

## Accumulation and translocation of heavy metals in soil & paddy plant samples collected from rice fields irrigated with recycled and non-recycled water in MADA Kedah, Malaysia.

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**Abstract:** The present study was carried out to evaluate the accumulation and translocation of heavy metals in soil and in paddy crop that have been irrigated with recycled and non-recycled water and to investigate the absorption of heavy metals in the crop. In this study, the amount of heavy metals (Cd, Cr, Cu, Pb, Zn, Mn and Fe) present in the various parts of the rice plants was ascertained. The results indicated that the average concentration of heavy metals, except for Cd was higher in the soil irrigated with recycled water than in the soil irrigated with non-recycled water. Meanwhile, in various parts of the rice plant (roots, stem, leaves, straw, and grains) the concentration of heavy metals, except for Cu and Mn, was higher in those plants that had been irrigated with recycled water compared to those that had been irrigated with non-recycled water. The highest concentration of heavy metals in this study was in the roots rather than in the parts of the rice plant that were above the ground (stem, leaves, straw and grains), except for Mn, which was present in significant amounts in the leaves. The bioaccumulation factor was higher for Cd compared to other metals in the area irrigated with recycled water, whereas it was higher for Cu than for other metals in the area irrigated with non-recycled water. The order for the transfer factors from the soil to the roots for the metals in the areas irrigated with recycled water and non-recycled water were Cd > Cu > Zn > Pb > Mn > Fe > Cr and Cu > Mn > Cd > Zn > Pb > Fe > Cr, respectively; from the roots to the straw the order was Mn > Cd > Zn > Cu > Cr > Pb > Fe for the area irrigated with recycled water and in the order of Mn > Zn > Cd > Cr > Cu > Pb > Fe for the area irrigated with non-recycled water; from the straw to the grains the order was Zn > Pb > Cu > Cr > Cd > Fe > Mn and Cd > Cu > Fe > Pb > Zn > Cr > Mn in the areas irrigated with recycled water and non-recycled water, respectively. However, these concentrations of heavy metals in the soil and rice grains were still below the maximum levels specified in the guidelines of the Codex Alimentarius Commission and the World Health Organization.

**Keywords:** Accumulation, translocation, heavy metal, paddy plant.

### Introduction

Other than oil palm and rubber, rice is considered to be one of the most important cultivated crops in Malaysia as it is the staple food of the country's population. Based on statistics obtained from the Food and Agriculture Organization<sup>1</sup>, approximately 30% of the energy is supplied through the diet and 20% of the dietary intake of protein globally comes from rice.

Paddy is planted twice annually, that is during the wet and dry seasons, with the fields being irrigated with water supplied by the Pedu dam in Kedah. The northern part of Peninsula Malaysia is the rice bowl of the country, which is also part of the Muda irrigation scheme. This area, which is made up of 97,000 ha of paddy fields, is administered by the Muda Agricultural Development Authority (MADA) and comprises an extensive network of irrigation canals and drainage systems that make it possible to practice double-cropping. The main sources of water supply for the scheme are from rainfall (56%), followed by water supplied by the dam (30%), non-regulated flow of water from rivers located below the dam (13%) and recycled water (5%)<sup>2</sup>. The recycling system was introduced in 1982 to solve the problem of water shortage in the Muda irrigation scheme<sup>2</sup>. Typically, the recycling system is operated in such a way whereby water is pumped from the rivers close by into specific irrigation canals and is stored there for a period of time before being channeled to certain paddy plots when required. There has been much apprehension among members of the public with regard to the introduction of the recycling system, especially concerning the safety of the recycled water<sup>3,4</sup>.

Serious environmental pollution issues have arisen due to the after-effects of the accumulation of heavy metals in plants and soil from natural and artificial sources, of which the primary concern is that of food safety and the possible threat to health<sup>5</sup>. An excellent way of monitoring heavy metal pollution is through soil samples because the accumulation of heavy metals due to human activities usually occurs in the top layers of the soil<sup>6</sup>. The ecosystem is disturbed when the soil is contaminated by heavy metals as these metals will gradually move into the groundwater or will be absorbed by plants and animals, thus threatening the ecosystem by their bioaccumulation<sup>7</sup>.

On-going pollution due to heavy metals and other organic contaminants are a cause of anxiety as they can eventually pose a danger to human beings and the environment. It has been shown in several studies that heavy metals can prove to be poisonous to plants, animals and humans when crops are cultivated in contaminated soils<sup>8,9</sup>.

