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COMPARATIVE STUDY ON SOIL POLLUTION WITH TOXIC SUBSTANCES ON FARMLANDS CLOSE TO OLD AND NEW INDUSTRIAL SITES IN ETHIOPIA

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ABSTRACT. Surface and profile soil samples from a Luvic Kastanozem at Awassa (Ethiopia), and Pelli Eutric Vertisols and a Vertic Fluvisol at Akaki (Ethiopia) were collected and analyzed for their total heavy metal contents. It was found that Cr and Ni have reached the toxic levels in the Vertisols at Akaki. There is a tendency that the other metals will also reach this level, unless the situation is improved soon. At Awassa, subsurface soil content of some metals surpass that of surface soil, an indication of rapid transport to ground water. Damage to growing crops and causalities of cattle and fish are also witnessed in Awassa. Human health is also endangered because vegetables and other crops grown on contaminated lands are being sold in the open market at the cities.

INTRODUCTION

The advent of industries in the big and small towns in developing countries like Ethiopia, is an encouraging phenomenon, when seen from the perspectives of economic and social development of a nation. Such development prospects, however, can be threatening and leading towards a horrifying environmental disaster, unless industrial wastes are avoided or monitored and disposed at recommended safe sites.

Proper disposal of industrial wastes is primarily necessary to safeguard crop plants from contamination with heavy load of toxic substances from affected soils and to hinder leaching of these substances into the ground water. This fact must regularly be brought to public awareness in developing countries like Ethiopia, where industrial wastes are drained into farm lands for irrigation purposes, without anticipation of the grave consequences that follow.

At Akaki, which is one of the oldest industrial towns in the country, vegetables like cabbage, Swiss chard, onion, potato, and red beet are extensively grown throughout the year along the banks of Akaki river. The liquid waste from the nearby textile industry together with the Akaki river water, which is also contaminated with the industrial wastes, are directly applied to irrigate these crops. The vegetables at harvest reach large number of consumers in the capital city, Addis Ababa. At Awassa (which is comparatively a recent industrial town), liquid waste from the textile industry there, drains into farmer's fields (mainly maize and "inset'' farms) and eventually to Lake Shallo which later on joins Lake Awassa. Terrestrial and aquatic life is very much endangered at both sites.

Contamination by heavy metals (which are major contributors of toxic substances) is not restricted to the soil alone, but goes beyond that, affecting every component in the food chain, namely: plants, grazing animals, and ultimately man himself. Air and aquatic environments including the sea foods of both plant and animal origin like fish are subject to this hazard [1]. Likewise, causalities of grazing animals and fish have been reported from Awassa.

Metals may accumulate rapidly in soils, but are removed from soils through leaching, plant uptake, erosion, or deflation very slowly, requiring time spans of centuries or even millennia [2]. Such persistence of contaminants in soil, make soil pollution far more serious than either air or water pollution. So far, no such work has been carried in the country and hence no critical limits have been set for the deficiency, sufficiency or toxicity of heavy metals (As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se, and Zn).

The objective of this study is to assess the extent of heavy metal contamination of Akaki and Awassa soils. The results of the study will help to predict the rate of heavy metal build-up within a given period of time and to the knowledge of entrance of toxic metals into the food chain. Ultimately, awareness will be created to all involved namely farmers, policy makers, environmentalists, etc. so that the magnitude of the problem will be appreciated and alternative ways of waste disposal will be sought.

MATERIALS AND METHODS

The soils used in this work were surface and profile samples from a Luvic Kastanozem at Awassa, and surface samples from Pelli-Eutric Vertisols and a Vertic Fluvisol at Akaki. At Awassa, five different core samples were taken at 25 m interval from the entrance of the liquid waste in the farm land along the drainage line. At Akaki, the sampling was made at 50 m intervals at different physiographic positions (summit, shoulder, backslope, footslope and toeslope positions). The drainage line does not pass through the summit position, and hence this position is not directly subjected to contamination with industrial liquid waste. The soil samples were then air dried and passed through a 2-mm mesh sieve.

