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Effect of Source of Irrigation Water on Soil Chemical Properties in Tamale Metropolis, Ghana

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ABSTRACT

This study analyzed the effect of different water sources of irrigation on the chemical constituents of soils in the Tamale Metropolis of Ghana. Soil samples were taken from depths of 0 – 30 cm and 30 – 60 cm in wastewater, pipe water and non-irrigated (control) sites. Variations in levels of concentration of the various chemical properties, however, occurred among the three different soils. With the exception of % N and Mg, there was no significant difference among all the three soils for all the parameters. The results indicated that N level increased in wastewater irrigated soils as compared to pipe water and non-irrigated soils. P increased with wastewater irrigation but decreased with soil depth. K concentration in wastewater irrigated soils increased in the depth of 0 – 30 cm but decreased in the depth of 30 – 60 cm. Wastewater and pipe water irrigation decreased soil Na and Cl levels compared to the control (non-irrigated soils). Wastewater irrigation increased the level of EC and CEC whilst Cu, Zn and Cd levels increased with soil depth. Cu, Zn and Cd levels of the wastewater, pipe water and non-irrigated soils were higher than the FAO (1985) recommended levels for both depths. It can be concluded that irrigation with wastewater increased soil primary macro nutrients (NPK) whilst micro nutrients such as sodium and chloride decreased with wastewater and pipe water irrigation.

Keywords: *Irrigation Water, Wastewater, Soil Nutrients, Chemical Properties, Nutrient Concentration*

INTRODUCTION

Nutrients for plant growth are provided by the dissolution of soil minerals and by microbial processes that convert organic matter forms to inorganic forms of nutrients. Increasing crop yield means that more nutrients are being exported from each hectare of soil each year (Singer and Munns, 2006). In arid and semi-arid regions, wastewater reclamation and reuse have become an important element in water resources planning (Abedi-Koupai and Bakhtiarifar, 2003). This has occurred as a result of increasing freshwater scarcity, high nutrients in wastewater, high cost of advanced treatment required for other applications and availability of wastewater all year round.

Irrigation with treated municipal wastewater is considered an environmentally sound waste disposal practice compared to its direct disposal to the surface or groundwater bodies. Also, wastewater is a valuable source of plant nutrients and organic matter needed for maintaining fertility and productivity levels of the soils (Rusan *et al*., 2007). However, Najafi and Nasr (2009) investigated comparatively the effects of wastewater on soil chemical properties in three irrigation methods with the results showing an increase of electrical conductivity (EC), calcium (Ca), sodium ions (Na), chloride ions, and a decrease in lead (Pd).

According to Rusan *et al*. (2007), continuous irrigation with wastewater could lead to accumulation of salts, plant nutrients and heavy metals (except for lead and cadmium) in soils beyond crop tolerance levels. Also, uptake of trace metals from soils differs from plant to plant and from site to site (Nabulo *et al*., 2008).

The study analyzed the effect of different water sources of irrigation on soil chemical properties in the Tamale Metropolis of Ghana.

MATERIALS AND METHODS

Study Area

The study was carried out in Gumbihine-Water Works in the Tamale Metropolis. According to Obuobie *et al*. (2006), Water Works was named after a dam originally built to provide water for Tamale Metropolis, the reservoir is now heavily polluted. Water flows through it and is used by farmers who have farms next to the stream originating from the dam and it is only about 1 km away from the city centre of Tamale.

The major vegetables grown by farmers in the area are *Amaranthus candatus*, *Hibiscus esculentus*, *Corchorus olitorius*, *Lactuca sativa* and *Brassica oleracea var. capitata*.

Materials and Data Collection

Materials used for the soil sample collection were soil auger, rule, polythene bags and a Global Position System (GPS). Soil samples were taken at depths of 0 – 30 cm and 30 – 60 cm. Soil samples were taken using a Randomized Block Design (RBD) with the study site divided into three blocks (B_1 = wastewater irrigated site (WW), B_2 = pipe water irrigated site (PW), and B_3 = non-irrigated site (NI). Each block had two sampling points resulting in a total of twelve (12) soil samples. The methods adopted for analysis of the soil samples are as presented in Table 1.

