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Preliminary Assessment of Heavy Metals in Soil along the Vaisigano River in Samoa

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Abstract

The contamination of heavy metals in various environmental matrices is a major concern to many researchers and requires attention due to their detrimental impacts on the environment and humans as well. This research was carried out to investigate heavy metal levels in soils of some selected sites along the Vaisigano river in Upolu, Samoa. The soil samples were also analysed for physicochemical parameters such as pH, Electrical Conductivity, Moisture Factor, Cation Exchange Capacity (CEC), Organic Carbon, Nitrogen, Phosphorus, and Soil texture. The mean concentrations of heavy metals at the Lelata site were 0.19 ± 0.05 mg/kg (Pb), 0.37 ± 0.45 mg/kg (Mn), 0.15 ± 0.02 mg/kg (Zn) and 0.56 ± 0.42 mg/kg (Cu). The mean concentrations of heavy metals at the Alaoa site were 0.13 ± 0.03 mg/kg (Pb), 0.42 ± 0.51 mg/kg (Mn), 0.16 ± 0.03 mg/kg (Zn) and 0.45 ± 0.43 mg/kg (Cu). The heavy metal concentrations from both sites were lower than the permissible levels given by the World Health Organization (WHO). The Geo-accumulation pollution index (I(geo)) of heavy metals in the Lelata site was Cu > Mn > Pb > Zn and from the Alaoa site was Cu > Pb > Zn > Mn.

Keywords

Toxicology, Land-Use, Agriculture, Pollution Index, Samoa

1. Introduction

Pollution by heavy metals in the various environmental matrices including soil is one of the major global and local concerns nowadays. Chronic exposure to these metals can have serious health consequences. Humans are exposed to heavy metals through inhalation of air pollutants, consumption of contaminated drinking water, exposure to contaminated soils or industrial waste, or consumption of contaminated food [1]. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Examples of some heavy metals are harmful to humans but not limited to iron (Fe), zinc (Zn), cadmium (Cd), copper (Cu), nickel (Ni), chromium (Cr), and lead (Pb) [2]. Soils are open systems that undergo continuous exchange with the atmosphere, hydrosphere, and biosphere. It is also the basic resource for living organisms and the most fundamental element of human production [3]. Soil heavy metals are divided into two categories based on biochemical (one is harmful to crops and humans and animals, such as Cd, Pb, and Hg and biological characteristics (when excessive, it will damage biological, such as Cu, Zn, Mn) [4]. In addition, the adverse effects of heavy metals on soil's biological and biochemical properties are well documented. The studies on the organic matter, clay contents, and pH and their influences on the extent of the effects of metals on biological and biochemical properties were well documented [5] [6]. In addition, the contamination of soil with heavy metals is common and it can be a major source of metals to crops and finally end up in the food chain [7]. There is mounting evidence from scientific reports that were documented identifying heavy metals as significant contaminants of vegetables being grown in and around soils in agricultural areas all over the world [8] [9]. The uptake of heavy metals by plants and subsequent accumulation along the food chain is a potential threat to human health [10]. Numerous reports indicated that consuming food contaminated with heavy metals can seriously deplete some essential nutrients in the body that are responsible for intrauterine growth retardation disabilities associated with malnutrition and high prevalence of upper gastrointestinal cancer rates and decreasing immunological defenses [11] [12]. From the evidence that was documented on the impact of heavy metals on various environmental matrices, there is a clear indication that heavy metals from agricultural and industrial activities instigate wider environmental problems and health hazards around the world. Soil heavy metal pollution is closely related to anthropogenic activities such as agricultural production, vehicle exhausts, unregulated waste disposal methods, smelting activities, and industrial manufacturing instigating the accumulation of heavy metals in the soil [13] [14].

The common pollution indexes for studying heavy metal pollution in various environmental matrices have been well documented including the Enrichment Factor [15] the Geo-Accumulation Index [16] [17] the Nemerow Pollution Index [18], and the Biogeochemical Index [19]. The most widely applied heavy metals estimation index method called the Geo-accumulation index (I(geo)) was used in this study to determine the level of contamination of heavy metals in the soil of selected sites. The information on the levels of heavy metals in soil in Samoa is very limited, hence, this study aimed to investigate the levels of selected heavy metals in soil samples collected from the selected sites along the Vaisigano River.