Total analysis of the elements (As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se, and Zn) was made by extracting the soil sample with aqua regia. About 5 g of each of the soil samples was weighed in a 250 mL Erlenmeyer flask to which was added 45 mL HCl and 15 mL HNO_3 sequentially. These were covered with convex glasses and let to stand overnight. Later, the samples were gently heated on a sand bath for two hours. Afterwards, about 200 mL of deionized water were added to the samples to the 250 mL mark, thoroughly mixed, and filtered with Whatman filter paper. The filtrates were collected into polythene bottles. Fifty mL aliquots of the filtrate were used for the analysis of metals. Hg, As, and Se were determined using a sequential ICP-OES (inductively coupled plasma optical emission spectrometer), model PS 1000, Leeman Labs Inc., USA. It was equipped with a grid nebulizer and the plasma was normally operated at 1 kW. Cd, Co, Cu, Ni, Pb, and Zn were determined using atomic absorption spectrometer (Varian Model Spect AA 200, Australia) with air-acetylene flame, while Cr was determined with nitrous oxide acetylene flame.

Soil pH was determined at ionic strength of 0.01 M $CaCl_2$ solution (1:2.5) using a pH meter [3]. pH values are expressed according to a teaching guide book in soil science [4]. CO_3^{-2} was determined with Wösthoff apparatus (Germany) against a $CaCO_3$ standard. Organic matter was determined by C:N analyzer through gas chromatography (CARLO ERBA NA 1500) [3]. Organic matter and carbonate contents are expressed according to reported method [5].

RESULTS

The pH (0.01 M $CaCl_2$) of the contaminated Awassa soils ranges between weakly alkaline (7.5) to medium alkaline (8.4) (Figure 1). The pH of the uncontaminated surface soil found in Akaki at summit position is weakly acidic (6.4). The pH of the other surface samples at Akaki ranges between weakly alkaline (7.1) to medium alkaline (8.3).

Organic matter contents of the Awassa contaminated surface soils ranges from medium (2.69%) to strongly humic (5.47%) (Figure 1). At Akaki also, the organic matter ranges between medium (3.18%) to strongly humic (4.62%). Organic matter tends to decrease with physiographic position (summit to toeslope) in Akaki. The surface soils at Awassa and Akaki generally have very small carbonate contents (Figure 1). In Awassa, carbonate content ranges between very poor (0.22%) to poor (0.81%). At Akaki, it ranges between very poor (0.07%) to weakly carbonated (2.83%).

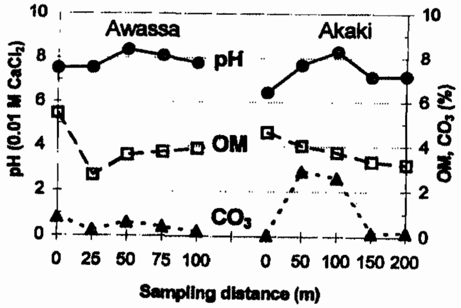

Figure 1. Selected chemical properties of Awassa and Akaki surface soils.

Soils at Akaki (the oldest industrial site) contain about 4 to 5 times more total Pb, Ni, Cu, Cr, Hg, and Co than Awassa soils and about twice as much As. Zn contents do not seem to differ much, although Akaki soils still have slightly higher contents (Figure 2). On the other hand, the site at Awassa contains slightly more total Cd than the site at Akaki and about twice as much Se.

So far, the heavy metal build-up at Awassa has not reached the "toxic level", but in Akaki, chromium and nickel contents of the contaminated soils have reached the "toxic levels", according to critical limits set by Hein and Schwedt [6]. According to Lindsay [7], lead levels at Akaki midslope positions have surpassed the average content (10 ppm) for most soils (Figure 2).

Profile contents of Awassa also indicate vertical contamination, thus endangering the situation for safe ground water. Especially with As, Cd, Cr, Hg, Ni, and Pb, the contamination is much stronger in subsurface horizons than surface horizons (Figure 3). Heavy metal build-up (particularly Cd, Cu, Ni, Pb, and Zn) sideways (up to 30 m radius from drainage line) is sometimes much stronger than from the disposal route (Table 1).

