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## Evaluation of Heavy Metal Pollution in Rice (*Oryza sativa* L.) Fields of Bafra Plain

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**Abstract:** Heavy metals are naturally present in the soils in trace quantity. Besides, some soils include these elements at high levels resulting from the weathering of minerals or human activities. Contamination of these metals has been of great concern in the environment interrelatedly with their toxicity, persistence and non-degradability. So, this article aimed to evaluate heavy metal pollution by using several pollution indices [contamination factor (CF), degree of contamination (CD), pollution load index (PLI)], summarization of the sources of heavy metals, and change of these metals along soil depth. For this purpose, 10 coordinated soil samples were taken from 0-20 cm and 20-40 cm depths in the rice fields of Bafra Plain in Samsun-Türkiye. In these samples, some physico-chemical soil characteristics (texture, pH, electrical conductivity, organic matter and lime content, available phosphorus and cation exchange capacity) and heavy metal contents [Zinc (Zn), copper (Cu), nickel (Ni), cobalt (Co), cadmium (Cd), chromium (Cr) and lead (Pb)] were determined. According to the results, metal contents were determined between 39.79-58.44 mg kg<sup>-1</sup>, 32.15-68.31 mg kg<sup>-1</sup>, 75.68-132.6 mg kg<sup>-1</sup>, 11.95-18.02 mg kg<sup>-1</sup>, 0.001-0.278 mg kg<sup>-1</sup>, 61.88-102.5 mg kg<sup>-1</sup>, and 9.942-14.67 mg kg<sup>-1</sup> for Zn, Cu, Ni, Co, Cd, Cr and Pb, respectively. While Cd content was higher at 0-20 cm depth, Cr, Ni and Zn values were higher at 20-40 cm. Cu, Pb and Co values did not show significant change with depth. Average CF values for heavy metals were determined as Ni>Pb>Cr>Cu>Cd>Zn>Co. Degree of contamination values varied between 4.922-7.848 and PLI values varied between 0.946-1.028. In all elements, CF and CD values were classified in the group of low and moderate contamination. Besides, significant relationships were found between soil physicochemical properties, heavy metal concentrations and pollution indices.

**Keywords:** Rice, heavy metal, soil, pollution indices

### 1. Introduction

Rice (*Oryza sativa* L.) is the basic food resource of about half of the world's population and acts a significant role in the food security of many countries (Sarkar et al., 2018). Rice, which is widely grown in tropical and temperate regions, is the only grain type that can germinate in the water and develops by using dissolved oxygen in the water. It is the largest user of water and approximately 34-43% of the irrigation water in the world is used in rice production (Rajwade et al., 2018; Tas, 2021). A significant amount of water is required for rice production. Because the continuous flood irrigation method is applied as a traditional irrigation method in rice cultivation in Türkiye and the world. This

system is used to produce more than 75% of the world's rice (Fawibe et al., 2020). In the method, water is constantly kept at a certain depth on the soil surface.

Due to population growth, tremendous economic development and fast growth in many areas, like agriculture and industry to high consumption of fertilizers and pesticides, the environment is becoming more polluted. Soil pollution with anthropogenic heavy metals (HMs) is great environmental trouble (Jalali and Hemati, 2013) and has become common across the globe. HMs defined as a group of naturally occurring elements that have atomic number, density and molecular weight bigger than 20, 6 g cm<sup>-3</sup> and 53,

respectively (Makuleke and Ngole-Jeme, 2020). HMs such as copper (Cu), lead (Pb), zinc (Zn), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and mercury (Hg) are common pollutants in the soil environment. Cause they accumulate in the environment easily, do not degrade and have hard bioavailability (Luo and Jia, 2021). Until 1990, studies about soil fertility and plant nutrient problems mostly focused on the relations of elements such as Zn, Cu and manganese (Mn). Despite their higher toxicity, other HMs such as Cd, Cr, Ni, Pb and Hg have been largely disregarded. In the last decade, most of the studies performed on HMs concentrated on toxicity potential from industrial and agricultural activities and waste disposal (Gjoka et al., 2011).

Natural and anthropogenic resources are thought to be the two basic sources of HMs deposition in the soils. As a natural component, HMs mainly depend on the geological parent material. Anthropogenic entries can deteriorate function and alter the physical and chemical characteristics of the soils and thus lead to other environmental problems (Zhang et al., 2019). HM contamination not only harms soil quality and reduces crop yields but also endangers water and atmospheric mediums, threaten human health, makes difficult global climate change and influences sustainable society progress (Wu et al., 2022). Some anthropogenic activities are metal mining and smelting, fossil fuels burning, fertilizers and pesticides used in agriculture, batteries and other metal products manufacturing, chemical industry processing, sewage sludge, and municipal waste disposal, greenhouse gas emissions (Chibuike and Obiora, 2014; Malidareh et al., 2014; Zhang et al., 2021). Compared with natural sources, anthropogenic inputs are primary sources of HMs (Zhao et al., 2021).