2. Methodology

2.1. Study Area

Samoa is a small, volcanic Pacific Island nation that lies between latitude

13˚45'26", and longitude 172˚6.278'W (**Figure 1**). There are four inhabited and four uninhabited islands (**Figure 1**) giving a total land area of about 2935 km^2 [20]. The bulk of the nation comprises the two largest islands of Upolu and Savaii with land areas of 1820 km^2 and 1113 km^2 respectively [21]. The two field sites along the Vaisigano River, the Lelata (13˚266'50"S, 171˚W 859'46"W and Alaoa (13˚377'52"S, 171˚205'45"W) were selected as typical residential and agricultural areas.

2.2. Soil Sampling

A composite sampling was used to collect each soil sample from the two selected soil sites. A 30 m measuring tape was laid in a zig-zag position to have different margins of the chosen area instead of a straight-line extraction which would have not been represented. An auger was used to drill each point marked, 30 cm deep into the soil. There were about three sub-samples from each of the two selected sites, transferred into a plastic bag and tied tightly to prevent any excess moisture or air from entering the samples as they were transported to the laboratory straight after a day later the most. The samples were then air-dried in an open, screen-wired room for a week before extraction and analysis.

2.3. Extractables

In the extraction stage, 10.0 g of soil was weighed from the air-dried, 2 mm sieved patch and transferred into a polypropylene centrifuge tube with a screw cap. For each element patch measurement, two reagent blanks were included before the addition of 20 mL of extracting reagent. For over two hours, the tube was inserted in an end-over-end shaker to be shaken. At 2000 rpm for 15

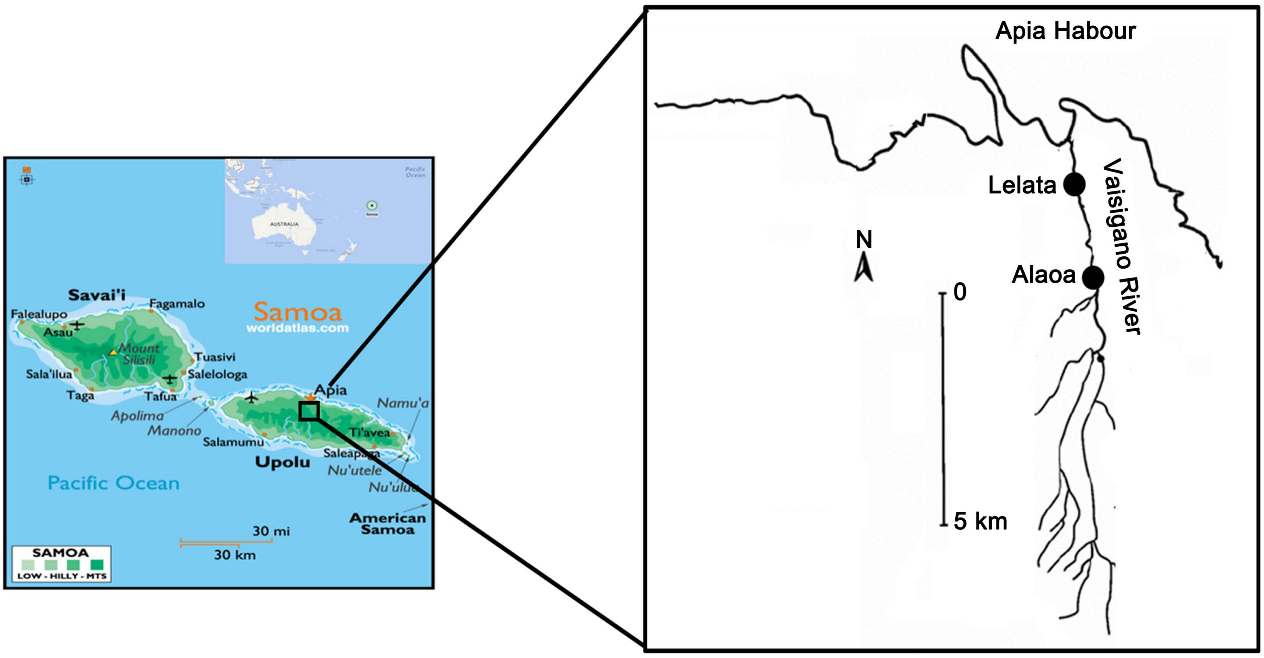

Figure 1. Location map of the study area [22] [23].

