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Heavy Metal Concentrations in Soil from Selected Rice Farms at Cheju, Zanzibar

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Authors' contributions

This work was carried out in collaboration between both authors. Author RKM designed the study, wrote the protocol, performed the statistical analysis. Author NKM wrote the first draft of the manuscript and managed the literature search and managed the analysis of the study. Both Author read and approved the final manuscript.

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ABSTRACT

Advancement of science and technology has enhanced the use of chemical products, such as fertilizer and pesticides, into agriculture to improve yield. Normally, these products contain metals which are detrimental to human health. These metals may be absorbed by plants and hence be introduced into food chain. In this study, samples of soil from Cheju rice farms were analyzed for heavy metals associated with agrochemicals using Energy Dispersive X-ray Fluorescence (EDXRF) Spectrometry. Sixty soil samples were collected from Cheju rice farms and 10 control samples were collected from Mwera about 25 km from Cheju. T-test to compare the mean concentrations of elements in fertilized and control soils showed that the soil samples from Cheju farms had significantly higher concentrations of most of the determined metals compared to the control sample. Higher concentrations of these elements in fertilized soil may be attributed to the repeated use of agrochemicals in farming. Analysis of rice grains from the field and other samples from the neighbouring ecosystem is recommended.

Keywords: Cheju rice farms; heavy metal; fertilizers; pesticides; EDXRF.

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1. INTRODUCTION

Rice farming activities in Zanzibar is being promoted by the Government as a step to decrease poverty among peoples. However, the promotion involves the use of pesticides and chemical fertilizers in the farms to increase yield. The most common fertilizer used in Zanzibar rice farming is the Nitrogen Phosphorous Potash (NPK) and the pesticides are bentazone, dichlorprop and malathion [1]. Many studies have related the use of fertilizers and pesticides with the concentration of heavy metals in soil [2-5].

The most commonly reported toxic metals in relation to agrochemicals are lead (Pb), chromium (Cr), arsenic (As), cadmium (Cd), mercury (Hg), and nickel (Ni) [6]. These elements are harmful to humans even in low concentrations. At the same time iron (Fe), copper (Cu), zinc (Zn) and other trace elements, which are important for proper functioning of biological systems, have also been reported in fertilizers and pesticides [7]. These elements in excess could lead to a number of disorders including effects of kidney, liver and central nervous system [8]. Therefore long term land application of agrochemicals might cause excessive accumulation of heavy metals in soil which may be passed over to the food chain and effect the health of humans and ecosystem [9].

The largest rice farms in Zanzibar with an average of 1,500 to 2,000 acres are found in Cheju area [1]. These farms are also about 5 km from Mapopwe Creek of the Chwaka bay. Mapopwe creek is the largest series of tidal creeks in Zanzibar which is an important national fishing area and is a refuge of a number of animals and plant species that have international significance [1,10]. There have been complains in Chwaka bay that shrimps are disappearing in the creek especially during and after the rain seasons (at end of March until mid May). Kruitwagen et al. [11] reported also elevated concentrations of Zn and Pb in fish samples collected from mangrove ecosystems at Chwaka. There is a possibility that heavy metals from Cheju rice farming are leached and transported to Chwaka bay and pollute the creek. This study aimed at assessing heavy metal concentrations in Cheju rice farms as a first step in controlling food contamination in Zanzibar.

2. METHODOLOGY

Sixty soil samples were collected in rice farms in Cheju and 10 control samples were collected from Mwera about 25 km from Cheju. No fertilizer is used in rice farming in Mwera. The samples were collected such that each paddy soil sample comprised a composite of four subsamples taken from within a 1x1m^2 at depth of 0 –30 cm from each location [12]. For each category the subsamples were combined and homogenized, giving a soil sample which is representative of the location. The resulting samples were placed in labeled polythene bags and then transferred to University of Dar es Salaam Physics laboratory for sample preparation. Fig. 1 shows the location of Cheju rice farm where the samples were collected.

