Research Article

Ecological risk assessment of domestic sewage sludge: a case study

Elif YAKAMERCAN1, Ahmet AYGÜN1,*

1Environmental Engineering Department, Bursa Technical University, Bursa, Turkey

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INTRODUCTION

A high amount of sludge is continuously produced as an unavoidable end product in wastewater treatment plants [1]. In the relevant literature, it is estimated that sewage sludge production is more than 22 million tonnes in the world, annually [2]. Although this high amount seems to be a problem, the sludge can be used for different beneficial purposes. Landfilling, soil application, incineration, and sea dumping are the well-known sludge disposal methods for a long time, among them landfilling is the most common disposal method and generally, it is used in developing countries due to the most economical way but it is not a beneficial purpose [3–4]. Incineration and land application of the sewage sludge are classified as a beneficial usage.
while during the incineration process air pollution occurs and also secondary pollutants can be generated [5].

Moreover, reuse options such as agricultural applications are the most ecologically and sustainable way [6–7]. The main cost of the land application of sewage sludge is transportation also finding a suitable area is also important [8]. The presence of a free field around the treatment plant for the use of treatment sludge also reduces the cost of transportation.

Sewage sludge can be used as a fertilizer (as soil additive) in agricultural areas due to its high organic and nutrient content, therefore, more than 50% of produced sludge is used in agricultural purposes in Europe [9]. It is reported that the land application of sludge increases the yield of crops and enhance soil properties [10–11]. However, some legislations have been imposed to control agricultural applications of sewage sludge [12–14].

In addition to providing nutrient sources for plants, sewage sludge may contain potentially bioaccumulative, toxic and carcinogenic elements such as heavy metals [4,8]. The heavy metal content of sewage sludge depends on the origin of the raw wastewater and the treatment methods [15]. In general, the heavy metal content of domestic sewage sludge is lower than industrial sludge [16–17]. Thus domestic sewage sludge can be more suitable for agricultural usage than municipal or industrial sludge.

Heavy metals can accumulate in the soil in long term applications of sewage sludge and can cause irreparable damage to the soil [15]. The optimum sewage sludge application dosage is also important and in literature, it is reported that no pollution occurs in soil and plants in sludge land application up to 30 t ha⁻¹ [18]. Land application of sewage sludge also causes both human health and environmental risks [19]. To prevent possible environmental problems in applications, the information on heavy metals concentration was not enough alone, a proper risk analysis should also be addressed before sewage sludge application in soil. In the relevant literature, there are a lot of studies based on the human health risk of sewage sludge land application [20]. Heavy metals are the most important pollutants and sensitive indicators for monitoring changes in the environment [21]. The behavior of heavy metals affects water chemistry [22]. On the other hand, heavy metals have the bioaccumulation potential and incorporated into the food chain in land application, thus ecological risk determination gains significance in terms of sustainability [4].

To determine the ecological risks and pollution potential of land application of the sewage sludge, some indices are used such as Enrichment factor (EF), Geoaccumulation index (I₆₉), Single-factor pollution index (PI), Nemerow’s synthetic pollution index (PN), Potential ecological risk index (RI), Sediment quality guidelines, and the Probability of toxicity (mERM-Q) [23]. PI and I₆₉ indicate the accumulation level of heavy metals in samples and, PN indicates the heavy metal pollution level of the samples, but toxicity is not considered these indices while RI and mERM-Q focus on the toxicity of heavy metals [23–25]. mERM-Q is among the most widely used sediment quality assessment indices [26]. In literature, although there are comprehensive studies about the potential ecological risks of soil, sediment and biochar [27–31], there are the limited studies about ecological risk assessment for use of sewage sludge in agricultural areas [4,9,32]. To the authors’ best knowledge, this is the first study on sediment quality guidelines, EF, and mERM-Q index calculations on determination of the sewage sludge land application potential. Many indices were developed for evaluating the environmental risks of toxic metals in surface sediments [23].

The aims of this study are (i) to evaluate the heavy metal (Cu, Cd, Zn, Pb, Ni, Cr, Se and As) content in sewage sludge samples collected from domestic WWTP (Yenişehir, Bursa) in terms of the regulations (national (TR) and international (EU and EPA)) on the land application; (ii) to define the relationship between heavy metals statistically; (iii) to assess the heavy metal pollution and ecological risks of heavy metal in sludge with using several indices; (iv) to compare and evaluate the indices results.

