Assessment of nutritional value of spinach (*Spinacia oleracea*) irrigated with domestic wastewater and potable water

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Abstract: Farmers along open channels in urban areas are taking advantage of the continuous flow of wastewater for irrigation of food crops. This study is aimed at assessing the effects of raw domestic wastewater on the nutritional composition of spinach (*Spinacia oleracea*) under field conditions from germination to maturity. To achieve this aim, spinach was irrigated with raw wastewater (plot A) and potable water (plot B) using surface irrigation technique. Physical and chemical properties of raw domestic wastewater and soil as well as proximate and mineral analyses of spinach were conducted. The results revealed a moderate restriction in the use of the raw wastewater in terms of its dissolved oxygen (0.18±0.11 mg/L), total dissolved solids (1403.67±15.82 mg/L) and electrical conductivity (1350±10 µs/cm). Other water quality parameters that made the raw wastewater unsuitable for irrigation are COD (250.67±6.03 mg/L), BOD_5 (117.33±3.06 mg/L), ammonium-N (40.34±0.76 mg/L), nitrate-N (163.33±1.53 mg/L), and phosphate-P (10.05±0.05). The high nitrogen content in the raw wastewater can result into intensive growth, retard or uneven maturity as well as low yield. Also, the soil analysis revealed that irrigation with raw wastewater increased the exchangeable Na, K and Mg in plot A than plot B. However, plot B showed a higher population density than plot B at germination stage with plot A exhibiting higher dominance at maturity. In addition, leafy spinach from plot B was observed to have higher quality than spinach cultivated with wastewater. Thus, it is highly recommended that raw domestic wastewater should be properly treated before use. Nevertheless, the use of wastewater for irrigation can have multiple benefits of wastewater management, alternative source of water resources and a source of nutrients.

Key-Words: Assessment, Domestic wastewater, Growth rate, Irrigation, Nutrition, Potable water, Proximate analysis, Spinach (Spinacia oleracea)

1 Introduction

High rate of dependence on the use of domestic wastewater for irrigation is on the rise in developing countries especially in Nigeria where water scarcity is a major problem. Globally, water stress has increased wastewater irrigated agriculture, for instance, Kaboosi [1] reported investment of 20 million ha of land into wastewater irrigation and this is expected to increase as water problem increases.

The application of domestic wastewater for irrigation purposes is an old aged practice [2, 3, 4], it is known to contain organic materials, sufficient quantities of nutrient, essential and non-essential metals which are considered harmful to both humans and animal [5, 3]. According to Bazai et al. [6], the concentrations of these constituents are dependent on the source of wastewater while Kaboosi [1] stated that the impacts were dependent on the climatic conditions of the target area, wastewater quality, rate, practices, period of irrigation as well as the soil, wastewater and crop properties. Continuous application of wastewater to agricultural fields can increase nutrients accumulation in the soil to an unfavourable conditions that could affect crop quality and yield [7]. In addition, the contamination of vegetables can occur through various means including environmental pollution, industrial activities or the heavy metals abdorption from polluted soils, industrial wastewater, or polluted irrigation water [8].

Spinach *(Spinacia oleracea)* are important source of nutrients including proteins, vitamins, micro and essential trace elements and minerals [8]. In Quetta, Pakistan about 26% of vegetables grown is irrigated with wastewater [6]. Thus, the aim of this study is to determine the effects of raw wastewater irrigation on the nutritional composition of spinach grown under the prevailing tropical climatic conditions.

2 Methodology

2.1 Experimental setup/study site

The study was conducted at Soje Irrigation Scheme, Minna, Niger state (Latitude 8°10'N and 11°30'N and Longitude 3°30' E and 7°30' E), Nigeria. Soje irrigation scheme is located in Soje, few kilometres from Minna railway station and 300 m from the west of Morris Fertilizer Company, Minna, Niger state, Nigeria. The climate of the study site is characterized by rain-bearing South West monsoon winds from the oceans and the dry dusty or harmattan North East winds (air masses) from the Sahara Desert giving rise to two main seasons, the raining and the dry (Harmattan). The raining season begins in April and ends in October while the Harmattan seasons runs from November to March, the subsequent year [5]. This present study was undertaken during the dry season. The climatic condition of Soje is such that it has an average annual rainfall of 103.3 mm, mean temperature ranges from 22.5°C minimum to 33.6°C maximum annually with a mean annual relative humidity of 50.3% (Nigerian Meteorological Agency (NiMet), Minna; [5]). The wastewater source is from Minna Township, it flows through unlined channels (Figs. 1 and 2). The farmers linear to the flow take advantage of its continuous flow for irrigation.