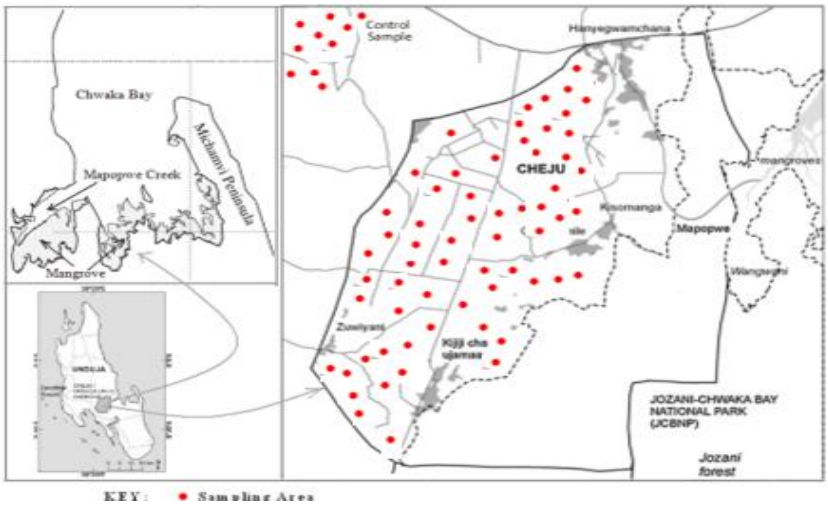


Fig. 1. Modified map showing locations where soil samples were collected in Cheju rice farms [13]

The samples were dried in an oven at a temperature around 45 - 50°C for 24 hours to remove moisture content as described elsewhere [14]. The dried samples were then sieved using a 2 mm polyethylene sieve to remove plant debris and stones. After that the samples were ground using an electric grinder into fine powder in order to have the same matrix as the reference sample and be homogenized. The powdered samples were then stored in well labeled polythene bags and transferred to the Tanzania Atomic Energy Commission (TAEC) laboratory for further preparation and analysis.

For specification of the size of pellets used in this machine, 12 g and 2.7 g of soil and binder respectively were measured using a sensitive digital balance. After that, pulverizing machine was used to mix soil and binder homogeneously into uniform powder. To ensure good results, pulverizer was set to run for 10 minutes at a speed of 120 rpm. Subsequently a hydraulic press was used to compress the mixture into a pellet of intermediate size of 32 mm outer diameter under application of a pressure force of 20 tones. The resulting pellets were then kept in a holder and labeled.

The analysis of the samples was carried out using EDXRF system of the Tanzania Atomic Energy Commission in Arusha. The machine was calibrated daily before analysis of elemental composition. The tube was operated at a current of 0.5 mA and 50 kV voltage and the resulting X-rays spectra were collected by a Si(Li) detector. Each pellet was analyzed three times in repetitive condition so as to assess the precision of the analytical results. The accuracy of EDXRF sytem used in this study was determined by analyzing the Certified Reference Material, IAEA SOIL-7 standard sample analyzed with the samples.

Three different statistical methods were used to analyse the data. These were Pearson correlation analysis, cluster analysis and Principal Component Analysis (PCA). All these methods are normally used to predict sources of the elements in the soil [15]. Pearson correlation analysis measures a direct linear relationship between elements in the samples. Cluster analysis identifies groups of elements that are similar to each other but different from elements in other groups. PCA is a way of identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences. PCA reduces the number of the studied elements into a relatively smaller number of components. In this study, PCA with varimax normalized rotation was used to group the elements in the components by their factor loadings. In interpreting the PCA results, excellent association of metals was assigned for factor loadings greater than 0.70 and very poor association for factor loadings less than 0.32 [15].

3. RESULTS AND DISCUSSION

Table 1 presents the mean concentrations (±Standard Error of the Mean) for 10 elements in soil samples from Cheju and Mwera rice fields (control). Whenever the concentration was below the detection limit (MDL) of the method, a mean value equal to half of the detection limit was used in the statistical analysis instead of a missing data [16]. In this study, Shapiro-Wills test, which is recommended for testing normality of small sample size (N< 2000), was used to test the data [17]. The non-normally distributed data were logarithmically transformed to obtain a normal distribution prior to multivariate analyses.

Table 1. The mean concentrations (µg/g) of heavy metals in soil samples of rice farm and control

Element	Cheju rice field (n=60)	Control soil (n=10)
V	48.6±1.7	MDL
Cr	56.4±1.5	28.9±1.8
Mn	247±20	1023±95
Fe	29516±807	10204±524
Co	19.5±1.0	17.7±1.4
Ni	27.1±1.8	7.8±0.5
Cu	10.3±0.5	3.7±0.4
Zn	37.2±1.5	18.8±3.5
As	4.0 ±0.4	1.2 ±0.2
Se	MDL	MDL
Cd	MDL	MDL
Pb	17.1±0.3	15.9±0.8