Agricultural land that is initially not affected can also be contaminated with heavy metals if it is irrigated with water coming directly from urban areas or from other polluted sources<sup>10</sup> and also by the constant application of fertilizers and agro-chemicals which contained heavy metals. It has been shown that crops and vegetables cultivated in soils with heavy metal contamination accumulate a greater quantity of heavy metals than those cultivated in uncontaminated soil<sup>11-13</sup>.

Metals such as Cd, Cu and Zn are usually transferred with industrial emissions connected to acid rain and are drained away from watershed soils, bedrocks and lake sediments under acidic conditions<sup>14, 15</sup>. Most of the heavy metals collect in the natural environment in various ways through the nutrition chain. When the heavy metal accumulation due to contamination in the environment reaches a critical level in living organisms, it may result in ill health and a surge in death rates.

Heavy metals are known to build up in living organisms<sup>16</sup>. Plants have a natural tendency to absorb poisonous substances including heavy metals that are eventually transferred along the food chain. The main reason for the decrease in productivity on the whole and the production of food grains and vegetables which adversely affect the health of human beings is the use of contaminated land or water for the cultivation of crops<sup>17</sup>. Therefore, the objective of this study is to evaluate the accumulation and translocation of heavy metals in the soil and paddy plants (*Oryza sativa*) irrigated with recycled and non-recycled water and to investigate the absorption of heavy metals by the crop.

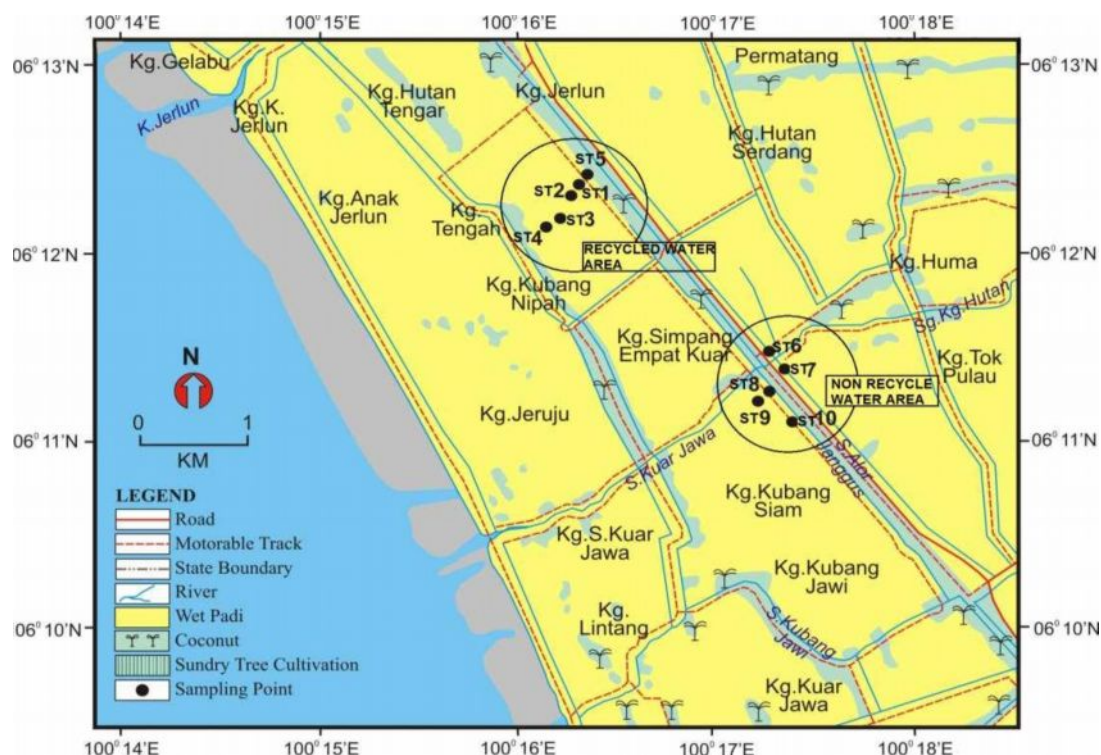
## Materials and Methods

### Sampling sites

The study was carried out on soils and paddy plants obtained from the MADA agricultural area in Kedah (6° 13' N, 6° 10' N and 100° 14' E, 100° 18' E), which is located in the northwest of Peninsula Malaysia (Figure.1).