**MATERIAL AND METHODS**

**Study Area**

Yenişehir is located in the eastern part of Bursa Province, Turkey with a population of 53,921, and covers 720 km² of a total surface area. The main economic activity of this rural district is agriculture and livestock, hence, there is not an industrial discharge to the treatment plant. Beet, pear, beans, wheat and peaches are the main agricultural products in Yenişehir [33]. The annual rainfall and temperature were 58.74 mm and 14.6 °C, respectively. The dry season is described between April and September, while the wet season is between October and March.

**Sampling of Soil and Sewage Sluge**

Soil samples were collected from an agricultural site in Yenişehir (North-Western Turkey), is located between 40° 17' 13" of the northern latitudes and 29° 38' 46" of eastern latitudes, from the surface layer based on Turkish National Standard TS 9923 [34]. The top 10 cm of the soil layer were sampled using a hand shovel. 3–5 subsamples were mixed to obtain a bulk sample. The soil samples were kept under 4°C in plastic containers and transported to the laboratory. Field moist soil was homogenized, sieved (2 mm), air-dried, and milled in compliance with TS 10308 ISO11464 for chemical analysis [35]. The soil background contents of As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Se and Zn are 8.74, 4.18, 34.30, 63.45, 25.63, 0.97, 39.75, 11.35, 1.35, 122.59 mg/kg, respectively.

In this study, sewage samples were collected from the Yenişehir wastewater treatment plant (WWTP) which is located between 40° 15’ 05” of the northern latitudes and
29° 40' 25" of eastern latitudes. The background soil type is alluvial and the heavy metal content of this soil was used in calculations.

The WWTP was operated as an A2O process and sludge dewatered with a decanter. In this study, dewatered sludge was used for the characterization of heavy metals. The volumetric flow rate and daily sludge production of the WWTP are 5,420–6,878 m$^3$ day$^{-1}$ and 20,471–24,258 kg day$^{-1}$, respectively. Sewage sludge samples were collected during 2019 for dry and wet seasons from the domestic wastewater treatment plant two times a month and 24 samples were evaluated totally. All collected samples were kept at 4 °C due to inhibition of biological activity until the laboratory analyses, especially for nutrients and organic content.

**RESULTS AND DISCUSSION**

**Physicochemical Characteristics of Sewage Sludge**

The physicochemical properties of sewage sludge samples were shown in Table 2. pH is an important determinant of metal mobility in soil, and increasing values of this parameter causes decreased heavy metal migration and enhances released content. In this study, the annual pH value of sludge samples ranged from 6.32 to 8.58. These values are in the same range as previous studies for sewage sludge land applications in other regions.

OM and nutrient content are important for determining the sewage sludge nutritive value for plants in land application. In this study, the sewage sludge, organic matter content was variable from 61.6 to 71.3%. These values were higher than organic soil range, thus the situation indicated that samples were rich in terms of organic matter. Nutrient concentrations were characterized by TKN (9.28–46.62 g/kg), and TP (8.86–13.97 g/kg), those provide high benefit for agricultural usage when compared to commercial fertilizers.

EC is an indicator of salt content, higher values may result in adverse effects on soil, and secondary salinization may occur high EC values can be harmful for plant. In this study, EC values ranged from 0.99 to 1.9 mS/cm, which were far from the risk of salinization.

When the obtained results are compared with previous studies, OM parameter is higher than relevant literature, while other parameters such as an EC is found to be lower than the values given in previous studies. Nutrient concentrations were characterized by TKN (9.28–46.62 g/kg), and TP (8.86–13.97 g/kg), those provide high benefit for agricultural usage when compared to commercial fertilizers.