The basic objectives of farmers in using chemicals are achieving better performance and yield, providing nutrients (fertilizers), or product maintenance and disease control (pesticides). These applications can lead to chemical degradation as a consequence of the accumulation of components at undesired rates. Fertilizers often contain various impurities, including heavy metals, as they are not purified adequately in production durations upon economic causes. Also, HMs are mostly a part of pesticides' active components (Gimeno-García et al., 1996; Malidareh et al., 2014).

Because of accumulating anthropogenic HMs often in the surface, soils are thought as a great medium to observe and evaluate this pollution. The upper 25 cm surface layer of soil is mostly affected by toxic metals. Hence, with the highly uniform

vertical dispersion of HMs in soil profiles, contamination is basically occurred by the effects on topsoil with fewer effects on subsoil. In time, HM pollutants from agricultural practices go deeper by the effects of continuous eluviation and thus the undersoil is contaminated. So just examining the total HMs on the surface is inadequate to represent the contamination characteristics (Sun et al., 2018). The change of these elements or compounds accumulated in the soil along the soil profile depends on the soil characteristics and intensity of agricultural activities. The dispersion of elements in the soil profile is an indicator of air pollution, soil genesis and anthropogenic pollution (Demir et al., 2016).

The content of HMs in soil and water resources is very important. Because these sources are the first critical link in the food chain. Assessment of HM pollution in farmland soil is of great significance to control and mitigate this pollution. Rice is one of the most significant products cultivated for people's consumption on Earth. Rice requires irrigation to grow and therefore rice soils are easier to become contaminated with HMs than in highlands (Jalali and Hemati, 2013). Evaluation of HM pollution in soils is done successfully across the world by using the quality indices method. These index methods have been verified to be an important vehicle to effectively aggregate the combined effect of indicators on total pollution (Akay and Öztekin, 2022). There are several pollution indices for soil and sediments. Choosing these is related to different purposes, such as pollution level, metal origin, and ecological risk potency. Enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF), pollution load index (PLI), degree of contamination (CD) and ecological risk index (ERI) are some of the largely used indices to assess contamination extent (Huang et al., 2019; Akay and Özyaytekin, 2022; Ahirvar et al., 2023). From this point of view; the goals of the study were (i) to determine the amounts of Zn, Cu, Ni, cobalt (Co), Cd, Cr and Pb in rice areas under humid ecological conditions, (ii) to evaluate the degree and dimension of pollution with the calculation of various pollution indices and also summarize of the sources of HM soil pollution, and (iii) to search the distribution of these metal contents through the depth.

## 2. Materials and Methods

### 2.1. General description of the study area

The research area is situated in the Central Black Sea Region in the north of Türkiye, between 41°28'-41°45' north latitudes and 35°43'-35°58' east longitudes, in the delta plain formed by Kızılırmak

and side streams. Bafra Plain starts from Çakırlar Region, 23 km west of Samsun province, and extends to the Yakakent location in the west. It is bordered by the extensions of the Canik mountain range in the south. Bafra district, after which the plain is named, is situated on the edge of Kızılırmak and 50 km away from Samsun province. Among the highest peaks of the plain are Derbent (240 m), Kışla Hill (231 m), Keller Hill (311 m), Kozağız (350 m), Kavak Hill (237 m), and Aktekke (210 m). Alaçam, Doyran, Mera, Tatlı, Harız, and Paşaboğazı creeks as well as Kızılırmak are the streams that provide the most important water source of the study area (Dengiz and Özcan, 2006). In the Bafra plain, the temperate climate is prevalent, characteristic of the Central Black Sea Region. Bafra district has been classified as *Wet Tempustic* according to the Newhall model (Turan et al., 2016).

According to Akkan (1970), the research area is divided into five main sections in terms of geomorphology. These are the delta plain and narrow coastal plains, the old delta of Kızılırmak, old coastal erosional surfaces, slopes, and high erosional plains, respectively, the most common of

which is the delta plain and the old delta of Kızılırmak.

45.8% of the district's land consists of arable land. Cereals and other plant products are in first place in the distribution of agricultural land, followed by vegetable growing areas. Among the field crops in Bafra, rice is ranked first with its cultivation of 134.022 da and production of 112.429 tons (Anonymous, 2023).

## 2.2. Soil sampling and laboratory analysis

Soil samples were taken from 0-20 cm and 20-40 cm depths from 10 coordinated points in rice fields in the study area (Figure 1). Sampling was done after the harvest to prevent the soil analysis from being affected by activities such as fertilization and irrigation. Coarse particles were removed from the samples and then the samples were air-dried in the laboratory conditions. The dried samples were sieved through a 2 mm sieve, and the sieved soil sample was placed in polyethylene boxes. Physical and chemical properties and total HM contents were determined in these soil samples. The protocols for the analyses are shown in Table 1.