Table 1: **Methods for Laboratory Analysis of Soil Samples**

S/No.	Element	Analysis Method	Reference
1.	Total Nitrogen (N)	Modified Kjeldahl	Soil Laboratory Staff (1984)
2.	Available Phosphorus (P)	Bray's Method No. 1 and Olsen's method	Bray and Kurtz (1945) and Olsen *et al*. (1954)
3.	Potassium (K)	Flame Photometer at 766.5 nm	Toth and Prince (1949)
4.	Sodium (Na)	Flame Photometry at 589 nm	Robbins and Wiegand (1990) and Helmke and Sparks (1996)
5.	Electrical Conductivity (EC) and Cation Exchange Capacity (CEC)	Conductivity Meter	Motsara and Roy (2008)
6.	Chloride (Cl)	Mohr's Titration Method	Mohr (1856)
7.	Calcium (Ca) and Magnesium (Mg)	Ethylenediamine Tetraacetic Acid (EDTA) Titration and use of AAS	Cheng and Bray (1951)
8.	Zinc (Zn), Copper (Cu) and Cadmium (Cd)	Ethylenediamine Tetraacetic Acid (EDTA) Titration and use of AAS	Lindsay and Norvell (1978)

Data Analysis
Data was analysed for the effect of the application of different irrigation water on the variation in concentrations of soil nutrients among the sampled soils. Analysis of variance (ANOVA) was employed for the differences in concentration for the various sampling points while the average concentrations were compared using the Fisher Pairwise Comparisons (LSD) method at 95 % confidence interval using Minitab 17. Mean levels were plotted with GraphPad Prism 8.

RESULTS AND DISCUSSION

Macronutrients Concentration in Study Soils
The primary nutrients for plant growth - nitrogen, phosphorus, and potassium (NPK) when insufficient limit crop growth. Nitrogen, the most intensively used element, is available in virtually unlimited quantities in the atmosphere and is continually recycled among plants, soil, water, and air. However, it is often unavailable in the correct form for proper absorption and synthesis by the plant (Gruhn *et al*., 2000)
Average nitrogen (N) concentration in cultivated soil has been reported as being 0.15 % (Brady and Weil, 2008). Tisdale *et al*. (1993), indicated that Nitrogen value >1 % is considered very high and 0 – 0.1 % is very low. The study results presented in Figure 1 indicate that nitrogen concentration in wastewater irrigated soils are moderate whilst pipe water irrigated and non-irrigated soils recorded low levels. Although low, the slightly high levels of nitrogen in the wastewater irrigated soils may be a result of the organic matter contained in it. Rusan *et al*. (2007) reported that wastewater irrigation increased significantly the soil nitrogen in the topsoil. Similarly, several researchers reported accumulation of nitrogen in the soil with wastewater application which was attributed to the original content of nitrogen in the wastewater applied (Monnett *et al*., 1996; Mojiri, 2011).
Low nitrogen has been reported to cause stunted growth, chlorosis (yellowish or pale green leaf colours) and reduced protein content in plants (Brady and Weil, 2008).
It was observed that nitrogen level was the same for both depths of wastewater irrigated soils but decreases with depth in pipe water irrigated and non-irrigated soils. The results of ANOVA indicated statistical difference for % N levels at Fpr of 0.025 and the difference was between wastewater irrigated soils and the other soils with the exception of the upper depth (0 - 30 cm) of pipe water irrigated soil as presented in Figure 1. Nitrogen compounds in raw wastewater in Tamale Metropolis has been reported by Osei *et al*. (2011) to range from 20.5 - 26.3, 0.43 - 4.8 and 0.14 - 25 mg/l for NH_3, NO_3^- and NO_2^- respectively.