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### Table 1. Pollution indices and description

| Indices | Equation | Class | Description |
|---------|----------|-------|-------------|
| **Geoaccumulation Index ($I_{geo}$)** [23] | \[ I_{geo} = \log_2 \left( \frac{C_n}{B_n \times 1.5} \right) \] | \( I_{geo} \leq 0 \) | Uncontaminated |
| | | \( 0 < I_{geo} \leq 1 \) | Uncontaminated to moderately contaminated |
| | | \( 1 < I_{geo} \leq 2 \) | Moderately contaminated |
| | | \( 2 < I_{geo} \leq 3 \) | Moderately to heavily contaminated |
| | | \( 3 < I_{geo} \leq 4 \) | Heavily contaminated |
| | | \( 4 < I_{geo} \leq 5 \) | Heavily to extremely contaminated |
| | | \( 5 < I_{geo} \) | Extremely contaminated |
| | \( C_n \): Measured heavy metal concentration in sewage sludge (mg/kg) | \( B_n \): Background soil heavy metal concentration (mg/kg) |
| **Single-factor pollution index (PI)** [23] | \[ PI = \frac{C_i}{C_n} \] | \( PI \leq 1 \) | No contamination |
| | | \( 1 < PI \leq 2 \) | Low level |
| | | \( 2 < PI \leq 3 \) | Moderate level |
| | | \( 3 < PI \leq 5 \) | Strong level |
| | | \( 5 < PI \) | Very strong level |
| | \( C_i \): Measured invidual heavy metal concentration in sewage sludge or regulation standard (mg/kg) | \( C_n \): Background soil or regulation limit value of invidual heavy metal concentration (mg/kg) |
| **Nemerow synthetic pollution index (PN)** [23] | \[ PN = \sqrt{\frac{P_{ave}^2 + P_{max}^2}{2}} \] | \( PN \leq 0.7 \) | Safety |
| | | \( 0.7 < PN \leq 1 \) | Warning line of pollution |
| | | \( 1 < PN \leq 2 \) | Slight pollution |
| | | \( 2 < PN \leq 3 \) | Moderate pollution |
| | | \( 3 < PN \) | Heavy pollution |
| | \( P_{ave} \): The average value of single factor pollution index | \( P_{max} \): The maximum value of single factor pollution index |
| | \( C_i \): Measured individual heavy metal concentration in sewage sludge (mg/kg) | \( C_n \): Background soil individual heavy metal concentration (mg/kg) |
| **Contamination factor ($C_i$)** [23] | \[ C_i = \frac{C_i}{C_n} \] | \( C_i < 1 \) | Low degree |
| | | \( 1 \leq C_i < 3 \) | Moderate degree |
| | | \( 3 \leq C_i < 6 \) | Considerable degree |
| | | \( 6 \leq C_i \) | High degree |
| | \( C_i \): Measured invidual heavy metal concentration in sewage sludge (mg/kg) | \( C_n \): Background soil individual heavy metal concentration (mg/kg) |
| **Integrated pollution degree ($C_d$)** [23] | \[ C_d = \sum_{i=1}^{n} C_i \] | \( C_i < 5 \) | Low contamination |
| | | \( 5 < C_i \leq 10 \) | Moderate contamination |
| | | \( 10 < C_i \leq 20 \) | Considerable contamination |
| | | \( 20 < C_i \) | High contamination |
| | \( n \): Number of heavy metals | \( C_i \): Contamination factor |
| **Pollution Load Index (PLI)** [23] | \[ PLI = \left( C_{f_a} \times C_{f_b} \times C_{f_c} \times \cdots \times C_{f_n} \right)^{1/n} \] | \( PLI < 1 \) | Denote perfection |
| | | \( PLI = 1 \) | Only baseline levels of pollution |
| | | \( 1 < PLI \) | Deterioration of soil quality |
| | \( n \): Number of heavy metals | \( C_{f_i} \): Contamination factor |
| **Monominal potential ecological risk (ER)** [25] | \[ ER = T \times P \] | \( ER < 40 \) | Low risk |
| | | \( 40 \leq ER < 80 \) | Moderate risk |
| | | \( 80 \leq ER < 160 \) | High risk |
| | | \( 160 \leq ER < 320 \) | Very high risk |
| | | \( 320 \leq ER \) | Extremely high risk |
| | \( T \): Metal toxic response factor | \( P \): Single factor pollution index |
| | \( Zn \) (1), \( Cr \) (2), \( Cu \) (5), \( Ni \) (5), \( Pb \) (5), \( As \) (10), \( Cd \) (30) |
| **Potential ecological risk index (RI)** [25] | \[ RI = \sum_{i=1}^{n} ER_i \] | \( RI < 150 \) | Low risk |
| | | \( 150 \leq RI < 300 \) | Moderate risk |
| | | \( 300 \leq RI < 600 \) | High risk |
| | | \( 690 \leq RI \) | Very high risk |
| | \( ER_i \): Monominal potential ecological risk |
| **Enrichment factor (EF)** [23] | \[ EF = \frac{C_{sample}}{C_{background}} \] | \( 0.5 < EF < 1.5 \) | Heavy metal in the soil is caused by natural processes |
| | | \( EF > 1.5 \) | Heavy metal contamination from anthropogenic activities |
| | \( C_{sample} \): Measured individual heavy metal concentration in sewage sludge (mg/kg) | \( C_{background} \): Background soil individual heavy metal concentration (mg/kg) |
seasonal characterization of land application potential. Total heavy metal concentration in samples compared the soil background and legal standards are demonstrated in Table 3. These concentrations were within the legal standards for sewage sludge using in agricultural land.

