Ecological Risk of Heavy Metal in Agricultural Soil and Transfer to Rice Grains

Upoma Mahmud
Khulna University
Md. Tareq Bin Salam (tareqss@swe.ku.ac.bd)
Khulna University
Abu Khan
Asia Arsenic Network, Jashore, Bangladesh
Md. Mizanur Rahman
Asia Arsenic Network, Jashore, Bangladesh

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Abstract

Higher accumulation of toxic heavy metals in rice grain and agricultural soil may lead to an imbalanced ecosystem. The present study was carried out to assess the risk of different heavy metals nickel, copper, arsenic, lead, and manganese in agricultural soil and transfer status to rice grain. The samples were collected from four agricultural fields at different times in the Dumuria Upazila (sub-district) under Khulna district in Bangladesh. Heavy metal concentration in soil extracts, irrigation water samples, and grain samples was determined by Atomic Absorption Spectrometry (AAS). Average metal concentrations were calculated and compared with the reference value in soil. In most of the cases, the existence of heavy metals in agricultural soil was greater than the reference soil which is a rising concern. Overall risk index (RI) stated that the examined soils were at moderate risk of contamination. Transfer factor (TF) of Arsenic (0.037 to 0.115) and Manganese (0.056 to 0.155) from soil to rice grain were higher that is also a matter of concern. On the other hand, TF of Lead (Pb) was found in a very negligible amount which is a good sign. Regular monitoring of heavy metals in agricultural soil should be initiated and the awareness level should be increased to avoid environmental problems.

Introduction

Heavy metals are ubiquitous in the environment, as a result of both natural and anthropogenic activities, and humans are exposed to them through various pathways [1]. Disposal of solid waste, different paints, and gasoline, agrochemical inputs like fertilizer, manures, residues, and human activities are the main cause for heavy metal accumulation in soil and increase heavy uptake through food consumption those grown on the contaminated area. Heavy metal load in soil and food crops is now taken research consideration in the scientific world due to the potential impact of human health risk. Heavy metal accumulation in plants depends upon plant species and the efficiency of different plants in absorbing metals is evaluated by either plant uptake or soil to plant transfer factors of the metals [2]. Heavy metals commonly found at contaminated sites and that are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni). Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), drinking of contaminated groundwater, reduction in food quality (safety and marketability) via phytotoxicity, reduction in land usability for agricultural production causing food insecurity, and land tenure problems [3]. In Bangladesh, there is no established tolerable/safe limit available for heavy metal in soil and crops. Therefore, the levels of heavy metals found in different sources of the present study were compared with the prescribed safe limit provided by World Health Organization [4] and other authors [5]. The soil in Bangladesh is highly variable and the concentration of mineral elements such as zinc, copper, and nickel vary drastically from one place to another [6]. Therefore, the research was conducted in Dumuria Upazila (sub-district) under Khulna district to find out the exposure and risk of different heavy metals in agricultural surface soil and its potential transfer to rice grain. However, the study has opened a new dimension about assessing heavy metal status in agricultural soil and rice grain that will help to take decisions for treating the soil in future land protection.

Materials And Methods

Site description

The samples were collected from four sampling sites in Dumuria sub-district under Khulna district in Bangladesh (Fig. 1). The sampling sites were in Gutudia (22°47´N, 89°27´E), Mechaghona (22°48´N, 89°24´E), Dhamalia (22°96´N,89°37´E), and Koiya (22°46´N, 89°31´E). The average temperature of the area is 28^0C and the land type is medium-high. Soil texture is mostly clayey loam and average rainfall per annum is 215 mm [7].

Sample collection and processing

Initial surface soils (0-15) cm depth were collected from twelve agricultural fields of four sampling sites before rice cultivation and the final soil samples were collected at the matured stage of rice after harvesting. Uncultivated soil was treated as reference soils for each sampling site and irrigation water samples were collected from the sampling sites regularly by using plastic bottles. Grain samples were collected at 14% moisture level after harvesting (at the matured stage). The collected samples were processed in the laboratory of Soil, Water and Environment discipline and kept air drying. Then soil samples were grinded and passed through a 2 mm sieve.

Samples Analysis

Soil organic carbon (SOC) was analysed by following the Walkley - Black wet oxidation method [8]. Soil pH was determined in distilled water using the pH meter with a water ratio of 1:5 [9]. Soil EC was measured by using Jeneway EC meter [9]. Heavy metal concentration in soil extracts, irrigation water samples, and grain samples was determined by Atomic Absorption Spectrometry (AAS) after acid digestion (HNO_3 + $HClO_4$ at 2:1).

Measurement of soil pollution (SPI) and ecological risk index (RI)

Soil pollution index (SPI) was measured by using the following Equation (1):

$$SPI = \frac{Ci}{Cbi} \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where, SPI is the soil pollution index, Ci is the concentration of the ith heavy metal in the soil, and Cbi is its reference soil value. SPI can be classified into five categories: unpolluted (SPI≤1), slightly polluted (1<SPI≤ 2), mildly polluted (2<SPI≤3), moderately polluted (3<SPI≤ 5), and highly polluted (SPI>5) [10].