According to Olaitan *et al*. (1988), phosphorus (P) is the most limiting plant nutrient in most agriculture soils after nitrogen (N) and that topsoil P is often greater than sub-soil P due to added P sorption, greater biological activities and accumulation of organic materials.
Phosphorus concentration presented in Figure 2 for this study was noted to be the highest across both depths in wastewater irrigated soils compared to pipe water irrigated and non-irrigated soils.
ANOVA at a 5 % level of significance yielded F-probability values of 0.214 thus indicating no significant difference among the study soils. Wastewater is reported to contain between of 1.97 - 2.03 mg/l of P (Osei *et al.*, 2011), while Anim-Gyampo *et al.* (2012) found 0.05 - 0.55 mg/l of Phosphate for irrigated water in the Tamale metropolis. Manzoor and Christopher (2010) indicated that excess P in wastewater can cause undesirable growth of algae,

periphyton attached algae and weeds and can also accumulate in the soil where it is immobile.

According to a study by Mohammad and Mazahreh (2003), extractable phosphorus was higher in soils irrigated with wastewater than in soils irrigated with freshwater or rainfall water. Also, Mojiri (2011) and Rusan *et al*. (2007) reported that soil irrigated with wastewater caused an increase of phosphorus.

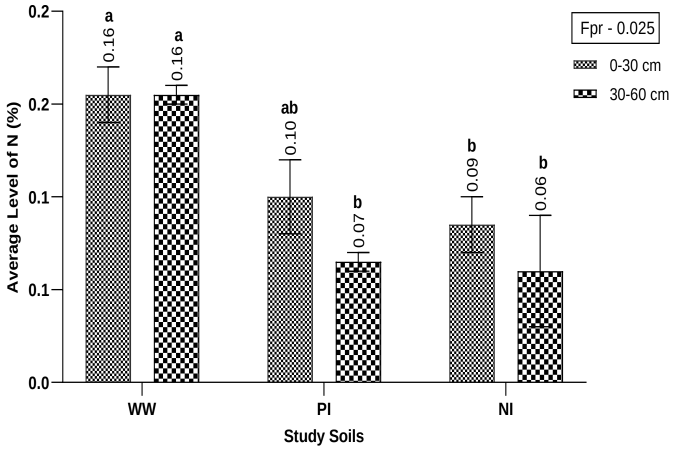

Figure 1: **Levels of Nitrogen in Sampled Soils**
(Error bars indicates standard deviation (±).
Means that do not share a letter are significantly different)

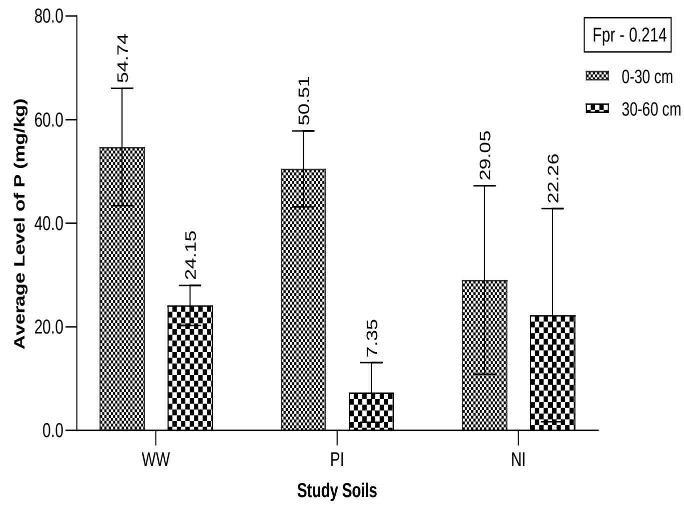

Figure 2: **Levels of Phosphorus in Soils**
(Error bars indicates standard deviation)