The average temperature in Malaysia is 27.5°C, while the average maximum temperature is 33°C and the average minimum temperature is 22°C. The average rainfall per year is more than 2,500mm, which is above the worldwide annual average of 1,050mm. The rainfall is closely related to the seasonal monsoons, which particularly affect agriculture and fishing. Rainfall is one source of water that is crucial for the successful cultivation of rice. Samples of mature paddy plants and soils were taken from ten paddy stations, which were divided into two areas: one had been irrigated with recycled water, while the other area had been irrigated with

non-recycled water. The paddy plants were collected from five sampling points at each station and the same was carried out for the soil samples at 0–30 cm in depth.



**Figure 1:** Location of the sampling stations in the paddy fields of the study area in MADA, Kedah

## Extraction procedures

### Soil analysis

An auger with a diameter of 7 cm was used to collect five replicates of soil samples from a depth of 0 cm to 30 cm. The samples were kept in polyethylene plastic bags and were then air-dried in the laboratory before being ground and sieved with a 250  $\mu\text{m}$  mesh<sup>18</sup>. The heavy metals were then extracted from the soil samples using a sequential extraction procedure<sup>18</sup>.

### Plant analysis

The soil was removed from the plant samples by washing them with tap water. The samples were then washed thrice with distilled water and once with distilled deionized water before being pat dried with tissue paper. They were then weighed directly after collection. The samples were divided into several sections, namely stem, roots, leaves, straw and grains. They were then sliced into small pieces before being oven dried at 70°C for 72 hrs. The samples were weighed and ground with a mortar before being put through a wet digestion procedure using  $\text{HNO}_3:\text{HClO}_4$  (2:1) in a conical flask for 2-3 hours on a sand bath<sup>19</sup>. 10 ml of hydrochloric acid (HCl) was then added to dissolve the inorganic salts and oxides. The digested samples were then filtered using a 0.45  $\mu\text{m}$  pore size cellulose nitrate membrane filter paper (Millipore). The volume was then increased to 50 ml using distilled water. The concentrations of heavy metals in the soil and the paddy plants were determined by using ICPms.

### Quality assurance and quality control

The necessary quality assurance procedures and precautions were observed to ensure the reliability of the results. Only double distilled water was used throughout the study. The glassware was cleaned thoroughly and analytical grade reagents were used. Blank determinations were used for the reagents to correct the instrument readings. The concentrations of heavy metals in the soil and crop were calculated according to their dry weight.

### Bioaccumulation factor

The bioaccumulation factor (BAF), which is an indicator of the ability of a plant to accumulate a specific metal in contrast to the concentration of the metal in the soil substrate<sup>20</sup>, was calculated as follows:

$$BAF = \frac{C_{plant}}{C_{soil}}$$

where the heavy metal concentration in the edible parts of the plant and the soil are represented by  $C_{plant}$  and  $C_{soil}$ , respectively.

### Translocation factor

In order to establish the relative translocation of metals from the soil to the other parts of the plant, namely the roots, stalks and grains, the Translocation Factor (TF) or mobilization ratio<sup>21, 22</sup> was calculated.

$$TF = \frac{\text{Concentration of metal in plant tissue(parts)}}{\text{Concentration of metal in corresponding soil or root}}$$

### Statistical analysis

The SPSS version 16 (SPSS Inc., USA) was used to statistically evaluate all the data obtained from the plant and soil samples. All the experiments were conducted in five replicates to make allowances for experimental errors and the results were reported as a mean  $\pm$  standard deviation (SD). A post-hoc multiple comparison of means was then conducted using the Duncan test ( $P < 0.05$ ), with the statistical significance being defined as  $p < 0.05$ .

## Results and Discussion

Table 1 shows the total concentrations of Cd, Cr, Cu, Pb, Zn, Mn, and Fe in soils irrigated with recycled water and non-recycled water. It should be noted that the highest concentrations of Fe, Mn, Cr, Zn, and Pb were in the study area. Analysis of variance between heavy metals concentration in the soil samples from the areas irrigated with recycled water and non-recycled water revealed that there were significant differences between the concentrations of all the metals, with the exception of Cr and Zn. The concentrations of heavy metals in the soils that were irrigated with recycled water and non-recycled water were in the order of Fe > Mn > Cr > Zn > Pb > Cu > Cd and Fe > Zn > Cr > Mn > Pb > Cu > Cd, respectively. These heavy metal concentrations were higher in the soil samples than in the different parts of the rice plants, except for Cd, Cu and Mn, which may be attributed to their weak adsorption properties in the soil<sup>23</sup>.

