INFLUENCE OF HEAVY METALS CONTAMINATED INDUSTRIAL WASTEWATER ON IRRIGATION WATER AND LETTUCE (*LECTUCA SATIVA)* QUALITY IN KANO SUDAN SAVANNAH ZONE OF NIGERIA

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Abstract

The aim of this study is to assess if discharged industrial wastewater containing heavy metals (HMs) from different industries of Gunduwawa industrial area in Kano and used for lettuce irrigation affect the quality of the irrigation water and the irrigated lettuce using international regulatory agencies standard. Water and lettuce samples were collected from three industrial locations and evaluated for quality using (HMs) under standard laboratory procedures. Findings indicated that out of the analysed metals; Lead (Pb), Nickel (Ni), Zinc (Zn) and Cadmium (Cd), only Cd and other irrigation water quality parameters; Chemical oxygen demand (COD), Nitrate-nitrogen (NO_3-N), and Ammonia nitrogen (NH_4-N) were non-compliant to standard of metals quality in the former and irrigation water quality in the latter and has recorded a significant difference ($P<0.05$) except for Ni that did not ($P>0.05$). Furthermore, COD and NO_3-N showed significant difference ($P<0.05$) in location I compared to other locations, NH_4-N in location II in comparison to locations I and III. Though pH complied with irrigation water quality standard, a highly significant difference ($P<0.05$) was noted in location II if compared with other locations. Overall, this indicates poor quality irrigation water for lettuce production and can potentially exert mutagenic and carcinogenic effects to the grown vegetables. Pertaining lettuce quality, results showed that the lettuce was contaminated with Cd metal and exceeded the standard limit for safety of food consumption.

Keywords: *Irrigation, Water quality, metals, lettuce, Wastewater*

Introduction

Irrigation with industrial wastewater globally increases due to fresh water scarcity induced as a result of population increase (Sani et al, 2022). This practice is gaining reputation and accepted by farmers because of the belief that the wastewater contains high amount of essential nutrients needed by the crops at the expense of none or cheaper price (Bichai et al; 2012; Sani et al, 2022). However, the industrial wastewaters occasionally contain some pollutants like heavy metals that degrade both the crops and soil quality depending on the source, composition and the concentration of the metals (Sani et al., 2023). For example, Sani et al. (2023) indicated that industrial wastewater irrigation affected negatively spinach vegetables cultivated at Sharada industrial irrigation scheme in Southern Sudan Savannah ecological zone of Nigeria with Pb and Cd concentrations in the irrigated spinach exceeding the food safety limit advocated by regulatory agencies (FAO/WHO, 2011).

Exceeding limits of HMs concentration in irrigation water leads to transfer of the metals to the growing vegetable crops where they bio accumulate and exert their carcinogenic and mutagenic effect (Ali et al., 2013; Sani et al., 2022, 2023) to their consumption recipients when applied as irrigation amendment. Furthermore, the wastewater degrades soil quality parameters; increases salt concentration, clay dispersion and decreases soil hydraulic conductivity, changes in organic carbon, pH, nitrogen, CEC and other essential nutrients concentration (Bichai et al., 2012; Sani et al., 2022).

Irrigation of lettuce with industrial wastewater can have a negative impact on lettuce quality depending on the different types of pollutants concentration in the wastewater. For instance, Mekonen and Habte, (2022) reported significant bio-accumulation of HMs in shoots and roots of their lettuce irrigated with HMs contaminated wastewater, subsequently, leading to decrease in the lettuce leaf area, fresh weight and dry weight of roots and shoots, as well as reduction in photosynthetic pigment content and damage to cell membrane. However, the reverse was the case with the data reported by Balghair (2016) elsewhere who indicated improvement in the lettuce quality and yield production in terms of fresh weight after being irrigated with HMs contaminated irrigation water. Moreover, the author reported high increase in K, Ca, Al and S soil nutrients after the irrigation.

Lettuce is cultivated and consumed by the whole world and its production exceeded 24 million tons (Mekonen and Habte, 2022). In Nigeria, it is the most consumed leafy vegetable probably due to its cheapness, easily bought and prepared, and its production occurs throughout the year (Moura et al., 2016).

The importance of this research is applicable to agricultural, environmental and other related industries with vital information on HMs concentration in contaminated irrigation water, soil and the irrigated vegetables. This will allow the affected industries to justify the application of the wastewater and their management, and potential reuse as irrigation amendments into agricultural food production.

