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Irrigation-Induced Infiltration and Recharge: Implication for Groundwater Quality

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Abstract: This study focuses on the quality impact assessment of irrigation-induced infiltration and recharge under amended agricultural fields on shallow groundwater systems using experimental pilot green-house set-up. The results show that irrigation leachate analyses under Waste-Dump Soils (WDS), Organomineral and NPK-amended soil substrates planted with a common edible vegetable crop (*Amarantus* species) exhibited 1.6 to 52.4 fold enrichment of Cu, Zn, Co and Ni under both Waste Water Irrigation (WWI) and Fresh Water Irrigation (FWI). However, the observed depletion of Pb, Cd and Cr can be attributed to possible uptake by the vegetable crop and enrichment in the residual soil as reflected by the estimated Enrichment Factor (EF) of >1.0. Despite depletion in the originally amended soils, the enrichment of Cd, Cr, Co and Ni in the NPK and organo-amended residual soils and irrigation leachates under WWI and FWI, points to the negative impact of wastewater irrigation and irrigation-induced leaching/mobilization of trace metals even at low concentrations. Also, the residual soils (after harvesting) when compared to the un-amended virgin soils exhibited positive enrichment with respect to Cu, Pb and Cd. However, only residual WDS exhibited enrichment with respect to Cr, Co and Ni, while the depletions in the other substrates (Orago and NPK-amended) imply that the organo and NPK-amendment do enhance enrichment of these metals in the residual soils. Nonetheless, the overall assessment shows a higher solubility and mobility of potential toxic trace metals in leachates from NPK-amended soils with leachate EF of 30.4 to 64.0 compared to (EF of 2.1-9.2 for organominerals-amended soils and EF of 6.4-8.9 for waste dump soils under both WWI and FWI. Furthermore, the observed enrichment in the residual soils imply potential sources of trace metal contaminations through leaching, long after harvest, with attendant negative impacts on the shallow groundwater quality.

Key words: Leachates, organominerals, NPK-fertilizer, waste-dump soil, trace metals, shallow groundwater

INTRODUCTION

Recent developments regarding sustainable water resources management have led to increased reuse of treated and untreated wastewater as irrigation water and/or as a means of artificial aquifer recharge. Also, the developments in agricultural practices have resulted in widespread use of both organic and inorganic soil amendments as well as other agricultural chemicals to boost agricultural production (Shiralipur *et al*., 1992) in the face of ever increasing world population. While such agricultural practices are usually coupled with appropriate management policies to ensure sustainable agriculture and water management, especially in the developed countries, such combined water and agricultural practices are not usually coupled with appropriate management practices to ensure sustainable agriculture and water management in the developing countries (He *et al*., 1992).

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Consequently, such emerging agricultural practices in many developing countries like Nigeria are characterized by negative environmental impacts on shallow groundwater quality as a result of infiltration-induced leachates from agricultural fields. Therefore, with the increasing use of fertilizers, biosolids and other related amendments to boost agricultural production and increasing reuse of treated and untreated wastewater as irrigation water, especially in the developing regions of the world, there is need to adequately assess the possible environmental impacts of such application and agricultural practices in terms of:

- Possible contaminant trace metals enrichment of irrigated agricultural soils with attendant effects of possible uptake by food plants through soil-plant transfer under amended agricultural fields.
- Possible vertical leaching/transport of contaminant trace metals (from waste water irrigation) into the shallow groundwater systems.

Although the potential positive contribution of municipal waste-based organo-minerals and inorganic NPK-fertilizer as amendment or nutrient supplements to boost agricultural food production are not in doubt, there had been reservation about the possible negative impacts of widespread applicability (Stratton *et al*., 1995; Cao and Hu, 2000; Bhattacharyya *et al*., 2006). This is due to possible trace metal enrichment of soils and attendant possible uptake by crop plant and contamination of food chain (Alva *et al*., 2000; Brun *et al*., 2001). Furthermore, there are insights into the potential of vertical leaching of trace metals and other agricultural chemicals leading to contamination of the shallow groundwater system under such amended agricultural soils (McLaughlin *et al*., 2000; Bhattacharyya *et al*., 2004). Hence, this study focuses on the quality impact assessment of irrigation-induced leachates under amended agricultural fields on shallow groundwater systems using a pilot experimental green-house. The overall evaluation highlights the danger of enrichment of toxic trace metals under biosolid/organomineral amended soils vis-à-vis impacts of irrigation-induced leaching on the shallow groundwater quality.