minutes the tube was centrifuged and filtered through a No.1 Whatman filter paper to achieve a clear filtrate. The second stage of the procedure is the determination of the concentration for each nutrient, which was directly determined in the filtrate within one day of extraction using an Atomic Absorption Spectrophotometer (AAS). The heavy metal concentrations (Pb, Mn, Zn, Cu) in the soil were determined using the SPACNET method employed at the Scientific Research Organisation of Samoa (SROS). A composite sampling was used to collect each soil sample from the two selected soil sites. A 30 m measuring tape was laid in a zig-zag position to have different margins of the chosen area instead of a straight-line extraction which would have not been represented. An auger was used to drill each point marked, 30 cm deep into the soil. There were about three sub-samples from each of the two selected sites, transferred into a plastic bag and tied tightly to prevent any excess moisture or air from entering the samples as they were transported to the laboratory straight after a day later the most. The samples were then air-dried in an open, screen-wired room for a week before extraction and analysis.

2.4. Statistical Analysis

Statistical analysis was done using the Statistical Package for Social Sciences (SPSS) software. Descriptive and inferential analyses were considered to seek the differences in means across each variable across the period of the study and the selected sites using the One-way analysis of variance (ANOVA) at $p = 0.05$ level of significance.

3. Results and Discussion

The statistical analyses of the physicochemical parameters of soil samples collected from the two sites are summarised in Table 1 below.

The pH of the soil samples analysed ranged from 6.43 to 6.81 indicating that the soil in the area studied is weakly acidic. The values obtained from this study were slightly more acidic than the values reported by [24]. The moisture factor

Table 1. Physicochemical parameters.

Parameters	Lelata	Alaoa
pH	6.81 ± 0.01	6.43 ± 0.03
Moisture Factor (%)	10.71 ± 0.01	10.90 ± 0.01
Electrical Conductivity (mS/m)	33.92 ± 8.65	36.40 ± 4.15
Cation Exchange Capacity (CEC) (meq/100g)	15.72 ± 1.06	20.48 ± 4.52
Organic Carbon (%)	1.46 ± 0.22	2.21 ± 0.82
Nitrogen (%)	0.14 ± 0.03	0.29 ± 0.09
Phosphorus (%)	10.21 ± 3.11	12.54 ± 2.01
Soil Texture	Sandy Loam	Sandy Loam

values ranged from 10.71% to 10.90% respectively for both sites and the overall is within the optimum levels of soil moisture ranging from 10% to 18% reported [25] [26]. The cation exchange capacity (CEC) of the soil samples was found to be 15.72 and 20.48 (meq/100g) respectively. For both sites, the means prove that are significantly different statistically ($p < 0.11$). The highest level of EC was found in the samples collected from the Alaoa site (36.40). The values obtained from this study are slightly lower than the values reported for Samoa and globally [27]. The organic carbon (OC) of the soil samples from all sites ranged from 1.46% to 2.21% respectively. The means have proved that is not significantly different ($p < 0.05$).

Heavy metals were detected in all soil samples collected at both sites and the concentrations are shown in **Figure 2** below. Lead was the second most abundant heavy metal in both sites. The levels of Pb in both sites (0.15 - 0.26 mg/kg) were lower than the maximum permissible level of 85 in the soil as given by [28]. These levels of Pb observed at the study site are not of great concern at present. The levels of Mn at the Lelata site (1.04 mg/kg) are higher compared to the Alaoa site (0.18 mg/kg). This could be due to vehicle exhausts and the runoffs from the residential area near the Lelata site. Copper with the highest heavy metal (0.54 mg/kg) at the Lelata site and the highest in the Alaoa sites (1.10 mg/kg). The mean concentrations from both sites are shown in **Figure 2** below. The concentration of heavy metals in all soil samples was below the maximum permissible levels (WHO). The result of this study in all soil samples from both sites is most likely attributed to anthropogenic activities including runoffs from the residential area for Lelata and the agricultural activities for the Alaoa site.