The ecological risk index (RI) was calculated by using the most accepting following formula to assess the ecological risk (ER) of heavy metals [11]:

$$RI = \sum_{i=1}^{n} \text{ERi} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$ERi = Ti \times (\frac{\text{Ci}}{Cbi}) \ldots\ldots\ldots\ldots\ldots (3)$$

Where, ERi is the ecological risk index for the heavy metal i, and Ti is the toxicity response coefficient for the metal i. The toxic response factors for Mn, Cu, As, Ni, and Pb are 10, 5, 10, 6, and 5 respectively [12]. According to Xia et al. [13], RI standard grading is given in Table 1.

Heavy Metal's Transfer Factor (TF) analysis

Transfer factor (TF) denotes the potential transfer of metals from soil to plants. It is usually used to evaluate the ability of plants to uptake metals from soil. Transfer factor of each heavy metal was analyzed by using the following formula [14].

$$\text{TF} = \frac{\text{Metal load in crop grain}}{\textit{Metal load in soil after harvesting}} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Statistical Data Analysis

The data for the soil samples were subjected to analysis of variance (ANOVA) using SPSS 24.0 Software to ascertain the accuracy and validity of the results from the study area. To identify the relationship among elements, a Pearson bivariate correlation was used. MS-Excel 2007 package was used for doing all calculations and drawing graphs.

Results

General characteristics of soil in different sampling sites

A table for the general soil characteristics at different times in the sampling sites was given in Table 2 where pH and EC were almost statistically similar for most of the sampling sites ($p<0.05$) before cultivation and after harvesting. pH ranged from 7.04 to 7.93 which indicated almost neutral to alkaline in character and EC ranged from 4.05 to 4.40 dS/m that represented the moderate saline soil. However, organic carbon was comparatively lower in every soil sample and ranged from 0.34% to 1.15% but a significant difference was observed among the variables ($p<0.05$). In most cases, SOC was improved after harvesting.

Heavy metal analysis

According to fig. 2, the highest concentration of Ni was found in Gutudia (94.52±8.04 mg/kg) for the initial soil before cultivation. On the other hand, the soil after harvesting, the highest concentration was observed in Mechaghona (93.71±8.17 mg/kg) and Dhamalia showed the lowest concentration (37.76±2.87 mg/kg). This may due to irrigation water contained more Ni concentration (0.13 mg/L) in Koiya rather than other sites (Fig. 5). According to Barałkiewicz et al., 1999, the solubility of nickel in soils increases with increasing Ni concentration in irrigation water that supports the study [15]. Following fig. 2, the highest concentration of Cu was reported in Koiya (37.5±4.08 mg/kg) for the initial soil before cultivation. In soil after harvesting, the highest concentration was also notified in Koiya (36.47±2.17 mg/kg). This may due to irrigation water contained more Cu concentration (0.144 mg/L) in Koiya rather than other sites (fig. 5). According to the World Health Organization [4], soil containing Cu more than 100 mg/kg can be exposed to contaminate the soil. But in Bangladesh, no permissible limit has yet been set for Cu in agricultural soil [5]. However, in the investigated areas, irrigated soil loaded more Cu concentration than reference soil which is a matter of rising concern.

As per fig. 3, the highest concentration of As was seen in Koiya (8.64±0.20 mg/kg) for the initial soil before cultivation, and again, the soil after harvesting, the highest concentration was also noticed in Koiya field (8.47±0.18 mg/kg). This may due to irrigation water contained more As concentration (0.032 mg/L) in Koiya rather than other sites (fig. 5). Most important thing is that the World Health Organization [4] reports that soil containing As more than 20 mg/kg can be exposed to contaminate the soil. But in Bangladesh, no permissible limit has yet been set for As in agricultural soil [5]. However, in the investigated areas, most irrigated soils loaded less As concentration than reference soil which is a good indication for farming. As load may happen due to the use of As contaminated water and As-enriched fertilizers, as well as pesticides, for irrigation in the agricultural land [16, 17]. From Fig. 3, the highest concentration of Pb was found in Mechaghona (19.33±1.70 mg/kg) for the initial soil before cultivation. On contrary, the soil after harvesting, the highest concentration was observed in Gutudia (19.73±1.84 mg/kg). This may due to irrigation water contained more Pb concentration (0.032 mg/L) in Gutudia rather than other sites (fig. 5). According to the World Health Organization [4], soil containing Pb more than 100 mg/kg can be exposed to contaminate the soil. But in Bangladesh, no permissible limit has yet been set for Pb in agricultural soil [5]. However, in the investigated areas, most irrigated soils loaded more Pb concentration than reference soil which is a matter of rising concern.

Fig. 4. explained that the highest concentration of Mn was pointed in Koiya (372±16.34 mg/kg) for the initial soil before cultivation but in the soil after harvesting, the highest concentration was reported in Mechaghona (478.45±16.33 mg/kg) This may due to irrigation water contained more Mn concentration (0.42 mg/L) in Mechaghona rather than other sites (Fig. 4). According to the World Health Organization [4], soil containing Mn more than 2000 mg/kg can be exposed to contaminate the soil. But in Bangladesh, no permissible limit has yet been set for Mn in agricultural soil [5]. However, in the investigated areas, some irrigated soils loaded more Mn concentration than reference soil which is also a rising concern.