**Table 1:** Concentration of heavy metals in paddy soil (mg/kg). n=25

| Metals | Recycled water area    | Non-recycled water area |
|--------|------------------------|-------------------------|
|        | Mean $\pm$ SD          | Mean $\pm$ SD           |
| Pb     | 7.821 $\pm$ 1.246      | 5.206 $\pm$ 1.050       |
| Cd     | 0.051 $\pm$ 0.020      | 0.065 $\pm$ 0.022       |
| Cu     | 2.079 $\pm$ 0.594      | 1.116 $\pm$ 0.398       |
| Cr     | 32.314 $\pm$ 5.429     | 26.590 $\pm$ 4.674      |
| Zn     | 29.665 $\pm$ 4.877     | 26.727 $\pm$ 9.864      |
| Mn     | 50.030 $\pm$ 13.932    | 22.917 $\pm$ 10.474     |
| Fe     | 43231.29 $\pm$ 8767.30 | 26353.84 $\pm$ 3113.80  |

### Metal concentration in paddy plants

From the average concentration of heavy metals in the paddy plant parts, as shown in Table 2, it can be seen that all metals under the study were present in the plant parts and that the highest accumulation of metals occurred in the roots, with the exception of Mn, which was heavily present in the leaves. It was also reported by

Mo et al. <sup>24</sup> that most of the heavy metal absorbed by the paddy plant accumulated in the roots, where there was a high metabolic rate and that the accumulation in the stem and leaves was very low.