Wastewater irrigated soils from the study recorded the highest level of potassium (K) compared to pipe water and non-irrigated soils at the depth of 0 – 30 cm as presented in Figure 3. Variation among mean concentrations were statistically insignificant at F pr value of 0.436. In a similar study, Faridullah *et al.* (2016) found Total soil K concentration in the range of 15.14 to 39.535 mg/kg for both wastewater and freshwater irrigated soils respectively, while water-soluble K of 39.07 and 19.12 mg/kg were respectively recorded for the wastewater and freshwater used for irrigation. According to Mojiri (2011), soil with wastewater irrigation caused an increase of potassium resulting from a higher K content of wastewater. Mohammad and Mazahreh (2003) found that K concentration increases with wastewater irrigation.

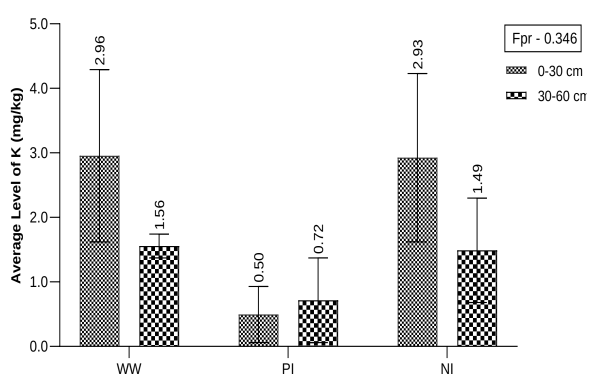

Figure 3: **Levels of Potassium in Soils**
(*Error bars indicates standard deviation)*

Micronutrients Concentration in Soils

Plant growth is noted to be influenced by micronutrients such as chlorine, iron, manganese, zinc, copper, boron, and molybdenum and these micronutrients are often required in small amounts for the proper functioning of plant metabolism. The absolute or relative absence of any of these nutrients can hamper plant growth; alternatively, too high a concentration can be toxic to the plant or humans (Gruhn *et al*., 2000). The levels of Na, Cl, Ca and Mg in the soils of the study area are presented in Figures 4, 5, 6 and 7 respectively.

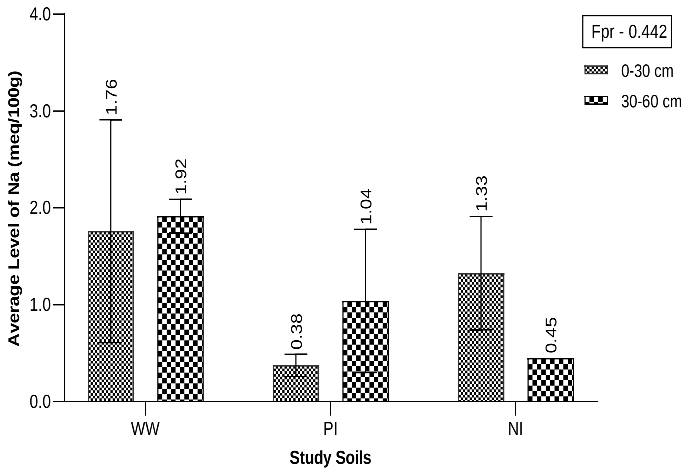

Figure 4: Levels of Na in Soils
Error bars indicates standard deviation (±)

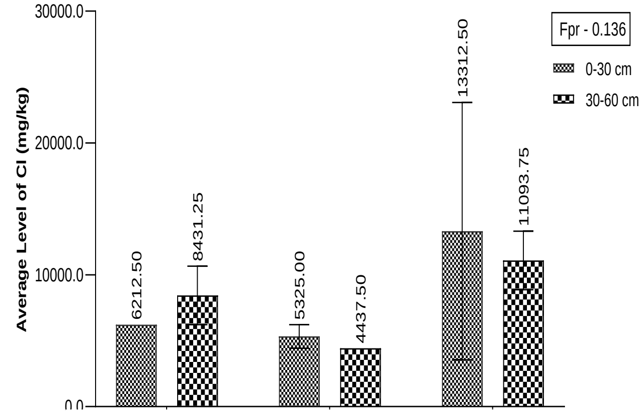

Figure 5: Levels of Cl in Soils
Error bars indicates standard deviation (±)