MATERIALS AND METHODS

The study which focuses on environmental impacts of agricultural amendments was conducted between April and June 2007 at the Department of Geology, University of Ibadan, Nigeria. The study approach involved a pilot experimental (greenhouse) set-up of test plots in four plastic troughs (40×47×46 cm) filled with 11 cm of topsoil and 23 cm of subsoil taken from 0-60 cm soil profile of fallowed arable lands. The basal part of the troughs was filled with a 3 cm gravel-filter pack of 9.52 and 4.75 mm fractions (with the coarser fraction at the bottom) to enhance basal permeability and collection of filtrate/leachate. The top 6 cm of the soils in the different troughs were amended separately with NPK-fertilizer and organominerals and allowed to homogenize for two weeks prior to planting with a common edible vegetable crop (*Amarantus* species) under wastewater irrigation (WWI) and freshwater irrigation (FWI). For the purpose of evaluation, a selected waste-dump soil and control a test trough without any amendment, but with only fresh water irrigation, were also planted with the selected vegetable plant.

Subsequent to planting and scheduled irrigation timings, filtrates/leachates were periodically collected at the bottom of the perforated troughs (test plots) for the determination of physico-chemical parameters such as pH, EC and TDS and chemical analyses of trace elements compositions following standard analytical procedures using ICP-OES and ICP-MS. In addition, samples of the primary virgin (unamended) soil, amended soil substrates before planning and residual soils subsequent to harvesting were separately collected, air-dried and gently grinded using porcelain mortar followed by sieving through a 300 μm (#50) mesh. The sieved samples were separately subjected to geochemical analyses for the determination of the trace metals concentrations. Also irrigation water samples and respective leachate samples were collected in plastic bottles and immediately acidified with HNO_3 and stored at 4°C prior to chemical analyses of the trace metal concentrations. Standard sampling and preparation and preservation procedures were strictly followed in the collection of soil and water samples while all the laboratory geochemical analyses were carried out at the Activation Laboratory, Ontario, Canada.

RESULTS AND DISCUSSION

Assessment of Amended Substrates and Residual Soils

Summary of the results of geochemical analyses of trace metals for the amended soils and the respective residual soils under WWI and FWI are shown in Table 1. As indicated water-soluble pH of 5.4-7.2 suggest a generally slightly acidic substrates, however, the measured water-soluble Electrical Conductivity (EC) show a marked difference between WDS and organomineral-amended soils on one hand and NPK-amended soil on the other hand (Table 1). While WDS and organomineral-amended soils exhibited EC of 2,100-2,160 μS cm^{-1}, NPK-amended soils exhibited EC value of about 32,000 μS cm^{-1}. This can be clearly attributed to relatively rapid or fast solubility of the metal salts in the NPK-fertilizer compared to the organically bounded forms in the WDS and organomineral-amended soils (Adriano, 1992).

With reference to the primary un-amended virgin soil, WDS exhibited high concentrations of all the analyzed metals (1.6-989 ppm) compared to NPK-amended (0.03-55.2 ppm) and organomineral amended (0.07-51.1 ppm). This, as expected, is a clear indication of the fact that WDS is a product of composted waste materials from varied contaminated sources enriched with most (if not all) of the analyzed trace metals. This is clearly demonstrated by the estimated enrichment factors of 1.1-34.1 for all the analyzed metals in the WDS compared to the enrichment of only Cu, Pb and Zn (EF = 1.1-1.9) and depletion of Cd, Cr, Co and Ni (EF = 0.6-0.94) in the NPK-amended and organomineral amended soils (Table 2). Therefore, prior to planting of the vegetable crop, the WDS is contaminated with Cu, Pb, Zn, Cd, Cr, Co and Ni while NPK-amended and organomineral amended soils are contaminated with only Cu, Pb and Zn compared to the primary unamended virgin soils.