Literature has documented many experimental works conducted on industrial wastewater irrigation in Kano industrial areas. For example, Bichi and Danazumi, (2010), Abdulmuminu et al. (2015), Pantami (2019) and Sani et al (2020, 2021, and 2022) assessed industrial irrigation wastewater quality and their impact on environment. However, researching the impact of the HMs contaminated industrial wastewater irrigation on vegetables quality particularly lettuce in the Gunduwawa industrial area was absently implemented. Therefore, the aim of this study was to evaluate the irrigation water quality and its impact on the grown lettuce quality in the industrial area through the following objectives;

1. To assess the irrigation water quality of the industrial wastewater
2. To assess the heavy metals concentration in the grown irrigated lettuce and compare with the international organization's standard for quality compliance.

Materials and Methods

Study Area Description

The research was conducted at Gunduwawa industrial area, Gezawa local government of Kano state. The area is located between latitude 1206'N and longitude 8044'E with average rainfall of 696.4mm per year. The area is an industrial, containing industries ranging from rice mill factories, detergents factories, shoes making industries, plastics industries, tanneries and other related domestic consumables industries. These industries release their wastewater to an outer sink like channels where farmers in the area use them for washing and vegetables irrigation.

Water and Lettuce Samples Collection

Discharged wastewater samples were collected randomly in triplicate in cleaned plastic bottles after bulking of the different composite water samples from three industrial wastewater collection sinks; locations I, II and III respectively where the farmers draw the wastewater for their vegetable's irrigation. Similarly, 10 lettuce samples from each location were sampled from the soils in the same sampling procedure of the wastewater using simple hoe in uprooting the irrigated vegetables in the three irrigated soil's locations. Consequently, all the collected lettuce samples were washed and dried before taken to laboratory for analysis using standard laboratory procedures.

Laboratory Analyses

The analysis of different wastewater and lettuce samples for some selected metals concentration was carried out in the laboratory using Varian 720-ES Inductively Coupled Plasma—Optical Emission Spectrometer technology (ICP–OES (USEPA, 1994) manufactured by Agilent echnologies UK (Wharfedale Road, Wokingham, Berkshire, UK). pH was measured with sensION+Benchtop Multi-Parameter Meter (Hach Lange, Düsseldorf, Germany). Standard water quality analysis procedures were applied for variables including chemical oxygen demand (COD), ammonia nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N). All the water quality analyses were performed according to APHA (2005) procedures.

Data Analyses

To assess the contamination level of the HMs, lettuce and irrigation water quality indices in different locations and their corresponding differences, data mean values of the concentration in each location were subjected to analysis of variance (ANOVA) using SPSS Statistical package. The treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability

Risk Assessment

The procedures governing the application of the hazardous substances (HMs in the wastewater) in the experimental research were listed in order to ensure that the research was carried out with minimum risk to health of the researcher or other people that may be affected. Furthermore, directives were stated to ensure safety in each step of the research including the types of materials which needed to be used such as clothes to be worn in the laboratory. The researcher was also trained and advised with regard to the health risks associated with possible exposure routes such as inhalation, absorption via the skin and oral ingestion of the industrial wastewater when working with hazardous substances like industrial wastewater HMs.

Result and Discussion

Irrigation Industrial Wastewater Quality

Comparison of Lead (Pb) Concentration

The irrigation water quality result of the Gunduwawa industrial wastewater in different locations was depicted in Table 1. The result indicated the concentration of both HMs and other water quality parameters. The concentration of Pb showed that, in location 1, it recorded highest values compared to locations 2 and 3 respectively, even though all the recorded values were low and below the irrigation quality standard of 0-5.0mg/l advocated by FAO (2023) for Pb concentration in irrigation water (Table 1).

Statistically, Pb in location 1 has the highest values compared to other locations ($P<0.05$) probably due to high amount of Pb containing substances released in the location 1 wastewater from the residing factories in that location compared to the ones in the other locations (Sani et al., 2021) but the concentration is within the compliance limit.

High Pb concentration in wastewater used for irrigation leads to soil toxicity with subsequent quality and fertility reduction, accumulation in the leafy parts of vegetables and in the grain yield of some crops (Chopra et al; 2009).

Comparison of Nickel (Ni) Concentration

The result of Ni in Table 1 showed that, Ni concentration was very low but recorded highest values in location 1 compared to locations 2 and 3 that recorded the same values. This result indicated that the water was not contaminated with Ni because the irrigation quality standard reported by regulatory authorities was 0-0.2mg/l (FAO, 2023) and all the values were below the permissible limit (Table 1).