Heavy metal status in irrigation water samples

Fig. 5 stated that irrigation water contained the highest amount of Mn (0.1 to 0.4 mg/L) rather than any other metals. According to WHO/FAO [4], Mn content should be less than 0.2 mg/L for using water in irrigation. In that sense, irrigation water in Mechaghona sampling sites exceeded the recommended value. Though the Pb contents of different sampling sites were not higher (0.03 to 0.65 mg/L), Gutudia and Koiya sampling sites lived in borderline of risk according to WHO/FAO [4], guideline (0.065 mg/L). On the other hand, Cu values (0.06 to 0.14 mg/L) exceeded WHO/FAO [4], recommendation value (0.017 mg/L) in all sampling sites that is another concern. In terms of Ni and As, all sampling sites represented the optimal values as compared with recommended values by WHO/FAO [4].

Pearson correlation coefficient among heavy metals and physiochemical properties of soil

Pearson correlation coefficient among heavy metals and physiochemical properties of soil are presented in Table 3. Significant positive correlation was observed between pH-As (0.86*), pH- Pb (0.97**), Ni-As (0.19*) and As-Pb (0.70*). In addition, significant negative correlation was also noticed between pH-EC (-0.89*), EC-Mn (-0.91**), EC-Cu (-0.97**). Other's correlations were found to be non-significant which means concentration of one element may not influence other elements concentrations in the studied area.

Soil pollution and risk index of heavy metal assessment

Soil pollution index (SPI) and Ecological risk (ER) status were presented in Table 4. According to the table, the SPI values of Mn before cultivation varied from 4.77 to 6.19 which indicated moderate to high soil pollution but the SPI values of Mn after harvesting ranged from 5.95 to 7.10 which indicated high soil pollution. The ER value of Mn was the highest in Dhamalia soil after harvesting (84.07) which recommended considerable ecological risk. It was also noticeable that all other sampling sites were presented the moderate ecological risk. This may due to irrigation water contained more Mn than other metals. The SPI values of Cu before cultivation varied from 1.78 to 3.62 which pointed slightly to moderate soil pollution but the SPI values of Mn after harvesting ranged from 2.37 to 3.53 which represented mild to moderate soil pollution. So, soil pollution is critically enhanced after cultivation and irrigation. The ER value of Mn was the highest in Koiya soil before cultivation (18.12) which indicated low ecological risk. However, all other sites also presented a low ecological risk. The SPI values of As before cultivation varied from 4.03 to 4.68 and the SPI values of As after harvesting ranged from 4.01 to 4.92 which specified moderate soil pollution. So, soil pollution is critically remained the same before and after cultivation and irrigation. The ER value of As was the highest in Mechaghona soil before cultivation (49.20) which indicated a moderate ecological risk. However, all other sites also presented the moderate ecological risk. This may due to sampling sites contained As bearing minerals. The SPI values of Ni before cultivation varied from 2.51 to 3.85 which showed mild to moderate soil pollution and the SPI values of Ni after harvesting ranged from 3.17 to 3.54 which symbolized moderate soil pollution. So, the soil pollution was increased after cultivation and harvesting especially in Dhamalia and Mechaghona soil because before cultivation SPI was mild in both fields which converted to moderate SPI after harvesting. The ER value of Ni was the highest in Gutudia soil after harvesting (21.22) because Ni content in irrigation water of Koiya field was higher than other fields. In terms of Pb, the SPI values were lower than other metals except Koiya field. ER values also indicated that all sampling sites presented a low ecological risk. This may due to irrigation water contained the lowest Pb concentration. According to Table 5, all studied area represented moderate risk of pollution in both stages (before cultivation and after harvesting). This is a great matter of concern because agricultural soils are loaded by heavy metals day-by-day thus can be a potential cause for human health deterioration due to carcinogenic effect through food ingestion, grown this soils.

Heavy metal assessment in the grain samples

As per Table 6, As concentration in all samples were crossed the permissible limit [18]. The highest As content was observed in Gutudia grains (0.53±0.05 mg/kg). Transfer factors of As were ranged from 0.037 to 0.115. According to Hojsak et al [19], the permissible limit of As in rice grains is 0.15 mg/kg. So, the sampling sites are now at great risk of As. Although the Mn content was still below the permissible limit, its transfer factor was quite higher (0.059 to 0.156). In terms of Ni, Cu, and Pb, metal concentrations in grain samples were not exceeded the permissible limit recommended by WHO/FAO [4]. But the transfer factor of Ni ranged from 0.071 to 0.148 and the TF of Cu ranged from 0.04 to 0.136. So, it might be a concern in the future. However, a higher transfer factor means a higher risk of metal exposure. The lowest TF was found for Pb that ranged from 0.002 to 0.008 which is a good indication for Pb accumulation in rice grain.

Discussion

pH and Soil organic carbon (SOC) has a potential influence on soil nutrient availability especially soil micronutrients and heavy metals mobility. In most of the cases, pH was insignificant with each other ($p<0.05$) and stated the neutral value that can enhance the mobility of heavy metals [20]. An increase in pH can disrupt heavy metals uptake but this could not be true all time. A high Cd accumulation and toxicity in high pH soil have been recorded [21]. In the study area, pH value showed an almost similar result before and after harvesting thus might be a possible reason for increasing mobility of heavy metals. Organic carbon influences to enhance the soil buffering capacity thus helps to increase the mobility of metals [22]. According to table 2, SOC was increased after harvesting thus might be the potential load of heavy metals in soils as well as crop.