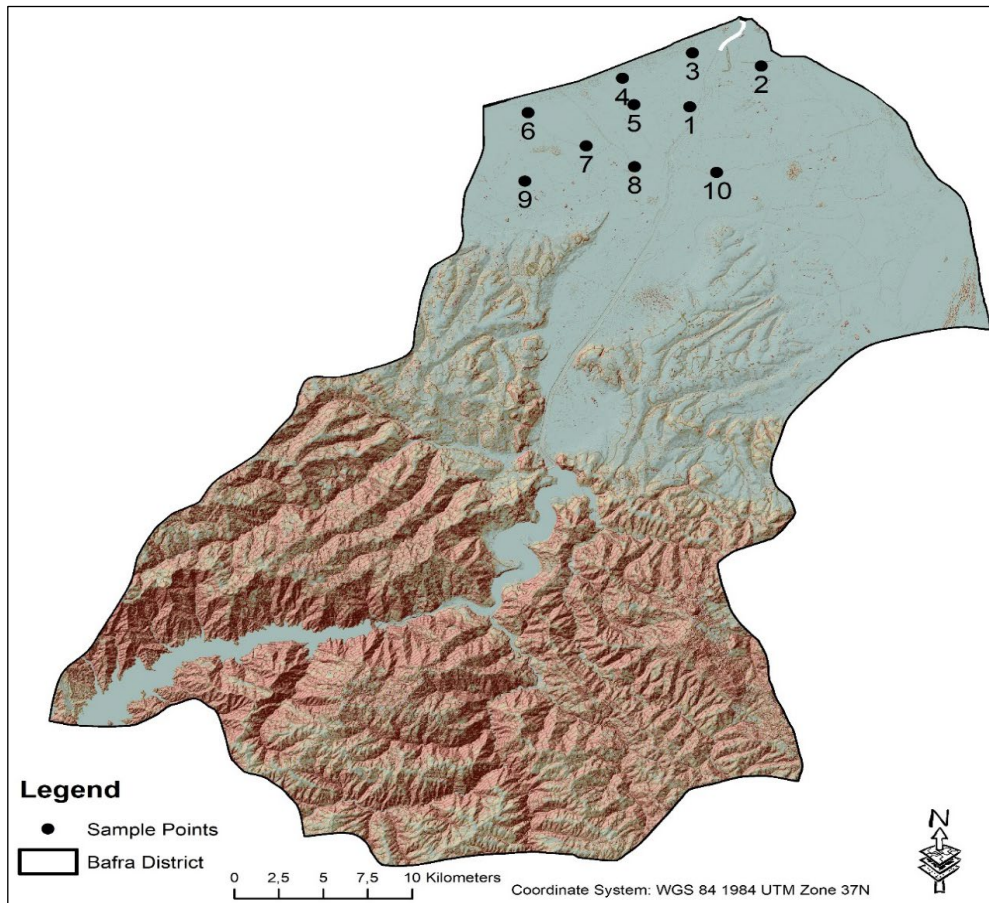


Figure 1. Soil sampling pattern in the study area

**Table 1.** Protocol measurements for parameters used in the study

Parameters	Unit	Protocol	Reference
Texture (clay, silt and sand)	%	Hydrometer method	Bouyoucos (1962)
Organic matter (OM)	%	Wet oxidation method (Walkley-Black) with potassium dichromate ( $K_2Cr_2O_7$ )	Nelson and Sommers (1982)
pH		(w:v) soil-water suspension (1:1)	Anonymous (1992)
Electrical conductivity (EC)	dS m <sup>-1</sup>	(w:v) soil-water suspension (1:1)	Anonymous (1992)
CaCO <sub>3</sub>	%	Scheibler calsimeter	Anonymous (1992)
NaHCO <sub>3</sub> -P	mg kg <sup>-1</sup>	The molybdophosphoric blue method	Olsen et al. (1954)
Cation exchange capacity (CEC)	me 100g <sup>-1</sup>	CEC= $Na + K + Ca + Mg$	Robbins (1984)
Total heavy metals (Cu, Cd, Cr, Pb, Co, Ni, Zn)	mg kg <sup>-1</sup>	Total heavy metal content was determined by wet burning the soil sample passed through a 0.05-mm sieve with a ratio of 3:1 nitric acid to hydrochloric acid and analyzing the obtained extract using the ICP-OES instrument.	Anonymous (1995)

### 2.3. Assessment of soil pollution levels

Contamination factor, CD, and PLI were evaluated as heavy metal pollution indices. The equality, classification, and contamination degree of these indices are shown in Table 2.