The experimental site has a plot size of 1.83 m x 2.44 m with three replicate each (Fig. 3). The plots consisted of wastewater irrigated plots (A) and potable water irrigated plots (B) serving as the control plot, the plots were sown with spinach seeds. The experiment took place during the dry season when less than 30% of the soil moisture was available to plants. The wastewater was applied by ponding on the plots (Fig. 3).

Fig.1. Unlined Wastewater Channel, Soje

Fig. 2. Wastewater supplied to the test plots

2.1.1 Sample collection

Wastewater, soil, and spinach (*Spinacia oleracea*) samples were collected to determine the effects of untreated wastewater on the nutritional value of spinach. Onsite measurement of wastewater samples was conducted immediately for temperature, electrical conductivity, pH, Total Dissolved Solids, turbidity and dissolved oxygen (DO) to avoid interference of the results and composite samples of three replicates were taken for laboratory investigations of total suspended solids (TSS), ammonia, nitrate, potassium, chemical oxygen demand (COD), biological oxygen demand (BOD) using Standard Methods for Examination of Water and Wastewater [9].

The soil samples were collected and analyzed before and after planting from the wastewater irrigated plots and controlled plots to determine the effects of wastewater constituents on soil quality. Five composite samples were collected randomly from different points at a depth of 25 cm from each plot with a soil auger were mixed together in a polyethylene bag to avoid moisture loss. The soil samples were air-dried at room temperature for 3 days in the laboratory, crushed and passed through a 2 mm aperture sieve. 450g of each sample was for analysis. Soil physical and chemical parameters were measured by standard methods, glad electrode, pH meter, bouyoucos method for particle size analysis, macro-kjeldahl method for mineral analysis.

Fig. 3. Experimental site: wastewater irrigated farm

A minimum of 40 - 55 spinach leaf samples were randomly collected from each plot; plot A and plot B. These samples were kept in polythene bags, subsequently, labelled then transported to the laboratory for preparation for analysis. The leafy parts were properly washed with deionized water to remove foreign particles. The samples were air-dried and then oven-dried at 70^{o}C after which they were grounded into powdered and were digested for proximate, mineral and vitamin C content analysis. The sliced samples were ash at 500 - 600^{o}C by placing a suitable weight (0.5 - 1.0 g) of the leaf in a Silica crucible and heating it in a muffle furnace for 4 – 6 hours. The ash residue was dissolved in dilute HCl filtered through acid-washed filter paper in a 100 ml volumetric flask. The estimation of P, K, Ca, Mg and micronutrients incubating B and Mo was carried out on the dry ash sample solution using flame photometer.

3 Results and discussion

Characteristic of raw domestic wastewater at Soje irrigation scheme used for this study is presented in Table 1. The wastewater showed an average pH of 8.78 which was slightly above the FAO threshold limit. This pH is considered unsafe for irrigation of food crops [2]. This is because high pH may lead to nutritional imbalance. On the contrary, electrical conductivity (EC) and total dissolved solids were found within the FAO threshold limits for wastewater irrigation, although with slight to moderate restriction [10]. High TDS content in the irrigation water can affect plant growth, crop productivity as well as the quality of produce if the value of TDS is above the threshold limit [10]. This is not the case with the TDS value of this study. The average dissolved oxygen (DO), BOD (Biological oxygen demand), COD (Chemical oxygen demand) content of the raw wastewater were found to be of unfavourable concentrations, not suitable for consumption (Table 1), and irrigation of some food crops. DO is an important component of water. This is because sufficient amount of DO can aid in plant and microorganism’s survival. Hence, the low concentrations of DO in the raw wastewater implies that the wastewater contained high concentrations of bacteria which could posse high risks to plant growth and nutrient decompositions by the microbes. Also, higher concentrations of COD and BOD and lower DO concentration is an indication that the water is polluted and not safe for irrigation of vegetables like spinach [2].