Table 1. Metal contents (mg/kg) of undisposed soil samples sideways from major disposal route.

Designation	As	Cd	Co	Cr	Cu	Hg	N	Pb	Se	Zn
L1 (15 m left)*	212	0.28	6.82	18.32	12.26	0.018	12.11	5.59	0.51	128.32
L2 (30 ml eft)	229	0.31	2.81	19.91	14.29	0.02	13.93	4.55	0.53	123.94
R1 (15 m right	207	0.25	2.05	20.05	11.21	0.02	12.66	5.71	0.46	109.01
R2 (30 m right)	208	0.23	1.88	18.51	10.04	0.019	12.69	5.51	0.38	96.08

*** Measured horizontally from major disposal roate.**

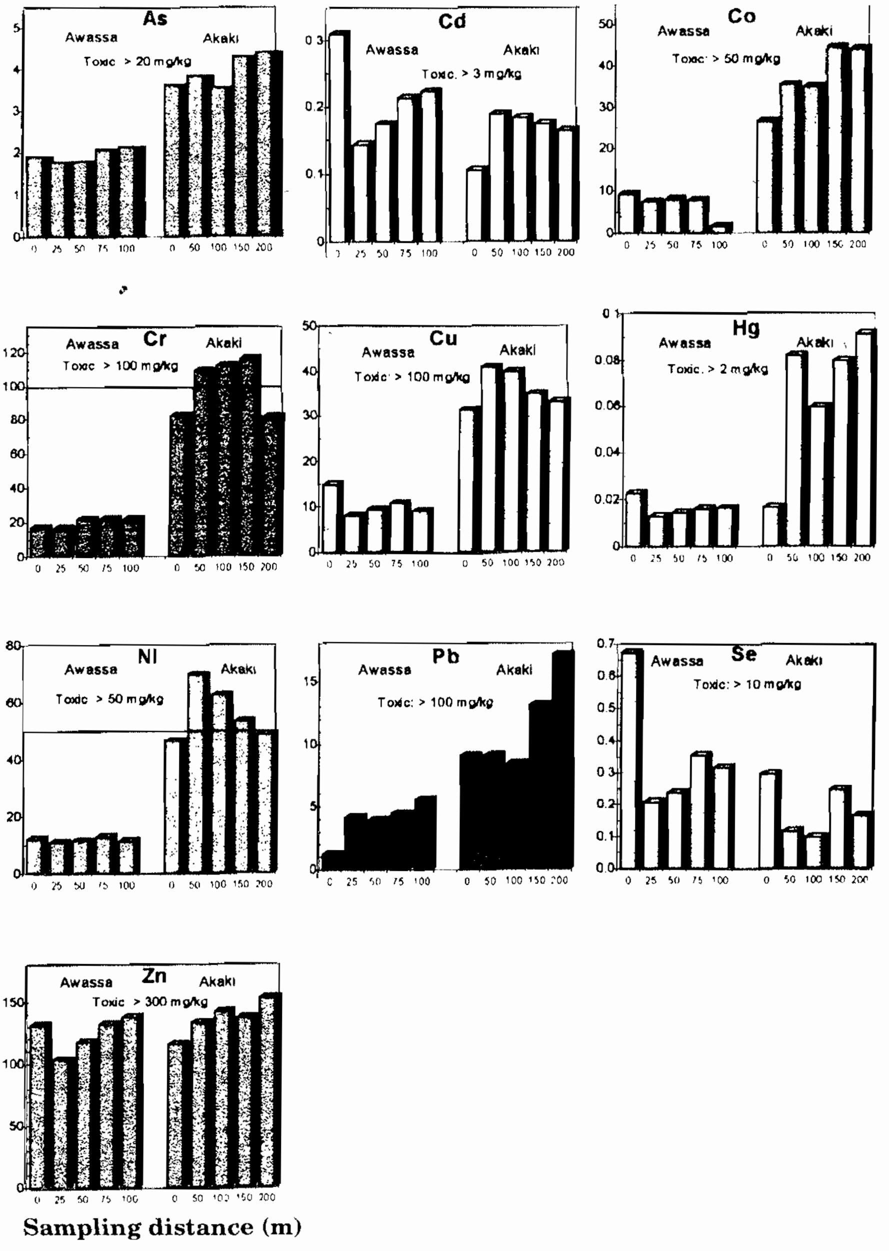

Figure 2. Heavy metal concentrations of contaminated soils at Awassa and Akaki, Ethiopia.

Accumulation of heavy metals on the farmlands does not follow the same pattern for the different elements. With the exception of the initial position of waste entrance into the farmland at Awassa, which has relatively the highest contamination value, toxic metal build-up tends to increase as one goes further away from the disposal site, specially with As, Cd, Cu, Hg, Se, and Zn. Cr and Pb tend to gradually build up along the drainage