Statistically, Ni concentration recorded in location 1 has the highest values compared to other locations (Table 1) but the difference was not significant ($P>0.05$).

Application of wastewater high in Ni concentration contaminates the soil growth media with negative impact to the crops grown which can accumulate high concentration of the metal to cause serious health risk to consumers (Chopra et al., 2009; Ali et al., 2013) upon the consumption of the crops.

Comparison of Zinc (Zn) concentration

The result of Zn was also shown in Table 1. The result showed that, Zn concentration was generally low in all the locations but recorded highest concentration in location 2 compared to other locations. Zn concentration in all locations indicated that the water was not contaminated because the irrigation quality standard for Zn in irrigation water was reported to be 0-2.0mg/l (FAO, 2023) and all the values in all the locations achieved the compliance Statistically, Zn concentration in location 2 has the highest values ($P<0.05$) compared to other locations (Table 1).

Crops irrigated with wastewater containing high amount of Zn deteriorates soil quality and subsequent impediment of the crops grown in the growth media with apparent browning of colloid roots and chlorosis particularly in vegetables in addition to health risks associated problems such as dizziness and fatigue (Abdullahi et al., 2024) on their host animal.

Comparison of Cadmium (Cd) concentration

The result of Cd concentration in the industrial wastewater was depicted also in Table 1. It indicated that, Cd concentration was very high and recorded highest values in location 1 followed by locations 2 and 3. This result showed that the water was contaminated with Cd and can cause negative impact to both soil fertility, quality and the grown crops because the irrigation quality standard of 0-0.01mg/l was advocated by agricultural regulatory agencies (FAO, 2023) for Cd in irrigation water and all the values were above the permissible limit (Table 1).

Statistically, Cd concentration in location 1 has highest values significantly different ($P<0.05$) compared to other locations (Table 1).

Application of high containing Cd wastewater as irrigation amendment leads to Cd soil toxicity and subsequent transfer of the toxic effect on to the roots and shoots of the affected crop, consequently, this leads to the development of harmful effects such as oxidative stress, genotoxicity in addition to impediment of the photosynthetic processes, and root absorption mechanism to the grown crops. Furthermore, consuming the Cd metal via affected crops or vegetables by humans or animals has carcinogenic, mutagenic and teratogenic effect (Ali et al., 2013; Sani et al., 2020).

Comparison of Chemical Oxygen Demand (COD) concentration

The result of COD in Table 1 showed that, the COD values in location 1 was highest than locations 3 and 2 respectively. According to agricultural regulatory agencies (Radaideh et al., 2009; Almuktar et al., 2018), irrigation water quality standard for COD was set to be 0-146mg/l and this shows that the irrigation water is contaminated and can cause negative impact to vegetables because all the locations in the research area recorded values above the permissible limit (Table 1).

Statistically, COD values in location 1 significantly recorded the highest values ($P<0.05$) compared to other locations which could be due to the fact that location 1 wastewater might have contained much recalcitrant chemicals that were not removed efficiently from the industries water treatment plants leading to the high observed recorded concentration of the oxygen demand variable confirming the data reported elsewhere (Abdulmumini et al., 2015; Sani et al., 2020).

High concentration of COD in irrigation wastewater used for irrigating crops, leads to nutrient toxicity and excessive morphological growth in crops (Almuktar et al., 2018).

Comparison of Ammonium Nitrogen (NH_4-N) concentration

The result of NH_4-N as depicted in Table 1 showed that, the NH_4-N concentration recorded in location 2 was highest than the concentration recorded in locations 3 and 1. The recorded concentration of ammonia-nitrogen in all locations was much and above the irrigation quality standard of 0-5mg/l set by FAO (2023) regulatory agencies. This high concentration recorded for ammonia-nitrogen of the irrigation water indicates that the water is highly contaminated and can cause negative impact to the irrigated vegetables.

Statistically, NH_4-N concentration recorded showed significant variations ($P<0.05$) among the different locations with highest values recorded in location 2 compared to other phases which could be possibly due to high influx and mixing of animal wastes, high sewage and leached nitrogenous containing ammonium fertilizers from urban and agricultural sources leading to the high recorded ammonia concentration in the location 1 wastewater in comparison to other locations and has been confirmed elsewhere (Paul, 2011; Sani et al., 2020).