Table 1. Raw wastewater constituents and FAO threshold limits

Parameters	Unit	Average Value ± Std	FAO Limit
pH	-	8.78±0.20	6-9**
Temperature	^{0}C	29.0±0.60	-
EC	µs/cm	1350±10	0-3000
TDS	mg/L	1403.67±15.82	0-2000
Turbidity	NTU	19.87±0.11	50*
TSS	mg/L	122±2.65	100*
Colour	TCU	241.33±4.16	-
DO	mg/L	0.18±0.11	>2.0**
COD	mg/L	250.67±6.03	200*
BOD_5	mg/L	117.33±3.06	100*
Chloride	mg/L	21.99±1.99	0-1050
Fluoride	mg/L	0.05±0.01	1.0
Magnesium	mg/L	33.95±1.08	0-60
Calcium	mg/L	43.86±1.72	0-400
Ammonium-N	mg/L	40.34±0.76	0-5
Nitrate-N	mg/L	163.33±1.53	0-10
Nitrite	mg/L	0.81±0.01	-
Phosphate-P	mg/L	10.05±0.05	0-2
Sodium	mg/L	141.50±8.79	0-920
Potassium	mg/L	15.81±0.36	0-2
Hardness	mg/L	128±8.00	-
Carbonate	mg/L	0.09±0.01	0-30
Bicarbonate	mg/L	161.67±3.79	0-610
Alkalinity (as $CaCO_3$)	mg/L	524±3.46	

Source: FAO [10]; * [1]; [11]: Standard for irrigation of effluent reuse for cooked vegetables

The elemental components of the raw wastewater including chloride, fluoride, magnesium and calcium were all within the permissible limits while the nutrient contents were above the limits. Irrigation water that contain high ions above the threshold limits can cause plant toxicity problems such as impaired growth, reduced yield, changes in plant morphology and even death. The high nitrogenous content is an indication that the raw wastewater contains organic matter of vegetable origin. In addition, the irrigation scheme is 300 m away from a fertilizer plant, this could also be responsible for the high nutrient contents in the wastewater. Excessive nitrogen in irrigation water may result into intensive growth, retard or uneven maturity and lower quality.

Table 2 presents the characteristics of experimental soil collected at 25 cm depth before the commencement of irrigation (SBI), soil irrigated with potable water (SIPW) and soil irrigated raw wastewater (SIRW). The average pH values of the irrigated soils are 7.32, 7.49 and 7.79, respectively for SBI, SIPW and SIRW. Application of potable water and raw wastewater showed an increased pH values for the both soils indicating that a decrease in nutrient availability is expected as explained by [7]. Similarly, an increase and a decrease in EC were observed for SIRW and SIPW, respectively. This finding was reported by different researchers [7] stating that wastewater irrigation increases salinity content of a soil. Both SIPW and SIRW contained higher organic matter (OM) compared with SBI in the top layer of the spinach soil. Increase in organic matter content of the soil can improve the physical, chemical and biological characteristics of the soil [12]. The total nitrogen (TN) content of SIRW was greater than those of SBI and SIPW. This is as a result of the application of domestic wastewater to the vegetated soil. This observation was also reported in [7], they stated that any type of waste including wastewater, pig slurry and sewage sludge can increase the fertility of the soil.

The SIRW has higher exchangeable Na, K and Mg than SIPW. Irrigation with raw wastewater is responsible for this increment. This is related to the observations made by [7]. Similarly, SIRW has higher cation exchange capacity (CEC), this will give SIRW more nutrient dominance which can be taken up by plants when the need arises [13].

Table 2. Soil analysis at depth 25 cm (average value ± Std)

Parameters	SBI	SIPW	SIRW
pH	7.32±0.05	7.49±0.01	7.79±0.01
EC (dS/cm)	0.89±0.01	0.61±0.02	2.280±0.07
OC (%)	1.69±0.01	0.65±0.01	1.81±0.06
OM (%)	2.70±0.06	2.94±0.07	3.10±0.15
TN (%)	0.27±0.02	0.09±0.01	0.69±0.02
Available P (mg/kg)	5.83±0.33	4.24±0.01	8.60±0.08
Exchangeable Na (cmol/kg)	1.35±0.21	1.18±0.01	1.26±0.01
Exchangeable K (cmol/kg)	1.31±0.04	1.91±0.02	2.26±0.20
Exchangeable Mg (cmol/kg)	9.78±0.15	6.77±0.04	7.34± 0.16
CEC (cmol/kg)	23.52±0.02	23.10±0.14	23.94±0.08

Figs. 4 and 5 shows observable physical growth differences between spinach grown in plot A (RW) and plot B (PW) subjected to the same growing conditions from germination to maturity. At germination, spinach in plot A had lower density while plot B showed a greater population density. This low yield is observed due to the quality of the raw domestic wastewater which contain low DO, TDS and EC values that were classified as moderate restrictions [3]. In addition, water with low DO are restricted for irrigation of vegetables [2]. Meanwhile, during the growing period, high prevalence of weeds was observed in plot A which hindered the growth of spinach, this was however not the case with plot B which had increased density. At maturity, spinach performed better in plot A than in plot B (Fig. 5).