line, right from the start, as one goes further away from the entrance site. Cobalt shows a decreasing trend while nickel does not show any significant difference along the drainage line (Figure 2).

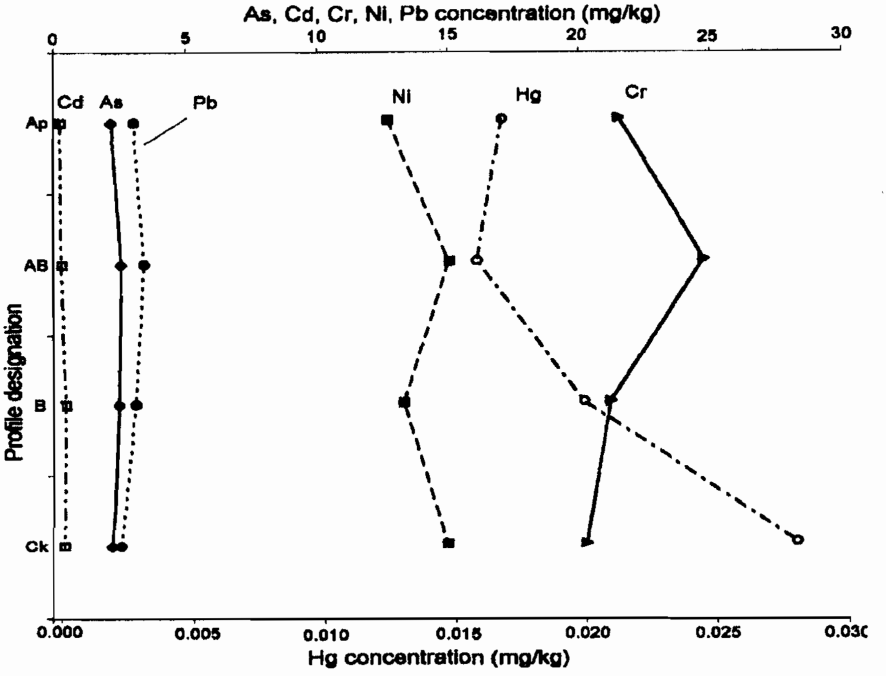

Figure 3. Metal distribution in a Luvic Kastanozem at Awassa.

On the other hand, the soil at summit position in Akaki, is collected from a farm site where no industrial waste enters, and hence the metal contents are generally lower than the values at the other physiographic positions. Therefore, excluding the soil at summit position, one can observe that Cd, Cu, and Ni contents decrease as one goes away from the entrance site and decreases with altitude. Ni and Cr, "toxic levels" have reached between shoulder to footslope positions (only in the Vertisols).

Surprisingly enough, though no industrial waste directly enters into the soils at summit position at Akaki, the heavy metal build up is generally higher (mostly more than double) than Awassa soils into which industrial waste drains directly.