The analysis shows that the Zn had the highest annual concentration in sewage sludge and followed by Cu, Ni, Cr, Pb, As, Se and Cd (Table 3). Similar studies also reported the concentration of the Zn and Cu were the highest and Cd was the lowest one in sewage sludge from municipal wastewater treatment plants [46–47].

Generally, municipal sewage sludge contains lower heavy metal content than industrial sewage sludge. The heavy metal concentrations in this study consistent with previous studies reported for municipal sewage sludge, but lower than industrial sewage due to the significant contribution of industrial processes on wastewater characteristics [16,21].

Average levels of almost all heavy metals, except As and Cd, in sludge samples were higher than corresponding values in background soil (Yenisehir). Toxic elements such as Pb and Cd are not expected to enrich from the sewage sludge disposal onto land ecosystems, but the environmental processes such as dry and wet atmospheric deposition and industrial discharges are well-known sources of those heavy metals in urban and background soil [48]. Some heavy metals were higher in wet season such as Ni and Se. Similar to previous studies, there was not a significant difference (p>0.05) between wet and dry seasons [21,49]. As it is stated above, atmospheric deposition resulting the enhancement in the urban run-off flows may be another reason of the seasonal fluctuations of heavy metal species in influent wastewater to the plant, and in the sludge samples indeed [50].

The main sources of heavy metals could be run-off flow of urban streets and corrosion within the sewage system besides the reason of the high Zn concentration is galvanized water supply pipes [40]. The concentrations of these metals depend on raw wastewater characteristics and treatment process [3].

The distribution fittings of heavy metals were inspected, then Spearman correlation coefficients (r) of the heavy metals were assessed to explain inter-relations among elemental species (Fig. 1a). There were both positive and negative correlations among heavy metals in the samples. The multivariate analyses (cluster and principal component analysis) showed that very strong correlation observed between Ni and Cr, and also Cr and Cu. Chromium was also shown a moderate correlation with Zn (p<0.05), and the observed relationships were also reported in similar studies [47]. The high correlation coefficients indicate that the statistically related heavy metals in sewage sludge probably have common sources according to their covariances. To evaluate the sources of the heavy metals, hierarchical cluster analysis (HCA) was applied to samples. There are three singletons in a cluster which were showed Fig. 1b. Similar to the previous study based on the elemental characterization of municipal sewage sludge samples in China, Zn and Cu were placed in a single cluster and related to other clusters, but in this study, Zn had the highest distance while the

Table 2. Physicochemical properties of sludge

| Parameters             | Max. | Min. | Mean |
|------------------------|------|------|------|
| pH                     | 8.58 | 6.32 | 7.44 |
| Electrical conductivity (EC) (mS/cm) | 1.89 | 0.99 | 1.45 |
| Organic matter (OM) (%) | 71.30 | 61.60 | 63.90 |
| Dry matter (DM) (%)    | 19.27 | 15.15 | 17.64 |
| Total Kjeldahl Nitrogen (TKN) (g/kg DM) | 46.62 | 9.28 | 18.60 |
| Total phosphorus (TP) (g/kg DM) | 13.97 | 8.86 | 10.93 |