After harvesting, the residual WDS and NPK-amended soils exhibited slight enrichment (EF > 1) of almost all the analyzed trace metals with exception of Zn with EF < 1 (Table 2) under both WWI and FWI. While this is an indication of contamination of other metals, it also signifies the uptake of Zn as an essential element for plant growth. However, the organo-amended residual soils revealed slight depletion of all the analyzed metals under both WWI and FWI suggesting uptake by the planted vegetable crop and/or leaching by irrigation water. Furthermore, a graphical presentation of the analyzed trace metal profiles in the different substrates as presented in Fig. 1 revealed enrichment of

Table 1: Geochemical analyses results (in ppm) of amended soil substrates and residual soils under WWI and FWI

Parameters	pH	EC	Cu	Pb	Zn	Cd	Cr	Co	Ni
Organomineral amendment			212.0	36.00	315.0	0.24	22.7	4.3	8.8
NPK-amendment			29.2	2.37	9.9	0.02	1.2	1.0	2.1
Virgin (unamended) soil	6.7	337	12.4	13.00	29.0	0.05	21.8	14.0	15.0
Organo-amended soil	6.8	2,100	20.0	16.70	51.1	0.07	20.6	12.4	11.7
NPK-amended soil	5.6	32,700	13.7	11.30	55.2	0.03	17.1	10.8	10.9
Waste-dump soil	5.4	2,160	120.0	102.00	989.0	1.58	37.4	14.7	24.2
Organo-RS (WWI)	7.2	503	15.9	15.80	41.3	0.06	20.4	12.1	11.2
Organo-RS (FWI)	6.2	271	16.9	15.00	44.8	0.07	18.3	12.3	10.6
NPK-RS (WWI)	5.5	1,734	13.6	12.50	21.5	0.06	17.6	13.1	11.1
NPK-RS (FWI)	6.1	820	17.0	12.20	35.3	0.06	18.3	12.1	11.2
WDS-RS (WWI)	6.0	2,300	123.0	91.80	786.0	1.37	39.7	14.8	26.5
WDS-RS (FWI)	6.2	2,520	134.0	110.00	790.0	1.90	41.8	14.1	25.8

RS = Residual Soil; WWI = Wastewater Irrigation; FWI = Freshwater Irrigation

Table 2: Estimated enrichment factor (EF) for the amended substrates and residual soils under WWI and FWI

Parameters	pH	EC	Cu	Pb	Zn	Cd	Cr	Co	Ni
EF (Organo-amended soil)	6.8	2,100	1.61	1.28	1.76	1.40	0.94	0.89	0.78
EF (NPK-amended soil)	5.6	32,700	1.10	1.01	1.90	0.60	0.78	0.77	0.73
EF (wastedump soil)	5.4	2,160	9.68	7.85	34.10	31.60	1.72	1.05	1.61
EF (Organo-RS-WWI)	7.2	503	0.80	0.90	0.80	0.80	1.00	1.00	1.00
EF (Organo-RS-FWI)	6.2	271	0.80	0.90	0.90	1.00	0.90	1.00	0.90
EF (NPK-RS-WWI)	5.5	1,734	1.00	1.10	0.40	2.00	1.00	1.20	1.00
EF (NPK-RS-FWI)	6.1	820	1.20	1.10	0.60	2.00	1.10	1.10	1.00
EF (WD-RS-WWI)	6.0	2,300	1.00	1.10	0.80	1.10	1.10	1.00	1.10
EF (WD-RS-FWI)	6.2	2,520	1.10	1.10	0.80	1.20	1.10	1.00	1.10