According to the I(geo) pollution index, the I(geo) of heavy metal pollution in the Lelata site was Cu > Mn > Pb > Zn, and from the Alaoa site was Cu > Pb > Zn > Mn indicating that the heavy metal pollution is slightly serious in Lelata than in Alaoa. The results revealed that both sites are contaminated by Cu. The sources could be vehicle exhausts and runoffs from residential households near the site. A similar trend was seen in Hangzhou, China by [29] who reported that the main pollution sources of heavy metals were agricultural activities (Cu, Cd,

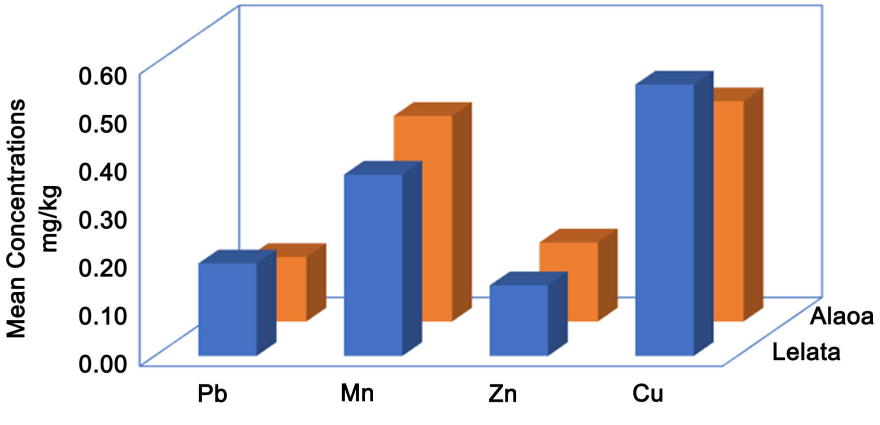

Figure 2. Mean concentrations of heavy metals (mg/kg).

Table 2. I(geo) values for the Lelata site.

Heavy metals	$I_{(geo)}$ values[1]	$I_{(geo)}$ Class[2]	Level of Contamination Classification
Pb	1.53	2	Moderately contaminated
Mn	2.66	3	Moderately to heavily (strongly) contaminated
Zn	0.19	0	Uncontaminated
Cu	2.17	3	Moderately to heavily (strongly) contaminated

Table 3. I(geo) values for the Alaoa site.

Heavy metals	$I_{(geo)}$ values	$I_{(geo)}$ Class	Level of Contamination Classification
Pb	0.74	1	Uncontaminated to moderately contaminated
Mn	−0.34	0	Uncontaminated
Zn	0.31	1	Uncontaminated to moderately contaminated
Cu	3.20	4	Heavily (strongly) contaminated

As), transportation emissions (Cu, Pb), coal combustion (As, Hg) and smelting activities (Zn, Pb, Cu). The concentration of heavy metals reported in this study is lower than the values reported in other studies [30] [31] [32]. However, consistent monitoring of heavy metals in soil and other matrices ensures the environment is safe and pollution-free from heavy metals.

The Geo-accumulation index (I(geo)) from each site is shown in Table 2 and Table 3.

4. Conclusion

The results from this study have revealed that the levels of Pb, Mn, Zn, and Cu do not exceed the permissible limits in soil. The heavy metal pollution index revealed that the soils are slightly contaminated by heavy metals but not too serious. The physicochemical parameters such as pH, moisture factor, electrical conductivity, CEC, organic carbon, nitrogen, phosphorus, and soil texture were analysed and most of these parameters were within the permissible limits set by the WHO. The results obtained from this study advocate for monitoring emerging threats of heavy metals on the soil ecosystem which have significant importance to the livelihood of the local communities in Samoa.

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[1] Calculated using $I_{(geo)} = \log_2(C_n/1.5B_n)$.

[2] Muller, 1969.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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