CF is accepted as an easy and efficient indice to observe HM pollution (Shen et al., 2019). The CF is a quantifier of pollution level based upon the average crustal composition of the metal in question or background values quantified from a geologically alike and unpolluted field. CF is utilized to evaluate the soil pollution level and to subtract anthropogenic entries from natural ones (Ahmed et al., 2016; Said et al., 2019). CD accounts for seven elements (Zn, Cu, Ni, Co, Cd, Cr and Pb) determined in this study, reveals the additive impact of HMs on soil contamination (Kumar et al., 2020)

and is described as the sum of all pollution components (Banu et al., 2013). PLI supplies easy but relative indice for assessing field quality (Proshad et al., 2019; Li et al., 2020) and has been utilized to evaluate the extensive level of HMs for location, region, or estuary (Shen et al., 2019).

### 2.4. Statistical analysis

Frequency distribution and the central tendency (mean), distribution relative to the center (standard deviation, variance, variation) or the coefficient of variation (CV) and the shape of the distribution (skewness and kurtosis) over this frequency distribution were examined as some descriptive statistical features in the obtained data. In addition, correlations between some physicochemical properties of soils, total heavy metal concentrations and pollution indices were determined.

**Table 2.** Different types of models for the definition of soil pollution, its classification and degree of contamination

Model	Equation	Index/class	Contamination degree	Reference
Contamination factor (CF)	$CF = C_{si}/C_{bi}$  $C_{si}$ is the measured concentration of the examined metal $i$ in the soil sample, and $C_{bi}$ is the background value of heavy metal.	$CF < 1$ $1 < CF < 3$ $3 < CF < 6$ $CF > 6$	Low contamination Moderate contamination Considerable contamination Very high contamination	Žvab Rožič et al. (2012), Joksimović et al. (2020)
The degree of contamination (CD)	$CD = \sum CF$	$CD < 6$ $6 \leq CD < 12$ $12 \leq CD < 24$ $CD \geq 24$	Low Moderate Considerable Very high	Hakanson (1980), Omran (2016)
Pollution load index (PLI)	$PLI = (CF_1 \times CF_2 \times CF_3 \dots \times CF_n)^{1/n}$  $n$ is the number of metals studied, and $CF$ is the contamination factor.	$PLI < 1$ $PLI = 1$ $PLI > 1$	Perfection Base line level of pollution Deterioration of site quality	Tomlinson et al. (1980), Omran (2016), Shahmoradi et al. (2020)



### 3. Results and Discussion

#### 3.1. The physico-chemical and heavy metal concentration of the soil samples

Descriptive statistics of soil physicochemical (sand, silt, clay, pH, EC, OM,  $\text{CaCO}_3$  and  $\text{NaHCO}_3\text{-P}$  and CEC) values are shown in Table 3. The clay content of the study area varied between 25.57-68.41%, with an average value of 51.36%. The pH values of the soils varied between 7.40-7.94 and are 7.65 on average (Table 3). The CV value, a significant parameter in identifying the variability of factors was 1.927% for pH and it was low (Wilding, 1985; Mulla and Mc Bratney, 2000). Soil characteristics influence metal availability in several ways. pH is the most important factor influencing metal availability in the soil (Chibuike and Obiora, 2014). The average OM value for the research area was calculated to be 2.38%, with values ranging from 1.45% to 3.77%. The CV value, on the other hand, has high variability, with its percentage reaching 29.90% (Table 3). pH, soil organic matter, and phosphate have been proven to influence soil metal concentrations by changing the solubility and mobility of metals (Chi et al., 2023). CEC values of the soils varied between 25.93-72.04, with an average of 47.93. The CV value was found to be 26.71 (Table 3). Soil structure, CEC, pH and organic matter content play an effective role in keeping pollutants in the soil. Especially clay soils adsorb heavy metals more than others because of their high CEC contents. Soils with higher clay and OM contents adsorb heavy metals and

form hardly soluble compounds (Demir et al., 2016). The lime content of the soils varies between 0.48-12.40% and is 6.08% on average (Table 3). Soil's metal contents were managed by soil characteristics including pH,  $\text{CaCO}_3$ , clay and organic matter contents, CEC, and iron oxides (Gjoka et al., 2011). The EC values of the soils vary between 0.577-1.936  $\text{dS m}^{-1}$  and are 1.067  $\text{dS m}^{-1}$  on average (Table 3). The depth, hydrogen potential (pH), EC and texture of the soil affect the transport and distribution of heavy metal pollutants (Teng et al., 2022).