EF = Enrichment Factor; WWI = Wastewater Irrigation; FWI = Freshwater Irrigation

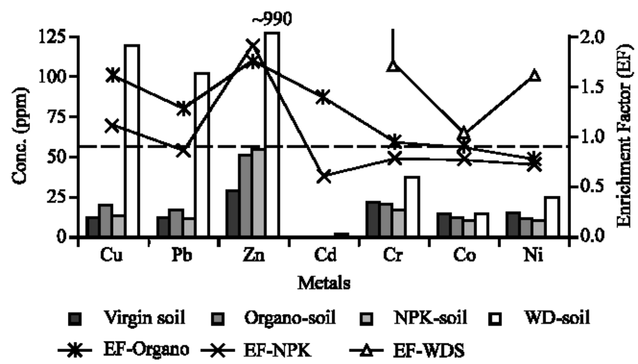

Fig. 1: Trace metals concentrations and enrichment in the different soil substrates with respect to the un-amended virgin soil

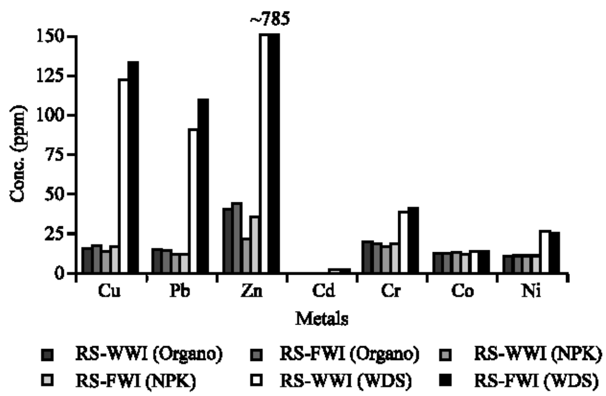

Fig. 2: Trace metals concentration profiles in the residual soils under WWI and FWI

Cu, Pb and Zn in all the three substrate compared to the un-amended virgin soil, indicative of anthropogenic trace metals inputs consequent to amendment application. However, with reference to virgin un-amended soil, Cr, Co, Ni and partly Cd exhibited depletion in NKP-and organo-amended soils unlike the enrichment in the WDS, a further confirmation of the contaminated status of the WDS.

Similarly, trends exhibited by the respective residual soils as shown in Fig. 2 revealed elevated concentrations for all the analyzed trace metals in the residual WDS compared to the NKP-and organo-amended soils under both WWI and FWI. Nonetheless, the enrichment of Cu, Pb and Zn in the residual soils of the substrates is of the order NPK < Organomineral < WDS. This is consistent with the fact

Table 3: Geochemical analyses results (in mg L^{-1}) of leachates from different amended soil substrates under WWI and FWI

Parameters	pH	EC	Cu	Pb	Zn	Cd	Cr	Co	Ni
Waste-water irrigation (WWI)									
Wastewater	6.8	799	<2	70	2470	2	20	<2	37
Leachate (control soil)	6.2	558	7	<10	21	<2	<20	4	7
Leachate (Organo-soil)	5.8	5,140	11	<10	59	<2	<20	6	34
Leachate (NPK-soil)	5.0	35,700	118	<10	105	2	<20	30	53
Leachate (WD-soil)	6.2	3,550	123	<10	1100	<2	<20	10	12
EF (Organo-leachate)		9.2	1.6	1.0	2.8	1.0	1.0	1.5	4.9
EF (NPK-leachate)		64.0	16.9	1.0	5.0	1.0	1.0	7.5	7.6
EF (WDS-leachate)		6.4	17.6	1.0	52.4	1.0	1.0	2.5	1.7
Freshwater irrigation (FWI)									
Freshwater	7.0	278	273	<10	64	<2	<20	<2	<5
Leachate (control soil)	6.1	1,083	10	<10	129	<2	<20	2	<5
Leachate (Organo-soil)	6.0	2,290	22	20	125	<2	<20	5	21
Leachate (NPK-soil)	4.8	33,100	41	<10	352	14	30	85	256
Leachate (WD-soil)	5.3	9,680	59	<10	300	<2	<20	11	11
EF (Organo-leachate)		2.1	2.2	2.0	1.0	1.0	1.0	2.5	4.1
EF (NPK-leachate)		30.6	4.1	1.0	2.7	7.0	1.5	42.5	51.2
EF (WDS leachate)		8.9	5.9	1.0	2.3	1.0	1.0	5.5	2.2

that trace metals are generally organically bound (in WDS and organo-mineral amended soils) and therefore slowly or less easily available for plant uptake or leaching compared to the more readily soluble metal salts in the NPK-fertilizer (Bell *et al*., 1991).

