samples for zinc. Contaminated areas by heavy metals are concentrated around industrial plants and in the center of the city as well as along highways.

Conclusion

The distribution of heavy metals in the profiles showed that these elements were accumulated at higher concentrations in the upper horizons than the lower horizons due to long term irrigation with polluted river water in the region. DTPA-extractable metals gradually decreased throughout the profiles. The obtained data indicated that continued irrigation of these agricultural lands have caused serious heavy metal pollution in the different horizons of all the soils studied. It is also suggested that sites would require remediation for sustainable agriculture for future use.

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