Descriptive statistics of total heavy metal (Zn, Cu, Ni, Co, Cd, Cr and Pb) concentrations are given in Table 3. When the soil samples were evaluated in terms of HM, contents were changed between 39.79-58.44  $\text{mg kg}^{-1}$  for Zn, 32.15-68.31  $\text{mg kg}^{-1}$  for Cu, 75.68-132.60  $\text{mg kg}^{-1}$  for Ni, 11.95-18.02  $\text{mg kg}^{-1}$  for Co, 0.001-0.278  $\text{mg kg}^{-1}$  for Cd, 61.88-102.50  $\text{mg kg}^{-1}$  for Cr, and 9.94-14.67  $\text{mg kg}^{-1}$  for Pb (Table 3). The average amounts of heavy metals are ranked as  $\text{Ni} > \text{Cr} > \text{Zn} > \text{Cu} > \text{Co} > \text{Pb} > \text{Cd}$ . Most heavy metals (Cu, Zn, Mn, etc.) are necessary nutrients needed for plant growth at low rates. Though other metals (Cd, Pb, As, Hg, etc.) are not required for plant growth, they can be taken and deposited in crops (Xu et al., 2022). According to the skewness coefficients given in Table 3, Cd, Co and Pb had normal distribution; Cd and Co showed negative distribution, while Pb had positive distribution. As for the CV values of the elements, they varied between 9.80-73.68. The highest CV value was obtained from Cd, whereas the lowest was from Pb (Table 3).

**Table 3.** Descriptive statistics of some physico-chemical properties and heavy metal contents of the soil samples (n= 20)

Parameters	Mean	SD	CV	Variance	Minimum	Maximum	Skewness	Kurtosis
Physico-chemical properties								
Sand, %	15.63	3.956	25.32	15.65	9.80	25.12	1.782	1.173
Silt, %	33.01	10.41	31.53	108.3	15.71	56.80	0.215	0.443
Clay, %	51.36	12.50	24.34	156.3	25.57	68.41	-0.551	-0.546
pH (1:1)	7.65	0.147	1.927	0.022	7.40	7.94	-0.788	0.173
EC (1:1), $\text{dS m}^{-1}$	1.067	0.391	36.62	0.153	0.577	1.936	0.140	1.036
$\text{CaCO}_3$ , %	6.08	3.608	59.36	13.01	0.48	12.40	-0.764	-0.299
OM, %	2.38	0.713	29.90	0.508	1.45	3.77	-1.130	0.172
$\text{NaHCO}_3\text{-P}$ , $\text{mg kg}^{-1}$	14.13	8.410	59.53	70.73	2.83	33.05	-0.585	0.354
CEC, $\text{me } 100\text{g}^{-1}$	47.93	12.80	26.71	163.9	25.93	72.04	-0.152	0.014
Total heavy metal ( $\text{mg kg}^{-1}$ )								
Cu	42.47	8.672	20.42	75.20	32.15	68.31	4.293	1.954
Cd	0.111	0.081	73.68	0.007	0.001	0.278	-0.409	0.362
Cr	83.71	11.31	13.51	127.9	61.88	102.50	-0.754	-0.109
Co	14.96	1.636	10.94	2.676	11.95	18.02	-0.474	-0.148
Pb	12.33	1.208	9.80	1.459	9.94	14.67	0.014	0.004
Ni	107.1	15.51	14.49	240.7	75.68	132.60	-0.514	0.027
Zn	48.55	5.091	10.49	25.92	39.79	58.44	-0.525	-0.225

SD: Standard deviation, OM: Organic matter, CV: Ccoefficient of variation, Skewness:  $< | \mp 0.5 |$  = Normal distribution; 0.5-1.0= Application of character changing for dataset, and  $>1.0 \rightarrow$  Application of logarithmic change.

The quantity of HMs penetrating the soil as a consequence of human activities or metal contamination can be assessed by the background (BGV) values of these metals. These values present the amounts found in nature reserves plus atmospheric sediments as quantified by chemical analysis in the soil and given as 90 percent (Gjoka et al., 2011). According to the BGV, other values, except for Ni, were found to be lower than the background value. The mean values of Ni and Cr evaluated in this study were found to be above the Maximum Allowable Concentration (MAC) values for HMs in agricultural soils stated by Kabata-Pendias and Mukherjee (2007). Similarly, the average values of HMs evaluated in the study (excluding Ni) did not exceed the tolerable amount of these elements in agricultural soils reported by Kloeke (1980), as shown in Table 4. Soil sample 10 had a higher Cu value than the BGV value at both 0-20 cm and 20-40 cm depth points. Cd values were higher than BGV values at 0-20 cm depths of soil sample 2, at 20-40 cm depths of soil samples 5 and 8, and at both depths of soil samples 6 and 7. Cd values were found to be higher than BGV values only in soil sample 40 at 20-40 cm depths. As for Pb values, the values were higher than the BGV values at 0-20 cm depth in soil sample 5, and at both depths in soil samples 6, 8, 9, and 10 (Figure 2).