**Table 2:** Concentration of heavy metals in different paddy plant parts (mg/kg). n=25

| Metals | Plant parts | Recycled water area          |                  | Non-recycled water area      |                 |
|--------|-------------|------------------------------|------------------|------------------------------|-----------------|
|        |             | Mean±SD                      | Range            | Mean±SD                      | Range           |
| Pb     | Root        | 2.803±1.266 <sup>a</sup>     | 1.193-6.036      | 2.241±1.347 <sup>a</sup>     | 0.693-4.965     |
|        | Stem        | 0.068±0.043 <sup>c</sup>     | 0.016-0.164      | 0.084±0.049 <sup>c</sup>     | 0.033-0.296     |
|        | Leaves      | 1.059±0.381 <sup>b</sup>     | 0.691-2.315      | 0.574±0.153 <sup>b</sup>     | 0.320-0.894     |
|        | Grain       | 0.151±0.229 <sup>c</sup>     | 0.049-2.014      | 0.090±0.027 <sup>c</sup>     | 0.056-0.185     |
|        | Straw       | 0.365±0.384 <sup>c</sup>     | 0.099-1.685      | 0.171±0.079 <sup>c</sup>     | 0.081-0.398     |
| Cd     | Root        | 0.072±0.028 <sup>a</sup>     | 0.029-0.131      | 0.053±0.018 <sup>a</sup>     | 0.026-0.090     |
|        | Stem        | 0.008±0.005 <sup>d</sup>     | 0.002-0.021      | 0.006±0.004 <sup>c</sup>     | 0.002-0.017     |
|        | Leaves      | 0.046±0.025 <sup>b</sup>     | 0.012-0.101      | 0.051±0.030 <sup>a</sup>     | 0.014-0.098     |
|        | Grain       | 0.023±0.015 <sup>c</sup>     | 0.004-0.065      | 0.023±0.014 <sup>b</sup>     | 0.004-0.067     |
|        | Straw       | 0.042±0.041 <sup>b</sup>     | 0.008-0.184      | 0.032±0.010 <sup>b</sup>     | 0.014-0.053     |
| Cu     | Root        | 1.464±0.909 <sup>a</sup>     | 0.499-3.080      | 2.956±0.515 <sup>a</sup>     | 1.812-3.693     |
|        | Stem        | 0.159±0.093 <sup>d</sup>     | 0.082-0.460      | 0.286±0.260 <sup>d</sup>     | 0.057-0.983     |
|        | Leaves      | 0.935±0.170 <sup>b</sup>     | 0.657-1.323      | 0.978±0.799 <sup>b</sup>     | 0.300-3.156     |
|        | Grain       | 0.552±0.245 <sup>c</sup>     | 0.212-1.027      | 0.657±0.381 <sup>c</sup>     | 0.112-1.455     |
|        | Straw       | 0.720±0.213 <sup>bc</sup>    | 0.345-1.113      | 0.998±0.408 <sup>b</sup>     | 0.404-1.903     |
| Cr     | Root        | 5.605±0.887 <sup>a</sup>     | 3.386-6.884      | 5.034±0.669 <sup>a</sup>     | 2.973-6.070     |
|        | Stem        | 2.401±0.461 <sup>b</sup>     | 1.625-3.918      | 1.531±0.385 <sup>d</sup>     | 0.917-2.190     |
|        | Leaves      | 5.230±0.533 <sup>a</sup>     | 3.776-6.044      | 4.579±0.665 <sup>b</sup>     | 3.502-5.991     |
|        | Grain       | 1.457±0.723 <sup>c</sup>     | 0.689-2.980      | 0.836±0.253 <sup>e</sup>     | 0.497-1.487     |
|        | Straw       | 2.553±0.931 <sup>b</sup>     | 0.900-4.506      | 1.937±0.973 <sup>c</sup>     | 0.810-4.440     |
| Zn     | Root        | 16.703±0.918 <sup>a</sup>    | 14.907-18.661    | 15.689±1.924 <sup>a</sup>    | 12.436-19.404   |
|        | Stem        | 8.120±4.907 <sup>c</sup>     | 3.561-18.795     | 3.463±1.062 <sup>e</sup>     | 1.641-5.665     |
|        | Leaves      | 14.785±2.691 <sup>b</sup>    | 10.282-19.533    | 11.947±1.292 <sup>b</sup>    | 9.270-15.155    |
|        | Grain       | 8.786±1.120 <sup>c</sup>     | 7.356-11.123     | 4.713±2.104 <sup>c</sup>     | 1.832-8.171     |
|        | Straw       | 9.597±3.009 <sup>c</sup>     | 5.586-15.780     | 9.615±3.523 <sup>d</sup>     | 4.757-15.270    |
| Mn     | Root        | 12.323±7.018 <sup>c</sup>    | 2.954-25.674     | 28.811±11.020 <sup>c</sup>   | 10.695-48.476   |
|        | Stem        | 6.526±2.957 <sup>d</sup>     | 3.333-13.021     | 11.313±5.709 <sup>c</sup>    | 3.160-20.642    |
|        | Leaves      | 42.962±5.199 <sup>a</sup>    | 33.945-53.616    | 103.100±74.061 <sup>a</sup>  | 24.379-215.693  |
|        | Grain       | 11.041±1.913 <sup>c</sup>    | 7.430-14.288     | 11.225±3.810 <sup>c</sup>    | 5.860-23.918    |
|        | Straw       | 29.584±3.723 <sup>b</sup>    | 23.269-36.780    | 53.214±31.447 <sup>b</sup>   | 18.241-102.285  |
| Fe     | Root        | 8533.92±3962.30 <sup>a</sup> | 4404.72-18460.00 | 5641.92±1791.35 <sup>a</sup> | 3528.10-9227.36 |
|        | Stem        | 65.785±38.518 <sup>b</sup>   | 32.930-153.392   | 42.261±4.341 <sup>b</sup>    | 33.045-50.755   |
|        | Leaves      | 237.876±51.783 <sup>b</sup>  | 140.621-348.399  | 154.213±40.269 <sup>b</sup>  | 84.455-248.145  |
|        | Grain       | 47.718±20.989 <sup>b</sup>   | 24.398-96.720    | 37.657±12.672 <sup>b</sup>   | 21.500-58.349   |
|        | Straw       | 89.390±28.928 <sup>b</sup>   | 44.605-167.275   | 69.766±21.888 <sup>b</sup>   | 39.189-126.719  |

In the plants cultivated in the area that was irrigated with recycled water, the order for the average concentration (mg kg<sup>-1</sup> dry wt) of each heavy metal in the roots was Fe (8533.920) > Zn (16.703) > Mn (12.323) > Cr (5.605) > Pb (2.803) > Cu (1.464) > Cd (0.072), whereas in the plants cultivated in the area that was irrigated with non-recycled water, the order for the respective metal concentrations was Fe (5641.920) > Mn (28.811) > Zn (15.689) > Cr (5.034) > Cu (2.956) > Pb (2.241) > Cd (0.053). Generally, the metal that was absorbed the most by the roots was Fe and the least was Cd in the areas irrigated with recycled and non-recycled water, respectively.