In the study area, all metals showed greater values than reference soil's metals value and they are significantly varied from each other ($p<0.05$). Apart from that Mn, Ni, and As also crossed the permissible limit value [4]. In the agricultural soil analysis, Iyaka and Kakulu [23]; Emurotu and Onianwa [24] found the heavy metal values within the permissible limit. But Jia et al. [25] found the heavy metals concentration higher in intensive farmland than the permissible limit that supports the study.

The ecological risk value of each heavy metals was decreasing order Mn>As>Ni>Pb>Cr. The overall RI value stated that all sampling sites were in a moderate level of contamination and the level of contamination was increased after harvesting. Chaoua et al [26] said that contaminated irrigation water can enhance the load of heavy metals in soils and crops. Balkhair and Ashraf [27] also found the same results for both soils and crops that support the study. In our study, irrigation water contained a greater amount of Mn concentration which might be a possible reason for accumulating Mn in a higher amount for both soil and rice grain. The agrochemical input can also enhance the potential load of heavy metals [25]. Wuana and Okieimen [28] also found that agrochemical inputs like pesticides, fertilizers, biosolids, and manures are the possible reason for increasing heavy metal concentration in soil. Atafar et al. [29] stated that Cd, Pb, and As content was significantly ($p<0.05$) augmented after applying chemical fertilizers in the soil. A similar finding was also observed in the study of Nicholson et al 2003 [30, 31].

The transfer factor of Mn was higher in rice grains thus create a chance for higher human consumption. Mn not only creates a negative impact on human health but also induces the plant function. Suresh et al. 2008 observed that excess soil Mn disrupts stomatal function in two soybean cultivars [31]. Mn also causes human lung injury like cough, bronchitis, pneumonitis along with damages lung [32]. As also showed higher transfer factor in rice grains which is a matter of concern. Exposure to As can lead to cancer risk for millions of people [14, 33]. In Bangladesh, rice is being cultivated by As-contaminated water thus lead to high As content in rice grain [34]. In our study, mostly groundwater was used for irrigation thus might be a possible reason for accumulating As at toxic level in rice grains. Other than that, all other metals demonstrated considerable transfer factor. Balkhair and Ashraf [27] observed a higher accumulation of heavy metals in okra plants. Sometimes transfer factor crossed the value of more than 1 because of applying wastewater for irrigation purposes. Due to the use of fresh groundwater for irrigation purposes, comparatively lower transfer factor was observed in our study.

Conclusion

The concentration of major heavy metals in agricultural soil, their risk index, and the transfer factor of these heavy metals from soil to rice grain stated that sampling sites were at potential risk of heavy metal inclusion especially Mn and As. The heavy metals content was higher after harvesting than before cultivation in most cases. This may due to irrigation water contained a potential amount of heavy metals that crossed the permissible limit in some cases. Soil pollution index (SPI) also demonstrated that Mn and As was shown at moderate to a high level of soil pollution thus should be taken into consideration. In the analysis of rice grain, Arsenic (As) and Manganese (Mn) were also represented higher heavy metal accumulation. Agricultural input might be another cause for heavy metal load although it was not analyzed in the study. Hence regular monitoring and assessment are recommended to prevent the heavy metal's excessive build up in the food chain.

Declarations

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Author's Contribution

Tareq initiated and supervised the whole work. Upoma collected data from the field as well as wrote the manuscript. Tareq also corrected and improved the manuscript. Shamim and Mizan helped in laboratory and calculation part. Finally, all authors read and approved the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

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References

1. Wilson B, Pyatt FB. Heavy metal dispersion, persistence, and bioaccumulation around an ancient copper mine situated in Anglesey. UK. Ecotoxilogy and Environmental safety. 2007;66:224-31.
2. Rattan RK, Datta SP, Chhonkar PK, Suribabu K, Singh AK. Long term impact of irrigation with sweage effluents on heavy metal content in soils, crops and groundwater-a case study. Agricultural Ecosystem and Environment. 2005;109:310-22.
3. McLaughlin MJ, Zarcinas BA, Stevens DP, Cook N. Soil testing for heavy metals, Communications in Soil Science and Plant Analysis. 2000;31(11–14):1661–700.
4. WHO/FAO (World Health Organization/Food and Agriculture Organization). Joint FAO/WHO/FAO, food standard programme codex alimentarius commission 13th session. Report of the thirty-eight session of the codex committee on food hygiene, Houston, USA. 2007, ALINORM 07/30/13.
5. Hasine MT, Huda ME, Khatun R, Saadat AHM, Ahasan M, Akter S, Uddin MF, Monika AN, Rahman MA, Ohiduzzaman M. Environment and Ecology Research. 2017;5(7):510-6.
6. Ahmad MSA, Asraf M. Essential roles and hazardous effects of nickel in plants. Rev. Environ. Contam. Toxicol. Whitacre. (ed.). 2017;214:63-86.
7. SRDI (Soil Resource Development Institute). Thana Nirdeshika Guide, developed by Ministry of Agriculture, Bangladesh. 2007.