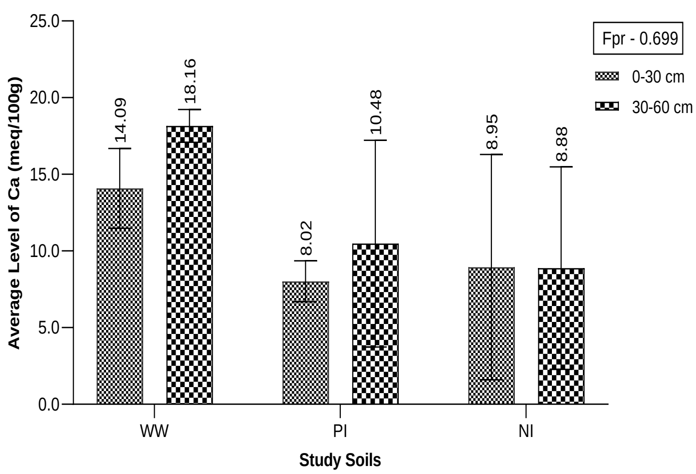

Figure 6: Levels of Ca in Soils
Error bars indicates standard deviation (±)

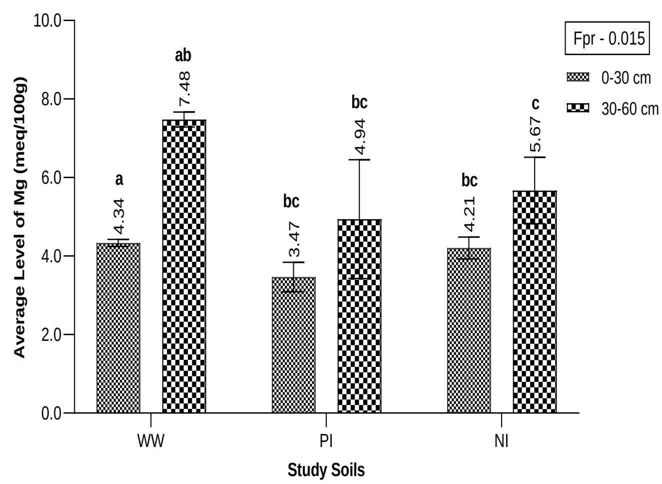

Figure 7: Levels of Na in Soils
Error bars indicates standard deviation (±). Means that do not share a letter are significantly different

Generally, wastewater irrigated soils recorded the highest levels of all the micronutrients tested for the study with the exception of Cl where the highest was recorded at the non-irrigated soils. Although variable levels of Na, Cl and Ca were recorded for the three (3) different soils, the results of ANOVA at 5 % level of significance resulted in F pr values of 0.442, 0.136 and 0.699 respectively, indicating no significant difference. Nonetheless, variation among Mg levels was statistically significant at F pr of 0.015. The upper soil depth (0 – 30 cm) of wastewater irrigated soil was significantly different from the other soils of pipe water and non-irrigated soils while the lower depth (30 – 60 cm) was significantly higher than that of non-irrigated soils as in Figure 7.

Tsai *et al.* (2004) and Hong *et al.* (2009), indicated that excess Na^+ is frequently assumed to be largely responsible for the reductions in growth and yield under salinity. Although less attention has been given to toxicity of excess levels of Cl^-, to salt stress, high concentrations of Cl^- are often found in tissues of plants growing under salt stress (Kingsbury and Epstein, 1986; Gorham 1990).

In a similar study, Faridullah *et al.* (2016), recorded an average extractable Ca of 6.05 and 3.55 mg/kg respectively for wastewater and freshwater irrigated soil and their corresponding water-soluble Ca of 73.5 and 106.05 mg/kg.