T-test was carried out to compare mean concentrations of elements between Cheju farm soil samples and control samples. The test shows that samples from Cheju rice farm have significantly (P = 0.05) higher concentration levels of V, Cr, Fe, Co, Ni, Cu, Zn, As and Pb than the control samples. On the other hand, Mn was found to be significantly (P = 0.05) higher in samples of control than in samples from Cheju rice farm. The concentrations of Ni, Cu, Zn and As, which are normally associated with the use of fertilizers and pesticides, were found to be 4, 3, 2 and 3 times, respectively higher in Cheju rice farm than in the control samples. At the same time, concentration of Cr was found to be about 2

times the concentrations in control samples. Although the concentration of V in control samples was below MDL (27.75 µg/g), its concentration in Cheju rice farm samples was 1.7 time the value of MDL. The comparison of Se, and Cd could not be carried out as the elements were found in concentrations below MDL (0.4 µg/g for Se and 5.6 µg/g for Cd) of the EDXRF technique used in this study.

Jung [18] in Korea reported similar results as those found in this study where Cu, Zn and Pb were higher in rice farm soil samples than in control sites. Chanda et al. [19] and Rakesh and Raju [20] in India observed higher concentrations of Cr, Cu, Zn, Ni and Pb in rice farm soils compared to that of control. The results of this study agree also with the result by Moradi et al. [21] who reported higher concentrations of Cu and Zn in rice farm soils from Iran than in control samples. All these literatures associated the elevation of heavy metals in farm soil with the extensive use of agrochemicals in the cultivation of rice. The concentration levels of elements found in this study were compared with their concentrations reported by Domingo and Kyuma [22] in paddy soils of 12 countries in Asia. It was found that Cheju rice farms has lower mean levels of Cu, Zn, V, Co, and Cr and higher mean level of Ni than paddy soils of 12 countries.

In the correlation test, all significant correlations of elements were positive. Table 2 shows the correlation matrix of concentrations of elements V, Mn, Cr, Fe, Co, Ni, Cu, Zn, As and Pb considering significant value of $P \leq 0.01$. The correlation coefficient between Cu and Zn was 0.93, which indicates strong correlation $P \leq 0.01$ significance level and a common origin of these elements. Fe and Zn formed another highly correlated pair with a coefficient of 0.82 ($P \leq 0.01$) suggesting probably originated from some common source. Fe correlated also with V (0.75), Cu (0.74) and Pb (0.67). On the other hand, Ni correlated with Mn (0.62) and As (0.54).

Fig. 2 shows the cluster analysis of elements in soil samples from Cheju rice farms. Two major groups of elements could be identified. The first group was formed by six metals Cu, Zn, Fe, V, Pb and Co indicating interrelationship of these metals. In a stronger association Zn formed a subgroup with Cu which then formed another sub group with Fe at a later stage. The second group contains four elements Mn, Ni, As and Cr. Ni forms association with Mn which then forms association at a later stage with As. However, the association of elements in this group is less than the association of elements in the first group.

The results of initial eigenvalues, in Table 3, show that concentrations of the elements could be reduced into two components which account for more than 71.57% of total variance of the data. Except for Cr, Co and Pb, each heavy metal had only one factor loading greater than 0.71 on the two rotated factors. Factor one (F1) was dominated by V, Fe, Cu and Zn and accounted for 54.41% of the total variance. This indicates strong interrelationship of these elements. In this group, Cu and Zn were highly associated having high factor loadings of 0.90 and 0.93, respectively. The attribution of Cr and Pb were ambiguous, given the loading values of 0.43 and 0.56 in F1 and F2, respectively for Cr and 0.69 and 0.46 in F1 and F2, respectively for Pb. The second Factor loading (F2), which accounts for 17.16% of variance, has small number of elements with high loadings. F2 contained strongly associated group of metals Mn, Ni and As corresponding with high loadings, suggesting that these metals have similar distribution pattern. Strong association between Cu with Zn and Fe, and Mn with Ni pairs in first and second components, respectively, have been well confirmed by the result of cluster analysis.