In addition, the observed enrichment of most of the metals in residual soil of WDS and Oragno-mineral as shown in Fig. 2 (though slightly higher for WWI compared to FWI) imply possible sorption immobilization potentials of the soils. However, such adsorbed metal concentrations may serve as potential sources of trace metal release/contamination of shallow groundwater, through leaching and remobilization, even long after harvesting. In other words, a clear indication of environmental significance of trace metals inputs into the soil through soil amendment and especially under wastewater irrigation.

Assessment of Irrigation-Induced Leachates

The summary of the geochemical analyses of the irrigation-induced leachates under both WWI and FWI are presented in Table 3. As shown in the Table 3, the leachates under the soils amended with NPK have EC value of 33,100 μS cm^{-1} for FWI and EC value of 35,700 μS cm^{-1} for the WWI. These values are significantly higher (4-10 folds) compared to the WDS and oragno-mineral amended soil with leachate EC values of 9,680 and 2,290 μS cm^{-1}, respectively for FWI and 3,550 and 5,140 μS cm^{-1}, respectively for WWI. This may be attributed to higher or relatively faster solubility and mobilization of the metal salts in the NPK-fertilizers compared to the organo-minerals. Furthermore, the observed high EC values of the amended soils compared to the low EC value of 1,083 μS cm^{-1} (FWI) and 558 μS cm^{-1} (WWI) for the control soils (without any amendment) as well as acidic nature of the leachate with pH of 4.8-6.2 are clear indications of mobility or solubility of trace metals and environmental significance of irrigation-induced leaching of agricultural chemicals with possible attendant contamination of shallow groundwater system.

As presented in Fig. 3, the elevated concentrations of Cu, Pb and Zn in the leachates are more or less a reflection of enrichment in the amended soils before planting. However, the elevated concentrations of Cd, Cr, Co and Ni in the leachates especially for NPK-amended soils (Fig. 3) is a confirmation of higher solubility of the NPK-fertilizers and leaching mobilization of trace metals under NPK-amended soils compared to the organo-minerals. Furthermore, the enrichment of Zn in the leachates of all the substrates under both WWI and FWI (Table 3) despite depletion in the residual soils of the different substrates (Table 1) can be attributed to preferential partitioning or mobilization into the liquid phase. But despite similar enrichment of both Cu and Pb in the residual soils of the

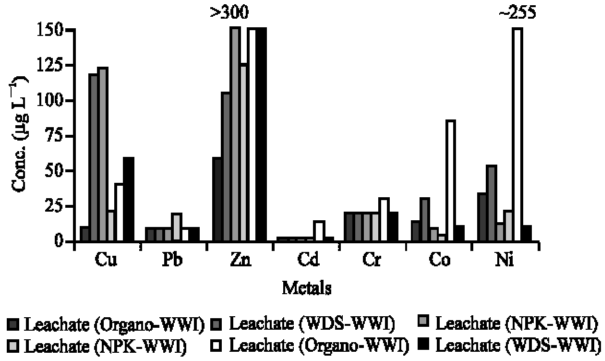

Fig. 3: Trace metals concentrations of the leachates from the different soil substrates under WWI and FWI

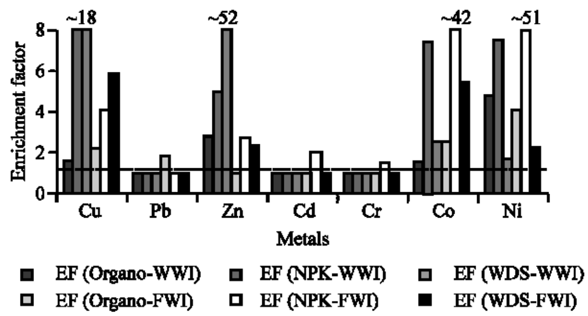

Fig. 4: Profiles of enrichment of the trace metals in the leachates from the different soil substrates under WWI and FWI

substrates, Pb exhibited significantly low concentrations in the leachates, partly due to possible uptake by vegetable plants and partly due to adsorption immobilization in the residual soils. This is clearly supported by a plot of the leachate enrichment profiles presented in Fig. 4, where Pb revealed EF of <1 compared to Cu and Zn.