**Table 4.** Comparison of heavy metal concentrations (mg kg<sup>-1</sup>) with BGV, MAC and MPC

	Zn	Cu	Ni	Co	Cd	Cr	Pb
BGV	70	55	75	25	0.15	100	12.5
MAC	100-300	60-150	20-60	50	5	50-20	20-300
MPC	300	100	50	50	3	100	100

BGV: Background value of chemical elements in the continental crust (Taylor, 1964), MAC: Maximum allowable concentrations for trace metals in agricultural soils (Kabata Pendias and Mukherjee, 2007), MPC: Maximum permissible concentration for trace metals in agricultural soils (Kloeke, 1980)

Overall, Cr, Ni and Zn values were higher at 20-40 cm soil depth, while Cd was higher at 0-20 cm depth. No significant change was determined at depths in terms of Cu, Pb and Co values. The dependence of the total metal contents of soils on parent materials is notified by Alloway (1995) and Kabata-Pendias (2001). Decreasing metal content across the soil depth partially can be the result of outside entries. Increasing content across the soil depth essentially shows the metal's geogenic origin. A little change in depth is indicated the metal content is recovered by losses such as leaching, erosion and uptake (Gjoka et al., 2011). According to Jalali and Hemati (2013), the greater contribution of Cd in paddy soils is anthropogenic and the most significant application in cultivation generating the highest Cd content is the usage of phosphatic manure and sewage sludge. Volcanically formed soils could be separated based on excess HM

depositions, especially Cr and Ni (Curran-Cournane et al., 2015). Kizilkaya et al. (2011), conducted a study to analyze the positional pattern of Cd, Co, Cu, Ni, Pb, Zn, and HM sources on the Bafra plain in 108 soil samples from 0 to 20cm layer. The soil enrichment factor was utilized to find out the source of the HM contamination (natural or anthropogenic). Only, the Ni amount was above the maximum allowed level. Researchers stated that this relatively high Ni concentration level is related to the characteristics of the parent material, which was a Ni-enriched alluvial resource.

### 3.2. Soil pollution indexes

CF, CD, and PLI were calculated to assess soil pollution in the study area. According to the descriptive statistics of CF, the average values for the HMs were detected as Ni>Pb>Cr>Cu>Cd>Zn>Co. CD value varied between 4.922-7.848, and the PLI value ranged between 0.946-1.028. CD and PLI were far from a normal distribution and showed negative distribution. The CV value of CD was found to be 15.37, and the CV value of PLI was found to be 2.708 (Table 5).

The CF values of HMs in the study area are given in Table 6. CF values in all elements were classified as low and moderate contamination. The highest CF values were determined in soil samples 10 for Cu, 6 for Cd, 8 for Cr, 8 for Co, 9 for Pb, and 8 for Ni. Bayrakli (2023), used the EF, CF, Igeo, CD, PLI, and potential ecological risk index (PERI) to evaluate the heavy metal pollution risks of hazelnut production areas. According to the parameters considered, pollution risk in the area was low for all metals outside of Cd. Cd is among the most geochemically mobile toxic metals. There are many works about toxic metal contents such as Cd in paddy fields in Japan, China and Indonesia (Machiwa, 2010). Results of a study in a province called Zhejong indicated that the potential for contamination with heavy metals was high, especially Cadmium (Malidareh et al., 2014).

Table 6 shows CD and PLI values for heavy metal accumulation in the study area. According to DC, the points are classified in low and moderate degrees in the study area. The PLI value was between 0.954 and 1.038 and found above 1 in soil sample 5 at 0-20 cm depth, in soil sample 10 at 20-40 cm depth and at both depths of soil samples in 6, 7, 8, and 9 (Figure 3).

Contamination indices, including CF, CD, PLI, PERI, Igeo, EF and PER were utilized to assess HM pollution degree in many studies (Banu et al., 2013; Bayraklı and Dengiz, 2019; Shen et al., 2019; Shirani et al., 2020).