Table 2. Pearson correlations matrix of toxic heavy metals in soils (n =60)

r	V	Cr	Mn	Fe	Co	Pb	Cu	Zn	Ni	As
V	1									
Cr	.42**	1								
Mn	.29*	.54**	1							
Fe	.75**	.55**	.37**	1						
Co	.47**	.31*	.51**	.59**	1					
Pb	.59**	.49**	.52**	.67**	.49**	1				
Cu	.70**	.39**	.53**	.74**	.58**	.63**	1			
Zn	.76**	.46**	.59**	.82**	.60**	.70**	.93**	1		
Ni	.27*	.44**	.62**	.34**	.21	.49**	.29*	.34**	1	
As	.07	.37**	.56**	.05	.27*	.35**	.05	.13	.54**	1

***. Correlation is significant at P ≤ 0.01level; *. Correlation is significant at P ≤ 0.05 level*

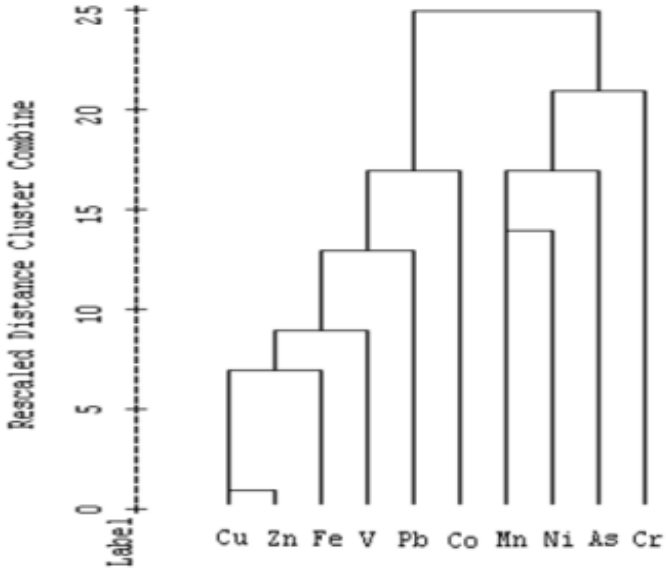


Fig. 2. Hierarchical dendrogram of the heavy metals obtained by the single-linkage clustering method

Table 3. Total variance explained and component matrixes for elements in Cheju soil samples

Extracted values of various FA parameters									
	Initial eigenvalues			**Extraction sums of squared loadings**			**Rotation sums of squared loadings**		
	Total	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**
1	5.44	54.41	54.41	5.44	54.41	54.41	4.47	44.65	40.37
2	1.72	17.16	71.57	1.72	17.16	71.57	2.69	26.92	71.57

Component matrixes				
Element	**Un-rotated component matrix**		**Rotated component matrix**	
	Factor 1 (FI)	**Factor 2 (F2)**	**Factor 1 (FI)**	**Factor 2 (F2)**
V	0.77	-0.37	0.85	0.08
Cr	0.66	0.26	0.43	0.56
Mn	0.73	0.47	0.38	0.78
Fe	0.84	-0.34	0.89	0.14
Co	0.70	-0.1	0.65	0.28
Pb	0.82	0.04	0.69	0.46
Cu	0.85	-0.34	0.90	0.14
Zn	0.91	-0.29	0.93	0.22
Ni	0.58	0.59	0.19	0.79
As	0.38	0.79	-0.08	0.87

Extraction Method: Principal Component Analysis. Rotation Method; Varimax with Kaiser Normalization

The results of Correlation, PCA and Cluster analysis are consistent on the basis of correlations between elements found in Cheju rice farms. Together they suggested that heavy metals in the Cheju soil form two main groups. The first group includes V, Fe, Cu, Zn and Pb, which are controlled by anthropogenic activities including the use of chemicals in farming. Occurrence of groups containing Cu and Zn associated with agrochemicals has been reported in paddy soils in Hong Kong and China [22-24]. The second group includes Mn, Ni, and As which might come mainly from natural source.

4. CONCLUSIONS

The results in this study have shown that samples from Cheju rice farms have significantly (P = 0.05) higher concentration levels of V, Cr, Fe, Co, Ni, Cu, Zn, As and Pb compared to the

control soils. Cheju farm is reported to use chemical fertilizers and different types of pesticides in the growing of rice. Correlation matrixes and multivariate analysis showed strong correlations between elements reported to originate from anthropogenic activities. In this study the strongest correlation were found between Cu and Zn indicating a common source. Therefore, the repeated application of fertilizer and pesticides in rice cultivation might be a source of elevated concentrations of heavy metals in Cheju farms. Heavy metals in Cheju rice farms might be absorbed by rice grown in the field and hence be introduced in the food chain. Analysis of rice grown in the field is recommended. The metals might also be leaching and be transported to Chwaka bay and hence be the source of pollution in the water, sediments and the ecosystem of Mapopwe creek. Therefore it is also suggested to conduct regular monitoring of Cheju rice farm soil in order to control heavy metal contamination in the food chain and neighboring ecosystem of Chwaka bay.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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