Comparatively, higher Mg concentration of 117.5 and 127.24 mg/kg was recorded by Faridullah *et al.* (2016) for freshwater and wastewater irrigated soils respectively while contents in the wastewater and freshwater was in the range of 116.2 to 189.325 mg/kg.

Electrical Conductivity (EC) and Cation Exchange Capacity (CEC) of Soils

Chemical properties of soil refer to the nature of the chemical changes taking place in them. These chemical changes depend upon their chemical compositions and the nature of the inorganic and organic materials contained in them, which have originated from the gradual decomposition of the sial and organic materials, mainly of plant origin (Kolay, 2000).

The concentration of total salt content in irrigation waters, estimated in terms of EC, is the most important parameter for assessing the suitability of irrigation waters. Generally, all irrigation waters with an EC of less than 2.25 μS/cm are considered suitable except in some unusual situations, e.g. very sensitive crops and highly clayey soils of poor permeability. The ideal value is less than 0.75 μS/cm (Richards, 1954).

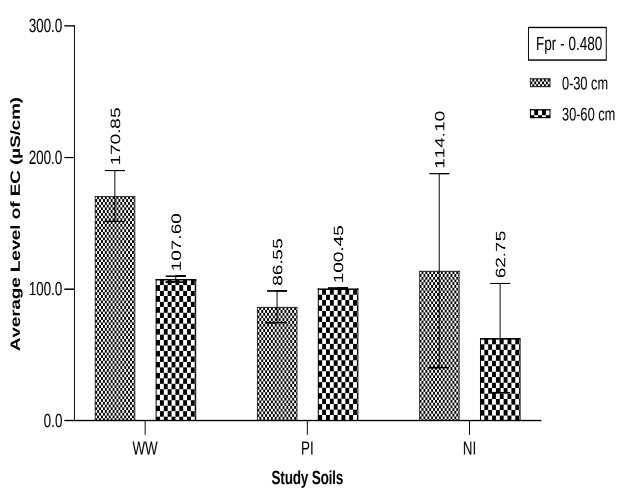

Figure 8: Levels of EC in Soils
Error bars indicates standard deviation (±)

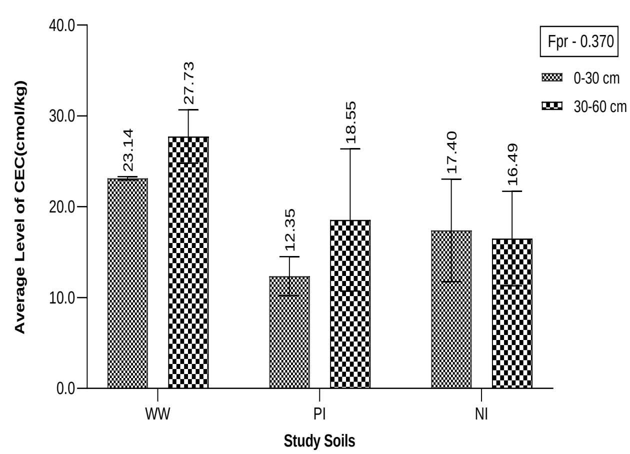

Figure 9: Levels of CEC in Soils
Error bars indicates standard deviation (±)

Electrical Conductivity (EC) and Cation Exchange Capacity (CEC) levels were noted to be high in wastewater irrigated soils compared to the other two (2) soils, however results of ANOVA indicates that the observed variation was statistically insignificant with F pr values of 0.480 and 0.370 respectively and presented in Figure 8 and 9. In a study by Rusan *et al*. (2007) soil salinity measured as electrical conductivity (EC) of the 1:5 soil extract in dS m^{-1}, was significantly higher with wastewater irrigation. Also, Khai *et al*. (2008) indicated that the higher concentration of cations such as Na and K in wastewater led to an increase in EC and exchangeable Na and K in soils irrigated with wastewater. No statistical difference was observed for both depths in terms of the concentration of EC and CEC.