8. Nelson DW, Sommers LE. Total carbon and soil organic matter. In: Methods of Soil Analysis. Part.3- Chemical Methods. ed.- Sparks et al. Madison, Wisconsin, USA:ASA-SSSA.1996, 961-1010.
9. USDA (United States Department of Agriculture). Soil survey laboratory manual. Soil survey investigation report no.42, version 4.0, USDA-NRCS, Nebraska, USA. 2004. Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.
10. Zang F, Wang S, Nan Z, Ma J, Zhang Q, Chen Y, Li Y. Accumulation, spatio-temporal distribution, and risk assessment of heavy metals in the soil-corn system around a polymetallic mining area from the Loess Plateau, northwest China. Geoderma. 2017;305: 188-96. https://doi.org/10.1016/j.geoderma.2017.06.008
11. Hakanson L. An ecological risk index for aquatic pollution control-a sedimentological approach. Water Res. 1980;14:975-1001. https://doi.org/10.1016/0043-1354(80)90143-8
12. Wang Y, Yang L, Kong,L, Liu E, Wang L, Zhu J. Spatial distribution, ecological risk assessment and source identification for heavy metals in surface sediments from Dongping Lake, Shandong, East China. Catena. 2015;125:200-5. https://doi.org/10.1016/j.catena.2014.10.023.
13. Xia W, Wang R, Zhu B, Rudstam GL, Liu Y, Xu Y, Xin W, Chen Y. Heavy metal gradients from rural to urban lakes in central China. Ecol Process. 2020;9:47. https://doi.org/10.1186/s13717-020-00251-8
14. Li QS, Chen Y, Fu H, Cui Z, Shi L, Wang L, Liu Z. Health risk of heavy metals in food crops grown on reclaimed tidal flat soil in the Pearl River estuary, China. J Hazard Mater. 2012;227-228:148–54.
15. Barałkiewicz D, Siepak J. Chromium, nickel and cobalt in environmental samples and existing legal norms. Polish Journal of Environmental Studies. 1999;8:201-8.
16. Alam MG, Snow ET, Tanaka A. Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. Science of the Total Environment. 2003;308:83-96.
17. Polizzotto ML, Lineberger EM, Matteson AR, Neumann RB, Badruzzaman ABM, Ali MA. Arsenic transport in irrigation water across rice-field soils in Bangladesh. Environmental Pollution. 2013;179:210-7.
18. Chiroma TM, Ebewele RO, Hymore FK. Comparative Assessment Of Heavy Metal Levels In Soil, Vegetables And Urban Grey Waste Water Used For Irrigation In Yola And Kano. International Refereed Journal of Engineering and Science. 2014;3(2):01-09.
19. Hojsak I, Braegger C, Bronsky J, Campoy C, Colomb V, Decsi T, Domellof M, Fewtrell M, Mis NF, Mihatsch W, Molgaard C, Goudoever JV. .Arsenic in rice: a cause for concern. J Pediatr Gastroenterol Nutr. 2015;60(1):142-5.
20. Mico C, Peris M, Sanchez J, Recatala L. Heavy metal content of agricultural soils in a Mediterranean semiarid area: the Segura River Valley (Alicante, Spain). Span J Agric Res. 2006;4(4):363–72.
21. Eriksson, JE. (The influence of pH, soil type and time on adsorption and uptake of cadmium. Water Air Soil Pollut. 1989;48:317.
22. McCauley A, Jone C, Jacobsen J. Soil pH and organic matter. In: Nutrient management module no 8. 2009. http://landresources.montana.edu/nm/documents/NM8.pdf. Accessed 10 Aug 2015.
23. Iyaka YA, Kakulu SE. Heavy metal concentrations in top agricultural soils around ceramic and pharmaceutical industrial sites in Niger State, Nigeria. Res J Environ Earth Sci. 2012;4(2):171–176
24. Emurotu JE, Onianwa PC. Bioaccumulation of heavy metals in soil and selected food crops cultivated in Kogi State, north central. Nigeria Environ Syst Res. 2017;6:21. DOI 10.1186/s40068-017-0098-1
25. Jia L, Wang W, Li Y, Yang L. Heavy Metals in Soil and Crops of an Intensively Farmed Area: A Case Study in Yucheng City, Shandong Province, China. Int. J. Environ. Res. Public Health. 2010;7:395-412. doi:10.3390/ijerph7020395
26. Chaoua S, Boussaa S, Gharmali AE, Boumezzough A. Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco, Journal of the Saudi Society of Agricultural Sciences. 2019;18(2019):429–36. https://doi.org/10.1016/j.jssas.2018.02.003
27. Balkhair KS, Ashraf MA. Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia Saudi, Journal of Biological Sciences. 2015;23:32–44. http://dx.doi.org/10.1016/j.sjbs.2015.09.023
28. Wuana, A.R.; Okieimen, F.E. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation International Scholarly Research Network, ISRN Ecology. 2011, Volume 2011, Article ID 402647, doi:10.5402/2011/402647
29. Atafar, Z, Mesdaghinia A, Nouri J, Homaee MJ, Yunesian M, Ahmadimoghaddam M, Mahvi AH. Effect of fertilizer application on soil heavy metal concentration, Environ Monit Assess. 2010;160:83–9. DOI 10.1007/s10661-008-0659-x
30. Nicholson FA, Smith SR, Alloway BJ. An inventory of heavy metals inputs to agricultural soils in England and Wales, Science of The Total Environment. 2003;311(1-3):205-19. DOI: 10.1016/S0048-9697(03)00139-6
31. Suresh R, Foy CD, Weidner JR. Effects of excess soil manganese on stomatal function in two soybean cultivars, Journal of Plant Nutrition. 1987;10(7):749-60. DOI: 10.1080/01904168709363606
32. Boojar MMA, Goodarzi FA. Longitudinal follow-up of pulmonary function and respiratory symptoms in workers exposed to manganese, J Occup Environ Med. 2002;44:282–90.
33. Argos M, Kalra T, Rathouz PJ, Chen Y, Pierce B, Parvez F. Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study, Lancet. 2010;376:252–8. doi: 10.1016/S0140-6736(10)60481-3.
34. Williams PN, Islam MR, Adomako EE, Raab A, Hossain SA, Zhu YG. Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters, Environ. Sci. Technol. 2006;40:4903–8. doi: 10.1021/es060222i