Table 3. Heavy metal in sludge samples and heavy metal limits for land application of sludge

| Heavy metals (mg/kg) | Min. | Max. | Ave. | Std. | EU [12] | TR [13] | USEPA [14] |
|----------------------|------|------|------|------|---------|---------|------------|
| As                   | 6.7  | 9.8  | 8.6  | 1.0  | –       | –       | 41         |
| Cd                   | 3.3  | 4.3  | 3.8  | 0.3  | 10      | 10      | 39         |
| Cr                   | 34.9 | 102.2 | 65.4 | 24.9 | 1000    | 1000    | –          |
| Cu                   | 117.8 | 197.6 | 151.4 | 21.2 | 1000    | 1000    | 1500       |
| Fe                   | 8444 | 11254 | 9385.7 | 919.9 | –       | –       | –          |
| Ni                   | 40.3 | 262.7 | 89.0  | 66.5 | 300     | 300     | 420        |
| Pb                   | 21.3 | 39.6  | 27.4  | 4.6  | 750     | 750     | 300        |
| Se                   | 5.2  | 10.2  | 6.3   | 1.4  | –       | –       | 100        |
| Zn                   | 566.8 | 900.3 | 716.8 | 99.5 | 2500    | 2500    | 2800       |
occurred due to the application of sewage sludge to back
ground soil.

**Geo-accumulation Index (I**$_{\text{geo}}$)**

The Geo-accumulation index (I$_{\text{geo}}$) for land application of sewage sludge revealed a different degree of heavy metal contamination. The annual mean I$_{\text{geo}}$ index results, given in Fig. 2, showed that the agricultural soil was uncontaminated with respect to, As and Cd. The average I$_{\text{geo}}$ values of heavy metals were in the decreasing order of $\text{Zn}>\text{Se}^\ast>\text{Pb}>\text{Cu}>\text{Ni}>\text{Cr}>0>\text{As}^{*}>\text{Cd}$. This index indicated that the soil was classified as “uncontaminated to moderately contaminated” with Cr, Cu, Ni and Pb. Besides, the pollution level of Zn and Se was “moderately contaminated”. Based on these results, it was indicated that Zn (1.95±0.21) caused the highest, and As (–0.61±0.19) caused the lowest contamination in sewage sludge. All of the I$_{\text{geo}}$ values in this study were lower than or consistent with previous study [9].

On the comparison of the dry and wet seasons in terms of I$_{\text{geo}}$, generally in dry season I$_{\text{geo}}$ values, except Ni and Se, higher than wet season due to sludge heavy metal content, although there was not a significant difference between dry and wet seasons (p>0.05).

Hierarchical Cluster analysis was used to determine the groups of heavy metals in terms of I$_{\text{geo}}$ index. Two clusters can be distinguished; As-Cd and Cu-Pb were the most similar to each other because they had the lowest distance. As, Cd, Cr, Ni, Cu and Pb can be a group in one cluster, while Se and Zn can be another cluster. The cluster formed for heavy metal concentrations was found to be different from previous one, and Cu had the highest distance [46]. Also, Cr-Ni and As-Cd–Se were placed in one cluster indicating all they are sharing the common drivers in their vicinity in municipal sludge. Almost similar clusters were observed in both dry and wet season samples, except Cu, was not placed a single cluster in the wet season indicating that this element may have variable sources in two seasons such as atmospheric deposition, agricultural production, traffic intensity on urban streets, etc.

**Assessment of Pollution Level and Ecological Risk**

Individual and complex indices were used to evaluate the pollution level and ecological risk when the sewage sludge applied to the agricultural soils [9,16]. The enrichment factors (EF), Geo-accumulation index (I$_{\text{geo}}$), Single-factor pollution index (PI) and Contamination factor (C$_{\text{f}}$) as the individual indices while Nemerow synthetic pollution (PN) index and pollution load index (PLI) as complex indices were applied in this study to evaluate the accumulation levels of the heavy metals. Besides, Potential ecological risk index (RI) and the probability of toxicity (mERM-Q) indices were used to assess the ecological risk of heavy metals in the domestic sewage sludge.

**Enrichment Factor (EF)**

Enrichment factor was calculated to evaluate the possible impact of anthropogenic activity [23]. Due to its stability in soil, iron (Fe) was selected as a reference element for enrichment calculations [51]. All EF values were lower than 0.5, this indicated that no enrichment would
due to Zn and Se (Fig. 3). Also, As and Cd were expected to result "low contamination" in the soil. Higher C values depend on the lower background soil heavy metal content in this study and Zn concentration in sewage sludge was far more than average soil background value.