Heavy Metal Concentration in Soils

The use of wastewater and sludge in agricultural lands was found to enrich soils with heavy metals to concentrations that may pose potential environmental and health risks in the long-term (Tabari *et al*., 2008). Nwuche and Ugoji (2008) found heavy metal concentrations adversely affecting the biological health of the soil manifested in lower rates of nitrogen mineralization, lower soil microbial biomass carbon and reduced rate of respiration by soil microbial population.

Kaonga *et al*. (2010) reported that heavy metals commonly enter soils through the addition of sludge (e.g. from treated wastewater), composts, or fertilizers. The risk is still there that some residual heavy metals may get into the soil and crops through the treated wastewater itself. Inadequately treated wastewater can pose a major risk to the physico-chemical characteristics of the watershed and environments where it is disposed as reported by Igbinosa and Okoh (2009). Table 2 presents the study results of the concentration of heavy metals in the study soils. From Table 2, Cu, Zn and Cd concentrations were higher in wastewater irrigated soils compared to pipe water and non-irrigated soils for the study. Cu, Zn and Cd concentrations were also noted to be above FAO (1985) recommended levels for crop growth, with wastewater irrigated soils recording exceedingly high concentrations for both depths. It can be indicated that the concentration of Cu increased with depth for wastewater irrigated soils but decreased with depth for pipe water and non-irrigated soils whilst the concentration of Zn decreases with depth for the pipe water and non-irrigated soil. Cd in the pipe water and the non-irrigated soils experienced an increase in concentration across the depths.

Aljaloud (2010) observed that zinc contents were slightly higher in treated municipal wastewater than freshwater irrigated plots. Boll *et al*. (1986) reported that using wastewater irrigation for 16 years increased the concentration of Zn to toxic levels in the soil. However, Abedi-Koupai *et al*. (2006) reported that treated wastewater showed no effect on the increase of zinc during the growing season.

Kirkham (2006) reported that Cd is a heavy metal that is of great concern in the environment, because of its toxicity to animals and humans. Moreover, with long-term use of sewage sludge, heavy metals can accumulate to phytotoxic levels and result in reduced plants growth and/or enhanced metal concentrations in plants, which consumed by animals then enter the food chain (Behbahaninia and Mirbagheri, 2008).

Table 2: **Heavy Metals Concentration in Soils**

Soil Sampling Location	Heavy Metals					
	Cu (mg/kg)		Zn (mg/kg)		Cd (mg/kg)	
	0-30 cm	30-60cm	0- 30 cm	30-60cm	0-30 cm	30-60 cm
WW	21.10	25.70	5.25	6.00	0.83	0.87
PW	11.60	9.90	2.99	1.70	0.32	0.75
NI	11.10	10.60	3.20	2.00	0.64	0.69
F pr	0.534		0.207		0.480	
FAO (1985) Standards	0.2		2.0		0.01	

WW = Wastewater Irrigated Soil, PW = Pipe Water Irrigated Soil, NI = Non-Irrigated Soil

CONCLUSIONS

The study revealed that irrigation with wastewater increased soil primary macro nutrients (NPK) whilst micro nutrients such as sodium and chloride decreased with wastewater and pipe water irrigation as compared with the non-irrigated soils.

Chemical constituents such as electrical conductivity and cation exchange capacity were also found to have increased in the wastewater irrigated soils compared to the other two soils.

Heavy metals such as copper, zinc and cadmium increased with wastewater irrigation with copper content exceeding the maximum threshold values of FAO (1985) at both depths in all the three soils. Zinc and cadmium were also observed to have exceeded the FAO (1985) recommended levels for all three soils. Although high levels of all the parameters were recorded, these were observed to have no significant difference in their concentration.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the conduct of the study and the publication of this manuscript.

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