Vegetables irrigation with wastewater rich in NH_4-N above maximum irrigation threshold safe limit leads to poor vegetables growth (Almuktar et al., 2018).

Comparison of Nitrate Nitrogen (NO_3-N)

The result of NO_3-N in Table 1 showed that, NO_3-N concentration recorded the highest values in location 1 compared to locations 2 and 3. The recorded values were high in all the locations and were above irrigation quality standard limit of 0-30mg/l advocated by agricultural regulatory agencies (FAO, 2003) indicating the contamination of the irrigation water with NO_3-N and can cause negative impact to vegetables grown on the irrigated soil.

Pertaining statistical analysis (Table 1), NO_3-N concentration in location 1 was statistically highest ($P<0.05$) in comparison to locations 2 and 3.

The high NO_3-N concentration recorded in all the locations could be attributed to the released wastewater containing NO_3-N from improper treatment of the industrial treatment facilities and merging of high municipal sewage, animal wastes, leached nitrogenous fertilizers and runoff from urban and agricultural catchments (Sani et al., 2020) and has been confirmed previously elsewhere (Abdulmumini et al., 2015).

Irrigating vegetables with high nitrate concentration irrigation water leads to soil quality degradation, excessive vegetables growth and maturity extension under long-term far-reaching application as irrigation amendment (Sani et al., 2020).

Table 1 HMs Average Concentration in the Irrigation Industrial Waste Water, their permissible limit and statistical differences in Gunduwawa industrial area mg/l in different phases

Parameters	Phase 1	Phase 2	Phase 3	Irrigation Quality Standard
Pb	0.054[a]	0.038[b]	0.08[c]	0-5.0[a]
Ni	0.021[NS]	0.017[NS]	0.017[NS]	0-0.2[a]
Zn	0.017[ab]	0.021[a]	0.015[b]	0-2.0[a]
Cd	0.018[a]	0.016[b]	0.01[c]	0-0.01[a]
COD	369.30[a]	311.70[b]	338.30[b]	0-146[b]
NH_4-N	62.20[c]	151.70[a]	91.10[b]	0-5[a]
NO_3-N	119.34[a]	59.58[b]	33.90[c]	0-30[a]
pH	7.04[b]	7.12[a]	7.01[b]	6.0-8.5[c]

Note, Pb, lead, Ni, nickel, Zn, zinc, Cd, cadmium, COD, chemical oxygen demand, NH4-N, ammonium nitrogen, NO3-N, nitrate nitrogen, pH, soil reaction, [a] FAO (2023), [b] Radaideh et al (2009) and [c] WHO (2008). Different letters in the same columns are statistically significant at5% level of probability using DMRT

Comparison of Soil Reaction (pH)

The result of pH in table 1 showed that, pH in phase 2 was greater than the result in phase I followed by phase 3. This result shows that the water has slightly neutral to slightly basic pH but the values were within the irrigation quality standard of 6.0-8.5 (WHO, 2008). Statistically pH in phase 2 has the highest value than other phases (P<0.05) probably due to high amount of the cations in that phase and has been confirmed elsewhere (Pantami, 2019).

Effect of the Industrial wastewater on the Vegetables quality

Comparison of Lead (Pb) in the Vegetables

The result of Pb in table 2 showed that, Pb in phase 3 was greater than the result in phase 2 followed by phase 1. This result shows that the lettuce is taint with Pb and can cause negative impact to human because the lettuce quality standard is between 0.50-30 (FAO/WHO, 2011) and all the values were above the permissible limit. Statistically Pb in phase 3 has the highest value than other phases (P<0.05) probably due to Pb containing substances in phase 3 wastewater making the metal concentration recording the higher observed values. This has been confirmed by data reported by Sani et al (2023).

Comparison of Nikel (Ni)

The result of Ni in table 2 showed that, Ni in phase 1 was greater than the result in phase 3 followed by phase 2. This result shows that the lettuce is not taint with Ni because the lettuce quality standard is 0.02-50 (FAO/WHO, 2011) and all the values were below the permissible limit and achieved compliance. Furthermore, statistically Ni in phase 1 has the highest value than other phases but not significant (P>0.05). The result was in conformity with the data reported elsewhere (Sani et al., 2023).