Tables

Table 1 Classification of potential ecological risk index [13]

ER value	Grade of ecological risk of single metal	RI value	Grade of potential ecological risk of the environment
ER<40	Low risk	RI<112.5	Low risk
40≤ER<80	Moderate risk	112.5≤RI<225	Moderate risk
80≤ER<160	Considerable risk	225≤RI<450	Considerable risk
160≤ER<320	High risk	RI>450	Very High risk
ER≥320	Very high risk	—	—

unpolluted (SPI≤1), slightly polluted (1<SPI≤ 2), mildly polluted (2<SPI≤3), moderately polluted (3<SPI≤ 5), and highly polluted (SPI>5) [25].

Table 2 Soil pH, EC and organic carbon content at different sampling sites

Sampling Sites	Parameters	pH	EC (dS/m)	SOC (%)
Gutudia	Soil before cultivation	7.47±0.02a	4.40±0.01a	0.93±0,05a
	Soil after harvesting	7.76±0.02a	4.20±0.04a	0.61±0.03b
	Reference soil	7.04±0.03b	4.24±0.01a	0.61±0.01b
Mechagona	Soil before cultivation	7.81±0.01a	4.22±0.01a	0.41±0.01b
	Soil after harvesting	7.62±0.37a	4.28±0.05a	1.15±0.01a
	Reference soil	7.93±0.01a	4.23±0.02a	0.44±.08b
Dhamalia	Soil before cultivation	7.21±0.04b	4.24±0.02b	0.62±0.02b
	Soil after harvesting	7.36±0.01a	4.48±0.05a	0.89±0.03a
	Reference soil	7.44±0.01a	4.32±0.02a	0.64±0.02b
Koiya	Soil before cultivation	7.46±0.01a	4.05±0.02b	0.31±0.02b
	Soil after harvesting	7.64±0.04a	4.14±0.02a	0.78±0.05b
	Reference soil	7.57±0.02a	4.24±0.01a	0.34±0.01b

Table 3 Correlation among different parameters of soil

	pH	EC	OC	Ni	Cu	As	Pb	Mn
pH	1							
EC	-0.89*	1						
OC	-0.39	0.37	1					
Ni	-0.34	0.22	0.97	1				
Cu	0.91	-0.97*	-0.15	-0.02	1			
As	0.86*	-0.84	0.10	0.19*	0.95	1		
Pb	0.97**	-0.84	-0.60	-0.56	0.79	0.70*	1	
Mn	0.94	-0.91**	-0.09	0.01	0.98**	0.98	0.82	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Table 4 Soil Pollution Index (SPI) and Ecological Risk (ER) status of sampling sites

Sites[1]	Metals	SPI value before cultivation	SPI Status before cultivation	SPI value after harvesting	SPI Status after harvesting	ER value before cultivation	ER Status before cultivation	ER value after harvesting	ER Status after harvesting
Gutudia	Mn	4.77	Moderate	5.95	High	47.69	Moderate	59.46	Moderate
Mechaghona		4.97	Moderate	7.10	High	49.74	Moderate	70.97	Moderate
Dhamalia		6.19	High	8.41	Mild	61.91	Moderate	84.07	Considerable
Koiya		6.03	High	6.90	High	60.34	Moderate	69.01	Moderate
Gutudia	Cu	2.87	Mild	2.54	Mild	14.36	Low	12.70	Low
Mechaghona		2.20	Mild	2.42	Mild	10.98	Low	12.12	Low
Dhamalia		1.78	Slight	2.37	Mild	8.88	Low	11.86	Low
Koiya		3.62	Moderate	3.53	Moderate	18.12	Low	17.63	Low
Gutudia	As	4.68	Moderate	4.59	Moderate	46.84	Moderate	45.90	Moderate
Mechaghona		4.44	Moderate	4.92	Moderate	44.44	Moderate	49.20	Moderate
Dhamalia		4.03	Moderate	4.47	Moderate	40.27	Moderate	44.65	Moderate
Koiya		4.04	Moderate	4.01	Moderate	40.43	Moderate	40.07	Moderate
Gutudia	Ni	3.85	Moderate	3.38	Moderate	23.10	Low	20.29	Low
Mechaghona		2.63	Mild	3.82	Moderate	15.81	Low	22.90	Low
Dhamalia		2.51	Mild	3.17	Moderate	15.09	Low	19.00	Low
Koiya		3.48	Moderate	3.54	Moderate	20.90	Low	21.22	Low
Gutudia	Pb	1.83	Mild	2.39	Mild	9.17	Low	11.93	Low
Mechaghona		2.64	Slight	3.99	Moderate	13.22	Low	19.97	Low
Dhamalia		2.48	Slight	2.97	Mild	12.42	Low	14.85	Low
Koiya		3.60	Moderate	4.60	Moderate	17.99	Low	22.98	Low