Figure 2. Heavy metal content of the soils depending on the depth



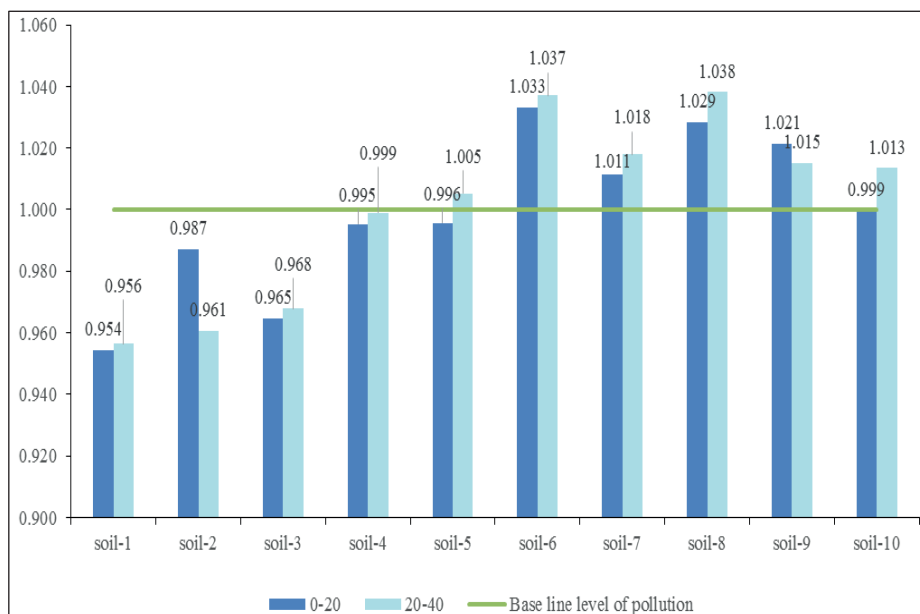
**Table 5.** Description statistics results of heavy metals for soil pollution indexes

Parameters	Mean	SD	CV	Variance	Minimum	Maximum	Skewness	Kurtosis
Contamination factor classes (CF)								
Cu	0.772	0.158	20.42	0.025	0.585	1.242	4.293	1.954
Cd	0.737	0.543	73.68	0.295	0.007	1.850	-0.409	0.362
Cr	0.837	0.113	13.51	0.013	0.619	1.025	-0.754	-0.109
Co	0.598	0.065	10.94	0.004	0.478	0.721	-0.474	-0.148
Pb	0.987	0.097	9.795	0.009	0.795	1.174	0.014	0.004
Ni	1.427	0.207	14.49	0.043	1.009	1.768	-0.514	0.027
Zn	0.694	0.073	10.49	0.005	0.568	0.835	-0.525	-0.225
Combined indices								
CD	6.052	0.930	15.37	0.865	4.922	7.848	-0.568	0.473
PLI	0.980	0.027	2.708	0.001	0.946	1.028	-0.784	0.314

SD: Standard deviation, CV: Coefficient of variation, Skewness:  $< | \mp 0.5 |$  = Normal distribution; 0.5-1.0= Application of character changing for dataset, and  $>1.0 \rightarrow$  Application of logarithmic change

**Table 6.** CF, CD and PLI for heavy metal accumulation in the study area

Sampling point	CF							CD	PLI
	Cu	Cd	Cr	Co	Pb	Ni	Zn		
soil-1 (0-20)	0.742	0.007	0.773	0.523	0.981	1.298	0.688	5.011	0.954
soil-1 (20-40)	0.740	0.007	0.775	0.534	0.936	1.301	0.694	4.986	0.956
soil-2 (0-20)	0.658	1.235	0.783	0.603	0.919	1.346	0.618	6.162	0.987
soil-2 (20-40)	0.629	0.330	0.731	0.519	0.873	1.245	0.595	4.922	0.961
soil-3 (0-20)	0.602	0.600	0.720	0.478	0.795	1.193	0.588	4.976	0.965
soil-3 (20-40)	0.585	0.603	0.701	0.492	0.832	1.198	0.582	4.992	0.968
soil-4 (0-20)	0.704	0.905	0.857	0.565	0.919	1.448	0.701	6.100	0.995
soil-4 (20-40)	0.745	0.703	0.888	0.627	0.939	1.543	0.723	6.167	0.999
soil-5 (0-20)	0.777	0.550	0.874	0.575	0.972	1.457	0.696	5.900	0.996
soil-5 (20-40)	0.737	0.928	0.821	0.615	1.009	1.454	0.698	6.264	1.005
soil-6 (0-20)	0.827	1.699	0.887	0.669	1.174	1.717	0.733	7.706	1.033
soil-6 (20-40)	0.823	1.850	0.987	0.672	1.035	1.732	0.748	7.848	1.037
soil-7 (0-20)	0.711	1.057	0.846	0.598	0.987	1.386	0.659	6.245	1.011
soil-7 (20-40)	0.756	1.110	0.893	0.594	0.957	1.490	0.699	6.501	1.018
soil-8 (0-20)	0.799	0.939	0.973	0.721	1.071	1.720	0.767	6.991	1.029
soil-8 (20-40)	0.821	1.291	1.025	0.689	1.090	1.768	0.780	7.462	1.038
soil-9 (0-20)	0.721	0.456	0.996	0.632	1.152	1.557	0.835	6.348	1.021
soil-9 (20-40)	0.699	0.453	0.911	0.603	1.029	1.458	0.745	5.898	1.015
soil-10 (0-20)	1.125	0.007	0.619	0.620	1.026	1.009	0.568	4.975	0.999
soil-10 (20-40)	1.242	0.007	0.683	0.637	1.038	1.226	0.754	5.587	1.013

**Figure 3.** PLI values of the soils depending on the depth

There were significant positive and negative relationships at different levels between physico-chemical properties, heavy metal contents and pollution indexes of the soils. These correlations are given in Figure 4.