Comparison of Zinc (Zn)

The result of Zn in table 2 also showed that, Zn in phase 2 was greater than the result in phase 1 followed by phase 3. This result shows that the lettuce is not taint with Zn because the lettuce quality standard is within the acceptable limit of 20-100mg/kg advocated by regulatory agencies (FAO/WHO, 2011) and all the values achieved compliance. Moreover, statistically, Zn in phase 2 has the highest values compared to other phases (P<0.05) and the difference was significant (P<0.05). The plausible reason responsible for the high difference could be attributed to high concentration of Zn containing substances in the phase 2 wastewater compared to other phases and was in agreement with the result of Sani et al.(2021, 2022).

Comparison of Cadmium (Cd)

The result of Cd in table 2 showed that, Cd in phase 3 was higher than the result in phase 2 followed by phase 1. This shows that the lettuce quality is taint with Cd because the lettuce quality standard is between 0-<2.4 (FAO/WHO, 2011) and all the values were above the permissible limit and did not achieve compliance. Moreover, Cd in phase 3 has the highest value than other phases and the difference was not significant (P>0.05) probably due to high Cd containing substances in the phase 3 wastewater in comparison to other phases wastewater and has been confirmed by the study conducted by Sani et al. (2023).

HMs average concentration in lettuce and their permissible limit in mg/kg

Parameters	Phase 1	Phase 2	Phase 3	Lettuce Quality Standard
Pb	34.0^{NS}	36.0^{NS}	36.70^{NS}	$0.50\text{-}30^{d}$
Ni	0.021^{NS}	0.017^{NS}	0.017^{NS}	$0.02\text{-}50^{d}$
Zn	0.017^{ab}	0.021^{a}	0.015^{b}	$20\text{-}100^{d}$
Cd	2.67^{NS}	2.71^{NS}	2.80^{NS}	$0\text{-}<2.4^{d}$

Different letters in the same columns are statistically significant at5% level of probability using DM and [d] FAO/WHO (2011).

Conclusion and Recommendation

Conclusion

The main objective of this research was to assess the quality of Gunduwawa industrial wastewater and their effects on irrigation of vegetables. Findings revealed that the major water quality parameters in the wastewater: Cd, Ni, COD, NH_4-N, NO_3-N, exceeded irrigation quality standard limit as recommended by FAO and WHO regulatory agencies. With regards to vegetables quality, Pb and Cd, exceeded lettuce quality standard limit and did not achieve compliance indicating that the industrial wastewater could be harmful to the vegetables and negatively affect public health particularly the end consumers due to toxicity of the water quality.

Recommendation

Based on the result in the research carried out, all industries in Gunduwawa industrial area should be directed by authority to discharge their wastewater to the sewer system not to discharge directly to the environment as is the practice of the farmers in the study area to protect the public from carcinogenic and mutagenic effect of the HMs contaminated lettuce and the poor irrigation water quality.

Reference

Abdullahi, N., Chukwusore, E.I., Abba, M.D., Yusuf, H.L and Sani, A 2024. Wastewater Irrigation Safety and Heavy metals Contamination Awareness of Farmers Along Jakara River Kano, Nigeria. *FUDMA Journal of Sciences 8 (5),* 394-399 DOI: https://doi.org/10.3300`/fis-2024-0805-2861

Abdulmumini, A., Abubakar, I. K., Magaji, L., Sani, M.G., Ayuba, A.M., Shehu, H., and Isa, B.K. (2015). A Review on Industrial Effluents as Major Sources of Water Pollution in Nigeria. *Chemistry Journal 1, (5),* 159-164

Ali, H., Khan, E. & Sajad, M. A. (2013). Phytoremediation of heavy metals – concepts and applications *Chemosphere, 91* 869-81

Almuktar, S.A.A.A.N., Abed, S.N and Scholz, M. (2018). Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. *Environmental Science and Pollution Research* https://doi.org/10.1007/s11356-018-2629-3

Balkhair, K.S. (2016). Microbial contamination of vegetable crop and soil profile in arid regions under controlled application of domestic wastewater. *Saudi Journal of Biological Sciences, 23,* S83–S92

Bichai, F., Polo-Lopez, M. I., Ibanez, P. F., 2012.Solar disinfection of wastewater to reduce contamination of lettuce crops by Escherichia coli in reclaimed water irrigation. *Water research. 46,*6040-6050

Chopra, A.K., Pathak, C and Prasad, G (2009). Scenario of heavy metal contamination in agricultural soil and its management. *Journal of Applied and Natural Science 1(1),* 99-108