Integrated pollution degree (Cd) values were the sum of individual C values. Considering this degree varied from 16.69 to 28.72 with an annual average of 21.35 (high contamination). Besides, C and Cd values were lower than previous study [16].

To compare the pollution status and heavy metal effect on sludge quality, pollution load index was evaluated. In this study, PLI of all sewage sludge samples were higher than 1 and the annual average was 2.2, indicated that sludge samples polluted the soil considerably. When the seasonal variation of PLI and Cd value was examined, the average value of PLI was higher in the dry season compared to the wet season, whereas in Cd it was the opposite.

Potential Ecological Risk (RI)
Determining the potential ecological risk from heavy metals is important before the sewage sludge land application. In this study, ecological risks were calculated based on Hakanson approach [25], this index was commonly used to the cluster for the Igeo index. This difference can arise from soil background content.

Single-factor Pollution Index (PI) and Nemerow Synthetic Pollution (PN) Index
In this study, the single factor pollution index was calculated based on two different approaches for C value [9, 23]. Firstly, soil background values were used as C and PI ranged from 0.9 to 5.85. Single-factor pollution index values of As and Cd were lower than one this indicated that no contamination occurs. Zn represented the highest pollution potential, whereas Cr showed the lowest to the soil when sewage sludge applied. Secondly, C is used as the standard of the individual heavy metal, mg/kg, according to standards for pollutants in sewage from agricultural use [12–14].

In the USEPA regulation on the application of sewage sludge to the land, there is no restriction for Cu, and EU and TR for As and Se [12–14]. The annual single factor pollution index ranged from 0.05 to 0.17 for USEPA and 0.03 to 0.34 for TR and EU 3rd Draft based calculations. All calculated PI values were lower than the suggested value for that no contamination occurs when sewage sludge applied to land. All Nemerow synthetic pollution (PN) index values were lower than 0.7 wherein the safety class. The PN values of heavy metals were in the following decreasing order Ni>Cd>Zn>Cu>Pb for TR and EU also this order Ni>Zn>As>Cu>Pb>Cd>Se was for USEPA rule regulation.

It has been observed that there is a significant difference in PI and PN values calculated using two different C values. The reason for this difference was that the background heavy metal concentration of the soil was considerably lower than the standard values of application of the sludge in the soil.

Contamination Factor (CF) and Pollution Load Index (PLI)
From the results of C evaluation, it was revealed that the land application may result "moderately contamination" due to Cr, Cu, Ni, Pb and Se; and "contamination" due to Zn and Se (Fig. 3). Also, As and Cd were expected to result "low contamination" in the soil. Higher C values depend on the lower background soil heavy metal content in this study and Zn concentration in sewage sludge was far more than average soil background value.

Integrated pollution degree (Cd) values were the sum of individual C values. Considering this degree varied from 16.69 to 28.72 with an annual average of 21.35 (high contamination). Besides, C and Cd values were lower than previous study [16].

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and Cd) and two clusters. Cluster 1 contained Cu-Pb and cluster 2 contained Cr-Zn. Of all heavy metals, ER values Cu and Pb were the more similar ones due to low distance. Besides, the distance between cluster 1 metals was lower than the distance between cluster 2 metals. The Cd singleton had the highest distance, thus it can be higher risk potential than other heavy metals, but all the sludge samples ER value was lower than the threshold. In the literature, HCA study based on ER from municipal sewage, heavy metals reported that one cluster (Zn and Pb) and three singletons (Ni, Cu and Cd) was observed [32]. The difference can be arise from the heavy metal content of the sewage sludges.

Sediment Quality Guidelines and the Probability of Toxicity (mERM-Q)

Sediment quality guidelines are commonly referred to estimate the biological effects of heavy metals in polluted sediments [23]. Biological effects are classified to effect range row (ERL) and effect range median (ERM) which were described in a previous study [26]. To best of the authors’ knowledge, it is the first time to use this index in sewage sludge. Based on this study’s results, it was indicated that Zn concentration of all sewage sludge samples was higher than ERL and ERM that can be risky for ecosystem while Pb was lower than ERM and ERL. The 70% of samples had higher As concentration than ERL and 10% of samples had lower Ni than ERM.