In addition, the initial wastewater used for irrigation has elevated concentrations of Pb (70 μg L^{-1}), Zn (2470 μg L^{-1}) and Ni (37 μg L^{-1}). However, while Zn and Ni show significant enrichment in the leachates (i.e., EF of 2.8-52.4 for Zn and 1.7-7.6 for Ni), Pb shows no enrichment (EF ~1), which is a further confirmation of possible uptake by the vegetable crop and adsorption immobilization to the different soil substrates.

Other metals i.e., Cu and Co not detected in the primary wastewater show enrichment in the leachates (EF of 16.9-17.6 for Cu and 2.5-7.5 for Co) apparently as a result of leaching of the substrates especially WDS and NPK-amended soils.

For the freshwater used for irrigation, only Cu and Zn are in elevated concentration of 273 and 64 μg L^{-1}, respectively (apparently as from the pipe/plumbing systems) with corresponding enrichment in the leachates (EF = 2.3-5.9) especially for WDS an NPK-amended soils. Furthermore, the enrichment of Co and Ni in the leachates (Fig. 4), despite low concentrations and depletion in the amended substrates before planting, suggest possible geogenic leaching from the substrates and hence a further confirmation of negative impacts of irrigation induced infiltration/recharge on shallow groundwater quality.

CONCLUSION

The results and evaluation presented in this study had shown the significance of irrigation-induced recharge and leaching or mobilization of potential trace metals on the quality of shallow groundwater system. In this experimental pilot study, prior to planting of the vegetable crop, the WDS is contaminated with Cu, Pb, Zn, Cd, Cr, Co and Ni while NPK-amended and organomineral amended soils are slightly contaminated with only Cu, Pb and Zn compared to the unamended virgin soils. After harvesting, the residual soils under WDS and NPK-amended soils exhibited slight enrichment of almost all the analyzed trace metals (with exception of Zn) under WWI and FWI apparently as a result of adsorption or sorption unto the soil materials. However, the organo-amended residual soil revealed slight depletion of all the analyzed metals under both WWI and FWI suggesting possible uptake by the planted vegetable crop and/or leaching by irrigation water.

Furthermore, the measured pH of the analyzed leachates (5.0-6.2 for WWI and 4.8-6.0 for FWI) suggests generally acidic conditions favorable for solubility/mobilization of trace metals through irrigation-induced leaching. This is significantly reflected in the measured high EC values (>33,100 $\mu S\ cm^{-1}$) for leachates under NPK-amended soils for both FWI and WWI compared to the leachates from WDS and oragno-mineral amended soils with EC value of 2,290-9,680 $\mu S\ cm^{-1}$. This is attributed to rapid/fast solubility and vertical translocation of the metals salts in the NPK-fertilizers compared to a longer mobilization lag-time for organically bounded metals in the WDS and organo-mineral amended soils.

In addition, the enrichment of Zn in the leachates of all the substrates under both WWI and FWI, despite depletion in the residual soils of the different substrates can be attributed to preferential partitioning or mobilization into the liquid phase. However, significantly low concentration of Pb in the leachates despite enrichment in the residual soils of the substrates is partly attributed to uptake by vegetable plants and partly due to adsorption immobilization in the residual soils. Also, the enrichment of Co and Ni in the leachates despite low concentrations and depletion in the amended substrates before planting, suggest possible geogenic leaching from the substrates and hence a further confirmation of negative impacts of irrigation induced infiltration/recharge on shallow groundwater quality under amended agricultural fields.

In summary, with the increasing call for fertilizers and organic amendments applications to boost agricultural productions in the developing countries of Africa, this study had shown the need to evolve appropriate agricultural practices that will ensure sustainable water quality management alongside increase agricultural productivity.

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