As far as the visually observable damage caused due to industrial waste on farmlands is concerned, maize plantations at Awassa are seen to have been affected seriously both in yield and quality of crop and the entrance into the nearby lake and seepage underground is a clear indication of the water pollution as well.

DISCUSSION

pH, organic carbon, and carbonates are among several components of the soil which affect the availability, retention, and mobility of metals. Therefore, knowledge of the different forms in which the metals exist is very important to discuss the influence of the above parameters.

Several studies show decreased availability of many of these metals with increasing pH [8]. In one study, it has been indicated that soils under differing cropping systems exhibit similar adsorption behavior with respect to solution pH [9]. The pH values at the study sites also indicate a general high tendency of lower availability of these metals. Hence, this is a favorable natural mechanism reducing risk of at least plant uptake.

It has been reported that there is a linear relationship between some of these metals and organic matter [10]. The organic matter contents of the study sites are sufficient to contribute to an increased total metal content. However, as stated above, fractionation of the different forms of the heavy metals is necessary to see which form has the greatest impact.

The entrance of liquid wastes directly into farmlands in Akaki and Awassa is a very endangering situation. Boekhold *et al.* [11] have reported that leaching and plant uptake of contaminants is very much dependent on the concentration of the contaminants in the soil liquid phase. This is because it is the liquid phase which can be transported to underlying layers and from which plant roots remove water and nutrients. In another study [12], it has also been expressed that the concentration of a pollutant in the soil solution is a better indicator of potentially adverse effects than its total content in the soil.

There is more build-up of toxic substances in Akaki than in Awassa, obviously because the heavy metal build up is a gradual process and hence farmlands closer to older industrial sites suffer greater. Analysis of the dyeing materials has to be made in order to say why the Awassa soils contain more Cd and Se.

In neutral to alkaline soils, as is the case with Akaki soils, chromium(VI) species are anionic and generally mobile [13]. This may be one reason why there is a high build up of this element. Ni^{2+} enrichment may be due to increased ionic strength as the soil approaches neutrality [14]. This was so justified because Ni^{2+} adsorption was accompanied by an equivalent Ca^{2+} desorption, indicating that all Ni^{2+} ions were retained at sites previously occupied by Ca^{2+} [14].

As discussed earlier, the uncontaminated soil sample from Akaki still contains more contents of the heavy metals than Awassa soils. This is mainly because although industrial waste does not drain through this soil, it is contaminated from emissions or through seepage from ground water. Sheppard and Thibault [15], have reported that unsaturated soil receives atmospherically transported particulates and gases from near and far at its surface and at its lower boundary through ground water.

There is a general lack of awareness in Ethiopia, on the adverse effect industrial wastes bring on human, animal, plant and the environment and also on the difficulty and cost of reclamation of polluted lands. In the industrial world, remediation technologies consist of removal and replacement of contaminated soils [16], or phytoremediation through plant species which are able to hyperaccumulate metals in plant shoots [17,18], or through biodegradation. All the above are very costly and high tech exercises which developing countries like Ethiopia can not afford.

CONCLUSIONS

Results of analysis show that toxic metal build-up will reach threshold levels in . years, unless direct entrance of waste disposal into farmlands is abated. As seen a Awassa, with some heavy metals, these levels could be reached even in shorter periods depending on the content of industrial waste, rate of entrance, soil conditions, protection measures, etc.

From the result of analysis of the sample at summit position at Akaki, it is easy to determine that it is not only sites directly receiving waste disposals which are affected but also closeby regions which may be contaminated through emissions or ground water seepage. Hence proper planning of industrial sites and selection of the appropriate disposal sites are very important considerations.

Farmers need to be advised regularly not to use industrial liquid wastes as sources of irrigation water. Consumers should also be made aware that crops grown on such farms are not safe for human health. Extension agents can play a big role on this, through field days and/or demonstrations.

The matter at this stage is identification of the extent of heavy metal build-up and creation of public awareness. In subsequent works, fractionation of the heavy metals will ensue to point out as to which form plays a bigger role in the pollution. It is also to be seen how crop and soil management techniques can ameliorate the situation.

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