Table 5 Risk status of sampling sites

Sites[1]	Risk Index value before cultivation	Risk status before cultivation	Risk Index value after harvesting	Risk status after harvesting
Gutudia	141.16	Moderate	150.28	Moderate
Mechaghona	134.18	Moderate	175.16	Moderate
Dhamalia	138.56	Moderate	174.44	Moderate
Koiya	157.77	Moderate	170.92	Moderate

Table 6 Heavy metal assessment in grain samples

Sampling sites	As (mg/kg)			Mn (mg/kg)			Ni (mg/kg)			Pb (mg/kg)			Cu (mg/kg)	
	Grain	*PL	TF	Grain	*PL	TF	Grain	#PL	TF	Grain	*PL	TF	Grain	*PL
Gutudia	0.53±0.05	0.15	0.065	52.16±3.12	500	0.118	5.93±1.2	67	0.071	0.08±0.03	0.3	0.004	1.32±0.4	73
Mechghona	0.36±0.04		0.037	28.08±3.9		0.056	6.78±2.1		0.072	0.06±0.02		0.002	3.39±0.8	
Dhamalia	0.27±0.04		0.115	67.98±3.94		0.155	11.49±2.4		0.148	0.12±0.07		0.006	4.25±0.7	
Koiya	0.39±0.03		0.046	36.95±4.27		0.087	9.23±3.4		0.106	0.17±0.06		0.008	2.67±0.5	

Note: *PL= Permissible limit recommended by WHO [Chiroma et al. (2014)]; #PL= Permissible limit recommended by China [Hojsak et al (2015)]; TF= Mean Transfer Factor