The average concentrations of Cd in rice grains were similar (0.023 mg kg<sup>-1</sup>) for both the areas irrigated with recycled and non-recycled water, while the concentrations of Cd in the rice straw were 0.042 mg kg<sup>-1</sup> and 0.032 mg kg<sup>-1</sup> for the areas irrigated with recycled water and non-recycled water, respectively. The approved

levels for polished rice and wheat grains based on the Codex Standard<sup>25</sup> are 0.4 and 0.2 mg/kg, respectively. The concentrations of Cd were equally low in the various sections of the paddy plant. According to Jarvis *et al.*<sup>26</sup>, Cd is easily absorbed by plants and conveyed to the different parts, although it does not benefit plants and animals in any way. Cadmium ( $Cd^{2+}$ ) is lethal to humans, animals and plants. It is passed into the environment mainly as a result of industrial processes and from phosphate fertilizers where it is absorbed by plants and passed on to animals and humans via the food chain. Cadmium is very poisonous in higher plants and its presence is usually marked by oxidative stress, as reported earlier<sup>27-30</sup>.

The lowest concentration of Cr in the rice plant was observed in the grains, with average concentrations of 1.457mg kg<sup>-1</sup> and 0.836 mg kg<sup>-1</sup> in the grains of plants from the areas irrigated with recycled and non-recycled water, respectively. This corresponded with the findings of Liu *et al.*<sup>31</sup> and Liu *et al.*<sup>32</sup>, who stated that the lowest concentration of Cr in paddy and wheat plants was in the roots, straw and grains. Kabata-Pendias & Pendias<sup>33</sup> recommended 30 mg kg<sup>-1</sup> as a safe concentration limit for Cr in paddy, while Kitagishi & Yamane<sup>34</sup> suggested 35 mg kg<sup>-1</sup> as an acceptable limit for the concentration of Cr in the upper sections of paddy plants cultivated in Japan.

The average concentrations of Pb in the rice grains were 0.151mg kg<sup>-1</sup> and 0.090mg kg<sup>-1</sup> for the plants cultivated in areas irrigated by recycled and non-recycled water, respectively. These concentrations were below the prescribed limits fixed by the Codex Standard<sup>25</sup> and the European Union (EU) standards (0.2 mg/kg). Among all the various parts of the paddy plant, the lowest concentrations of Pb were observed in the stems, where the value was 0.068mg/kg for those plants cultivated in the area irrigated with recycled water and 0.084mg kg<sup>-1</sup> for those in the area irrigated with non-recycled water. Lead is normally present in very small quantities in nature but its concentration levels have risen in many places throughout the world due to human activities<sup>35</sup>.

Table 2 shows that the highest concentrations of Cu and Zn were observed to be in the roots, followed by the leaves and straw of the rice plant, whereas the highest concentration of Mn was located in the leaves. The majority of the metals that were present in substantial amounts in the paddy plants were nutritious components like Fe, Mn, Zn, and Cu that are essential for various enzymatic functions and which play vital roles in photosynthesis and plant growth<sup>36,37</sup>.

### Bioaccumulation factor

Figure 2 lists the bioaccumulation factors (BAFs) that have been calculated for the transfer of heavy metals from soils to the rice plants. The BAF for heavy metals in the area irrigated by recycled water is given in descending order as Cd (0.461) > Zn (0.296) > Cu (0.266) > Mn (0.221) > Cr (0.045) > Pb (0.041) > Fe (0.001), whereas in the area irrigated with non-recycled water the order is given as Cu (0.589) > Mn (0.490) > Cd (0.358) > Zn (0.196) > Cr (0.031) > Pb (0.017) > Fe (0.001). The BAF values for Fe, Pb and Cr in the paddy plants were comparatively low, whereas the highest BAF values were recorded for Zn (0.563) in the area irrigated with recycled water and Cu (0.589) in the area irrigated with non-recycled water. The food chain (soil–plant–human) route is primarily recognized as being one of the main routes whereby humans are exposed to contaminants in the soil. The transfer of metals from the soil to the plant is one of the key elements of human exposure to metals via the food chain<sup>38</sup>. When the BCF is <1 or the BAF=1, it indicates that the plant only absorbs but does not store heavy metals; when the BCF is >1, it is an indication that the plant stores metals. BAF values of less than 1 were obtained for Cd, Cr, Cu, Pb, Zn, Mn, and Fe in the rice grains. The results showed that the bioavailability of metals was low in both the areas under study.