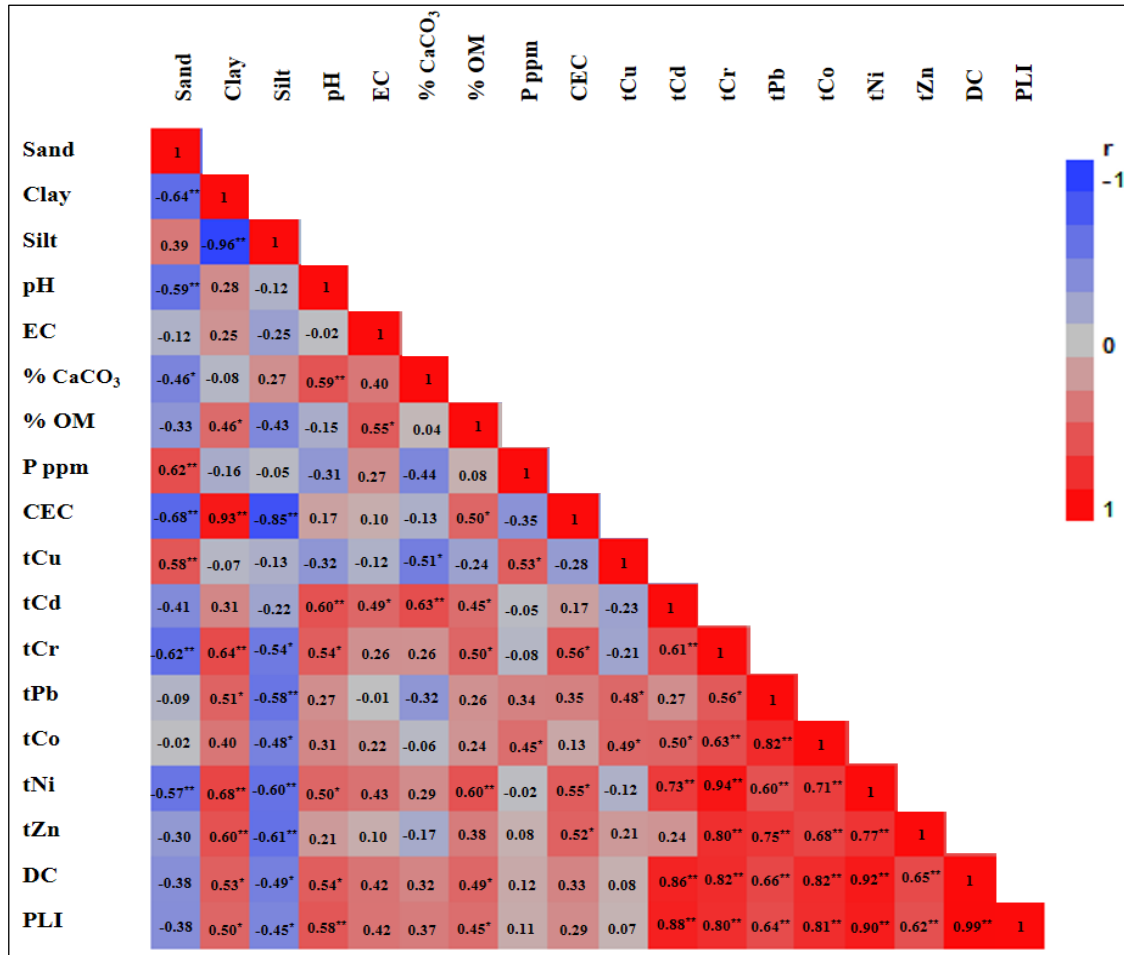


Figure 4. Relationships between physicochemical properties, HM contents and pollution indices of the soils

#### 4. Conclusions

In the study, some physicochemical characteristics, HM concentrations and changes of these metals at depths of the rice cultivation areas were determined and heavy metal pollution was evaluated by calculating some pollution indices and the sources of this pollution were examined. For soil depths, Cd was higher at surface soil and Cr, Ni and Zn values were higher at 20-40 cm. Cu, Pb and Co values, did not show a significant change in depth. The study reported here provides data as information in the literature, since there is lack of previous findings on soil quality of this study area. Prediction of total HMs is insufficient to establish pollution and toxicity degrees in the mediums. It is necessary to observe the distribution of these metals depending

on the soil depth. These results can provide a reference for the prevention and control of heavy metals contamination.

#### Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

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## Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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