Dan'azumi, S and Bichi, M.H. (2010). Industrial Pollution and Heavy Metals Profile of Challawa River in Kano, *Nigeria. Journal of Applied Sciences in Environmental Sanitation, V (N):* 56-62

FAO (2003) *User's manual for irrigation with treated wastewater. Food and Agriculture Organization (FAO) of the United Nations*. FAO Regional Office of the Near East, Cairo

FAO/WHO (2011); *Joint WHO/FAO food standards programme codex committee on contaminants in foods*, fifth session pp64-89

FAO. (2023). *Land degradation neutrality*: Creating resilient landscapes. Food and Agriculture Organization of the United Nations

Hillel, D. and Vlek, P. (2005) *The Sustainability of Irrigation. Advances in Agronomy, 87, 55-84*. https://doi.org/10.1016/S0065-2113(05)87002-6

Mekonen N, Habte G (2022) Effect of Water and Soil Contamination by Heavy Metals in Lettuce (*Lactuca sativa*), Cabbage (*Brassica oleracea var. capitate*),and Turnip (*Brassica napus L.*) at Different Stage. *Ann Environ Sci Toxicol 6(1):* 035-040. DOI: https://dx.doi.org/10.17352/aest.000050

Morari, F. and Giardini, L. (2009) Municipal Wastewater Treatment with Vertical Flow Constructed Wetlands for Irrigation Reuse. *Ecological Engineering, 35*, 643-653. https://doi.org/10.1016/j.ecoleng.2008.10.014

Pantami, S.A.(2019). Effects of Tannery wastewater on soil physico-chemical properties and heavy metals concentration in Challawa industrial estate of Kano state. *Proceedings of the 43rd Annual Conference of the Soil Science Society of Nigeria, 457-467*

Phuntsho, S., et al. (2013) Assessing the Major Factors Affecting the Performances of Forward Osmosis and Its Implications on the Desalination Process. *Chemical Engineering Journal, 231, 484-496*. https://doi.org/10.1016/j.cej.2013.07.058

Impact of industrial effluents on water quality of receiving streams in Nakawa-ntinda, Uganda. *Unpublished thesis.*

Al-Zboon, K., Al-Harahsheh, A. and Al-Adamat, R. (2009). Quality assessment of harvested rain water for domestic uses, Jordan. Journal of Earth a reduce contamination of lettuce crops by Escherichia coli in reclaimed water irrigation. *Water Research, 46,* 6040-6050

Sani, A., Scholz, M. and Bouillon, L. (2013) Seasonal Assessment of Experimental Vertical-Flow Constructed Wetlands Treating Domestic Wastewater. *Bioresource Technology,* *147, 585-596*. https://doi.org/10.1016/j.biortech.2013.08.076

Sani, A., Ahmad, R.S., Mohamed, U.M., Uzaifa, K.A and Abdulkadir, N.N. (2020). Discharged Industrial Effluents Quality Appraisal and Its Uses for Agricultural Production in Sudan Savannah Ecological Zone, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), 13(3), 45-51*

Sani, A., Isah, A.M., Adamu, U.K., Adam, I. A.,Garba, M.D.,Abdullahi, N.,Dandago, M.A, Haruna, A.K., Aliyu, J.A. Aliyu, R.W and Auwal, M. (2022). Effect of Hydrocarbon Contaminated Irrigation Water On Some Selected Soil Physical and Chemical Properties of Sudan Savannah Alfisols. *Global Journal of Agricultural Research 10, (5), pp.28-46*

Sani, A., Adamu, U.K., Adam, A.I., Sanda, A.R., Amin, M.A., Aliyu, R.W and Garba, M.D 2023 Variation of Chemical and Physical Characteristics of Sandy loam Soils After Long-term Irrigation with Treated Wastewater in Semi-arid Tropical Zone of Nigeria. *Current Agriculture 40 (2), 83-90*

Shahinasi, E. and Kashuta, V. (2008) Irrigation Water Quality and Its Effects upon Soil. *Tirana Agricultural University, Tirana, Albania. BALWOIS, 2008.*

WHO (World Health Organization). *Guidelines for the safe use of wastewater, excreta and greywater. In: Volume 2:* Wastewater use in agriculture. Geneva: WHO; 2006.

WHO (2008).*Guidelines for Drinking Water Quality, 3rd Edition Incorporation the First and Second Agenda Vol. 1* Recommendations, World Health Organizations Geneva