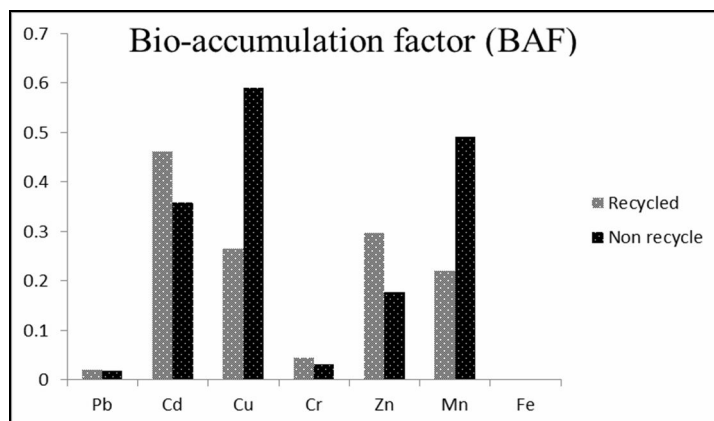
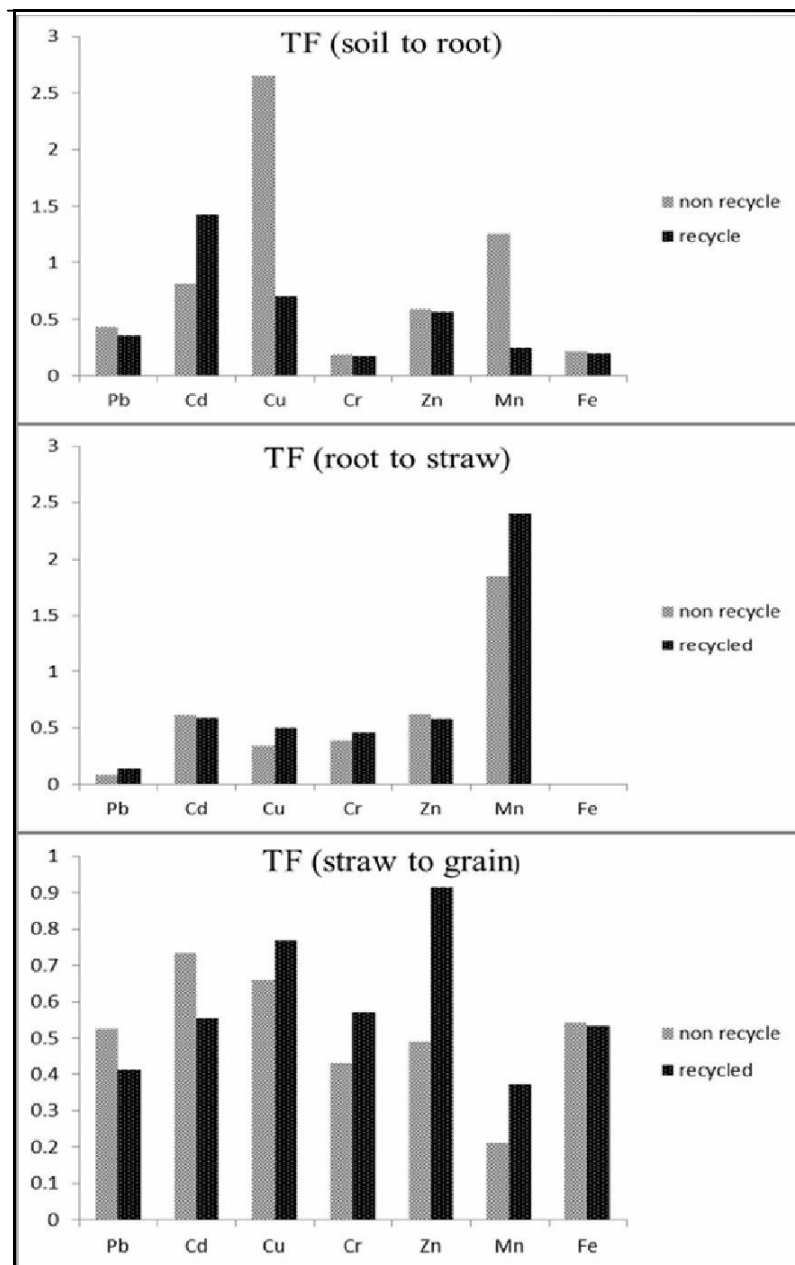


Figure 2: BAF of metals in the recycled and non-recycled water.