Also, mERM-Q index was applied to determine the probability of toxicity. The mERM-Q values were ranged from 0.47 to 1.26. These values indicated that the probability of toxicity 21–49 % (medium to high-risk level) when sewage sludge applied to the land. The major risk contributor metals were Ni and Zn besides, minor risk contributors were Cr, As and Pb. In wet season average mERM-Q value was higher than the dry season but significant differences were not observed between seasons (p>0.05).

The soil pollution from sewage sludge land application studies generally used sediment pollution indices [9,25,26,32] thus in this study, sediment quality guidelines applied to determine toxicity profile of sewage sludge.

**Figure 4.** ER and RI values of heavy metals (a) and dendrogram for IR values (b).
Evaluation of the Indices

The heavy metal concentration of sewage sludge was not enough for determining the appropriateness or not the agricultural application alone, thus some calculations based on predefined indices were necessary to clarify the pollution, toxicity and risk degree. Although these indices were generally used for determining soil and sediment pollution, nowadays they applied the sewage sludge [9,32].

In this study, though CI and PI were calculated with the same formula, the results of the indices were evaluated according to their different ranges. Therefore, some differences were observed in the interpretation of the calculated values. For example, CI and PI for Cr were found to be 1.9, according to the evaluation table of the indices (Table 1), this value was interpreted as moderate pollution in CI and low pollution in PI.

Although, similar interpretation of results was observed between Igeo and CI calculations the pollution level of some indices varied due to their different calculation methods. During the PI calculations, CI value used as background soil heavy metal content and legal standards [13]. PI and Nemerow index values based on legal standards were lower than CI based on background soil. Higher CI values depend on the lower background soil heavy metal content in this study and Zn concentration in sewage sludge was far more than average soil background value. The sewage sludge land application regulations allow higher heavy metal concentrations than soil background values, thus the differences were originated from this situation.

Based on ecological risk calculations, there is no risk potential was estimated due to the low ER and RI values, on the other hand, pollution indices demonstrate the contamination level was high for some heavy metals such as Zn and Se. The reason for this situation is the soil background contained low heavy metal content. Besides, the contamination degree of the samples based on before mentioned indices can be decreased with mobility and degradation of the heavy metals.

Statistical methods such as hierarchical cluster analysis (HCA), principal component analysis (PCA) and regression analysis (for Igeo, CI, PI, PN, ER indices) can be applied to the comparison of indices. The dendograms for indices were shown in Fig. 5. The dendrogram based on Igeo, CI, PI, PN, ER indices can be divided into one cluster and singleton. ER index included singleton because ER was used to determine the ecological risk and others are commonly used to determine the pollution degree of heavy metal (except mERM-Q). CI and PI were the same clusters due to they calculated with the same equation. EF was similar to Igeo consistent with the literature due to they both involving soil background values [23]. Igeo and mERM-Q were the most similar to each other even though they used different purposes, but they can group in one cluster. PN and PI can be grouped in another cluster because PI (or CI) values used in PN calculations.

The risk level calculations based on mERM-Q index were found medium to high while the ecological risk calculation from ER and RI demonstrated that there was no risk occur when sewage sludge applied to the land. The reason for this can be due to the ERM values used in the mERM-Q index calculations.

Although the ER and Igeo indices are mostly used in the risk and pollution assessment of the sewage sludge in the literature [4,16,19], in this study, these assessments were made from different perspectives by applying the indices.

CONCLUSION

The domestic sewage sludge samples are suitable for use instead of fertilizers in terms of having low heavy metal content (within the permissible values permitted by the legal standards) and high nutrient content. However, it is imperative to determine the potential ecological effects of heavy metal content. According to pollution indices, the pollution degree varied from "uncontaminated" to "considerably contaminant" and Zn caused the highest and As caused the lowest contamination in sewage sludge. Because, soil background value was lower than sewage sludge samples. On the other hand, all samples posed a low risk based on ER and IR indices. To ensure the safely land application of sewage sludge, health risk assessment is recommended. At the same time, ecological and health risk assessment studies are site-specific, even the heavy metal concentration’s is the same, the ecological and health risks maybe quite different if the sludge applied in different sites.

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AUTHORSHIP CONTRIBUTION

Authors equally contributed to this work.
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