Figures

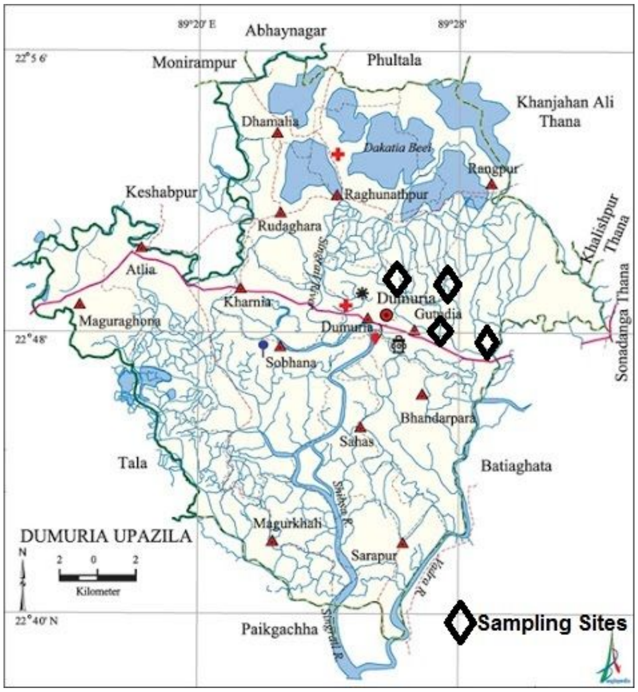

Figure 1

Map of the study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

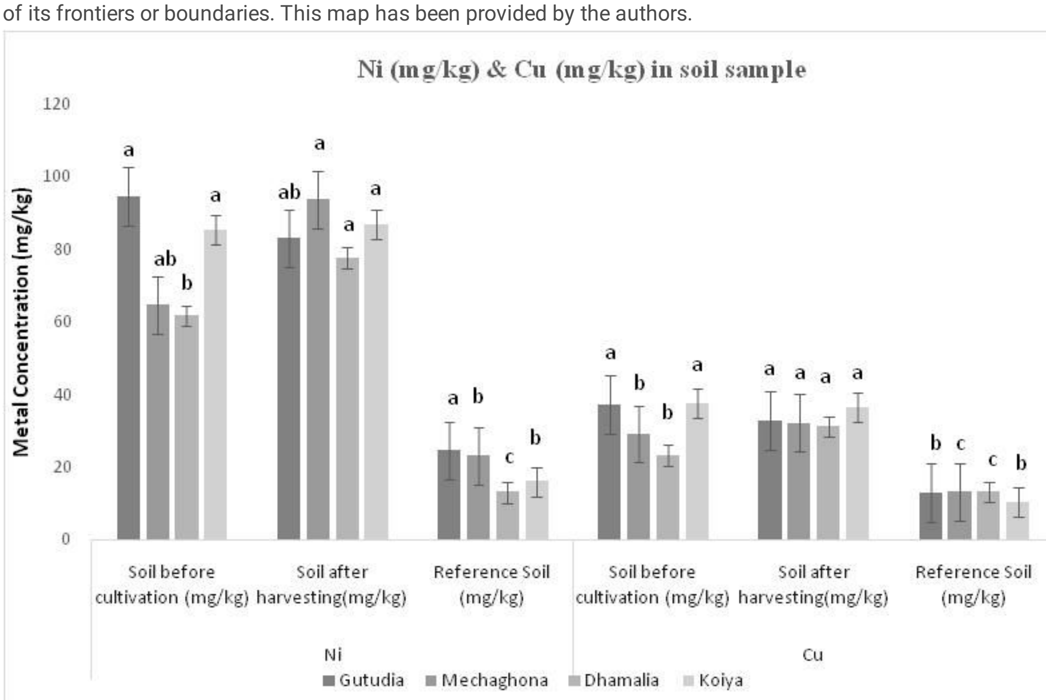

Figure 2

Ni (mg/kg) & Cu (mg/kg) in soil samples

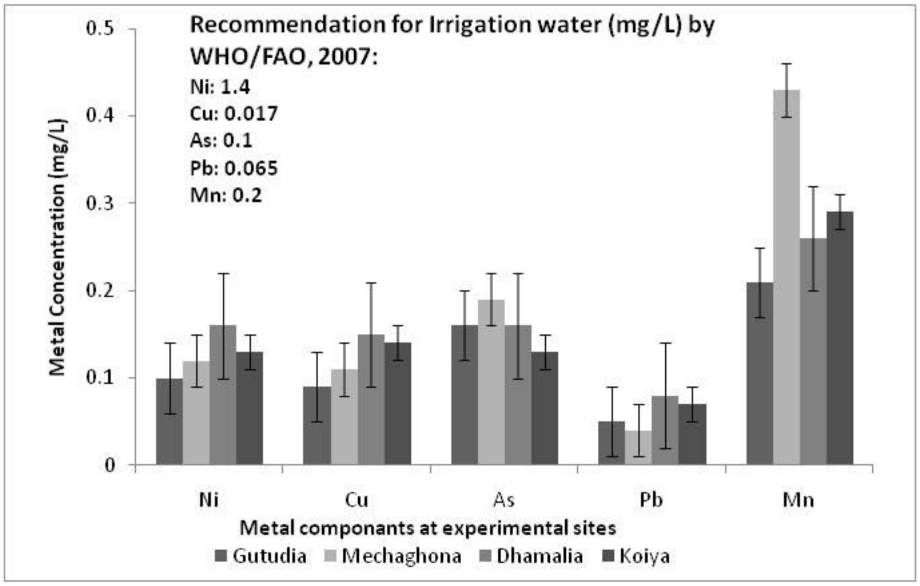

Figure 3

As (mg/kg) & Pb (mg/kg) in soil samples

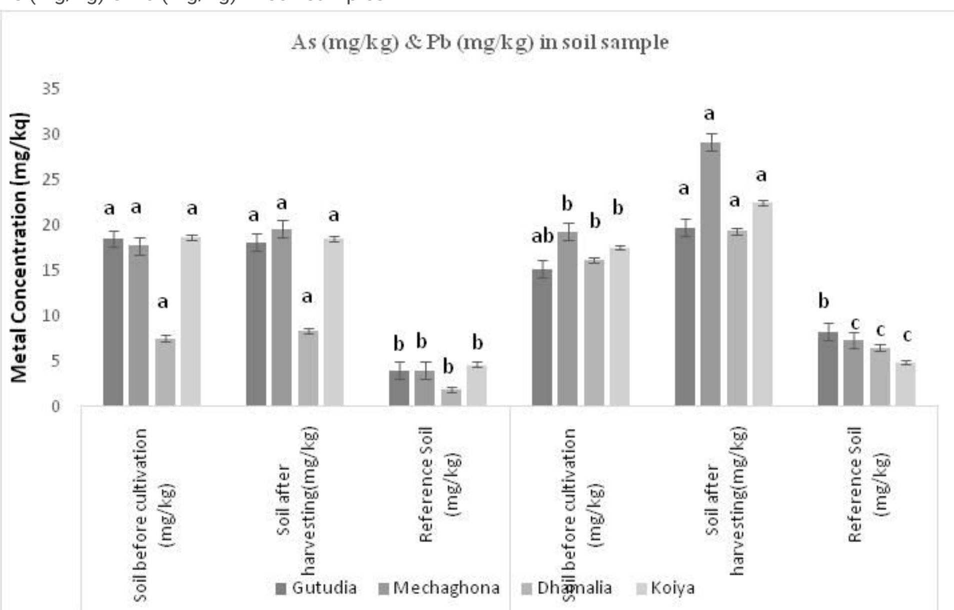

Figure 4

Mn (mg/kg) in soil samples

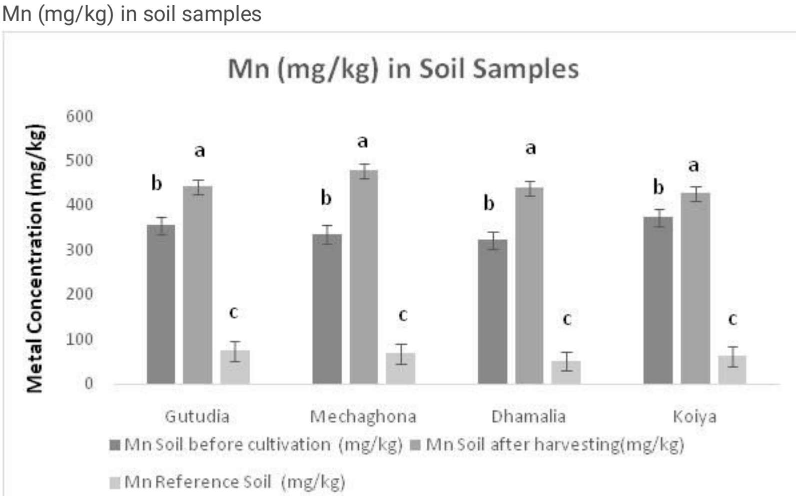

Figure 5

Heavy metals in irrigation water samples