**Translocation factor**

One of the key elements of human exposure to metals via the food chain is the transfer factor (TF). Figure 3 presents the transfer factors (TF) of various heavy metals from the soil to the rice plants. The TFs were calculated for the translocation of metals from the soil to the roots ( $TF_{Soil}$ ), from the roots to the straw ( $RF_{Root}$ ), and from the straw to the grains ( $TF_{Straw}$ ). The order for the average translocation values of metals from the soil to the roots ( $TF_{Soil}$ ) in the areas irrigated with recycled water and non-recycled water was  $Cd (1.419) > Cu (0.704) > Zn (0.563) > Pb (0.526) > Mn (0.246) > Fe (0.197) > Cr (0.173)$  and  $Cu (2.649) > Mn (1.257) > Cd (0.812) > Zn (0.587) > Pb (0.430) > Fe (0.214) > Cr (0.189)$ , respectively. The data indicated that Cu had the highest  $TF_{Soil}$  value in the area irrigated with recycled water, while Cd has the highest  $TF_{Soil}$  value in the area irrigated with non-recycled water compared to all the other metals. One of the reasons for these results is that Cd occurs with Zn in nature and Cd (II) is not retained in the soil as strongly as other lethal cations<sup>39</sup>. The roots of the paddy plants retained just as high a quantity of  $Cd^{2+}$  when planted in non-contaminated soil as in soils containing this metal<sup>40</sup>. Lee *et al.*<sup>41</sup> also stated that  $Cd^{2+}$  is absorbed to a greater degree by plants compared to other heavy metals such as Zn, Cu and Pb, due to its higher biological absorption coefficient. Cu concentrations in brown rice rose somewhat with an increase in Cu concentrations in the soil<sup>42</sup>. Plant factors have also been reported to have a great influence on the uptake of Cu from the soil by the roots. Different plants display different properties with regard to root activities and exudates and these have a significant impact on the solubility and phytoavailability of Cu in soil<sup>43</sup>.



**Figure 3:** TF of metals for roots, straws and grains in recycled and non-recycled water.

The order for the  $TF_{Root}$  values from the roots to the straw was Mn (2.401) > Cd (0.586) > Zn (0.575) > Cu (0.491) > Cr (0.455) > Pb (0.130) > Fe (0.010) for the area irrigated with recycled water and Mn (1.847) > Zn (0.613) > Cd (0.602) > Cr (0.385) > Cu (0.338) > Pb (0.076) > Fe (0.012) for the area irrigated with non-recycled water. Chaney and Giordano had three classifications for heavy metals based on their capacity to be translocated to the plant shoots. Thus, Mn, Zn, Cd, B, Mo and Se were grouped together as elements which were readily translocated while Ni, Co, and Cu were in the intermediate category and Cr, Pb and Hg were in the lowest category<sup>44</sup>. Lethal heavy metals (Cd, Cr and Pb) are given translocation values of less than 1 for translocation from the roots to the straw for plants cultivated in areas irrigated with both recycled and non-recycled water. The order for the translocation values from the straw to the grains ( $TF_{Straw}$ ) in the areas irrigated with recycled water and non-recycled water was Zn (0.916) > Pb (0.869) > Cu (0.767) > Cr (0.571) > Cd (0.554) > Fe (0.534) > Mn (0.373) and Cd (0.733) > Cu (0.659) > Fe (0.540) > Pb (0.526) > Zn (0.490) > Cr (0.432) > Mn (0.211), respectively.

The  $TF_{straw}$  values were below 1 for all metals at the two areas. The absorption of most of the lethal heavy metals by the rice plants was in the following order: root > leaves > straw > grain > stem. The important point to note is that only small quantities of toxic heavy metals were translocated to the paddy grains. In addition, it may be useful to determine the translocation pattern of metals from the roots to other parts of a plant in order to biologically monitor contamination by heavy metals and to differentiate between those plant species that accumulate metals and those that are tolerant to metal contamination. The translocation of metals in plants is a key element in ascertaining the distribution of the metals in the various plant tissues<sup>45</sup>. The accumulation and distribution of heavy metals in the upper parts of a plant are determined by several factors, including anatomical, biochemical and physiological factors<sup>46</sup>.

## Conclusions

This study was carried out to investigate the accumulation of heavy metals in rice plant samples harvested from fields that were irrigated with recycled and non-recycled water. The findings revealed that the metal concentrations in the soils that were irrigated with recycled and non-recycled water were within the approved limits. Cd and Cu had the highest BAF compared to all the other metals at the areas that were irrigated with recycled water and non-recycled water, respectively. The findings also revealed that most of the heavy metals in the study accumulated mainly in the roots of the paddy plants except for Mn, which was retained in the leaves. Meanwhile, the metal concentrations in the other parts of the plant, including the stem, straw and grains were less than the approved levels specified by the Codex Alimentarius Commission standards and the WHO guidelines. The heavy metals in the soils that were investigated were mainly obtained from marine, alluvial and peat deposits and their concentrations were naturally low in the area under study. It was found that the paddy plants were exposed to very low levels of metal contamination.

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