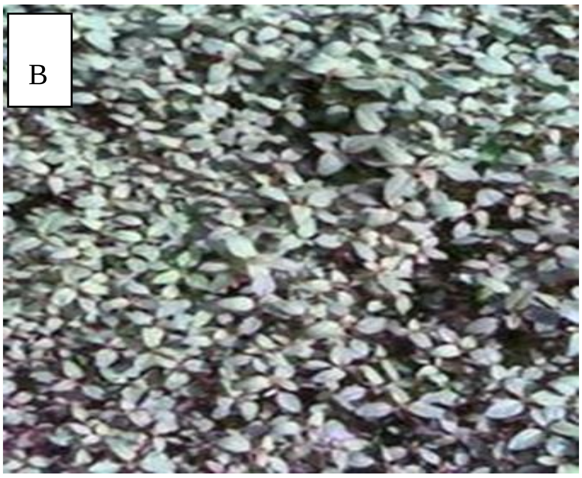

Fig. 4. Spinach germination on: (A) SIRW and (B) SIPW

To determine the nutritional composition of spinach grown in soil irrigated with raw domestic wastewater and potable water, proximate, mineral and vitamin analysis were carried out. The proximate composition of spinach leaf is presented in Table 3. Comparing the composition of spinach from plot A and plot B, spinach from plot A has a moisture content (MC) of 87.07% and a higher MC of 90.80% from plot B. These values are higher than the value reported for water spinach by Umar et al. [14]. Generally, leafy spinach from plots A and B are slightly higher than each other. It has a low ash content, indicating that it contained low mineral content [14], since ash content is an indication of mineral composition [15].

Table 3. Proximate composition of spinach leaf (value per 100g of edible portion)

Parameter	RWW	PW
Moisture content, %	87.07	90.80
Ash	2.41	2.50
Protein	2.70	2.79
Fat/Oil	0.36	0.31
Fibre	1.78	2.00
Carbohydrate	5.46	3.60

The mineral nutrient of edible part of spinach is presented in Table 4 the concentrations of these elements varied in the spinach samples with K having the highest value for both spinach from plot A and plot B. Umar et al. [14] suggested that the high content of potassium in leafy spinach may be attributed to its abundance in Nigerian soil. Other element following the order of Ca > Mg > P > Vit. C > Fe. The Fe content in the edible part of the spinach was low for plot A and plot B with plot B exhibiting a higher content (Table 4). Al-Ansari [4] in their study also reported low concentration of Fe for sweet pepper (0.14-0.24 mg/kg), tomato (0.25-0.38 mg/kg) and cauliflower (0.12-0.22 mg/kg). Arora [16] reported that spinach has higher affinity for Fe.

Fig. 5. Maturity Stage of Spinach on: (A) SIRW and (B) SIPW

Table 4. Mineral nutrient content of spinach leaf (value per 100g of edible portion)

Parameter	RWW	PW
Potassium	543	530
Calcium	97.0	95.0
Magnesium	76.1	75.0
Phosphorus	47.4	45.1
Iron	1.21	1.93
Vitamin C	25.4	24.1

4 Conclusion

Spinach (*Spinacia Oleracea*) is common vegetable that is easily cultivated either by rainfed or by irrigation. It is rich in macro and essential nutrients. This study investigated the effects of raw domestic wastewater on its nutritional composition. The proximate and mineral nutrient composition of spinach irrigated with raw domestic wastewater (plot A) was lower than the potable water fed plots (plot B) implying that the spinach from the raw domestic wastewater irrigation had lower quality. At maturity, spinach from plot A had higher population density than plot B.

The raw domestic wastewater contained excessively high nutrients, resulting into intensive growth, retard maturity as well as low yield. The wastewater irrigated soil had increased exchangeable Na, K and Mg. the quality of the raw wastewater was of moderate restriction, thus proper treatment of the water is highly recommended before irrigation of vegetables.

References

[1] K. Kaboosi, "The assessment of treated wastewater quality and the effects of mid-term irrigation on soil physical and chemical properties (case study: Bandargaz-treated wastewater)," *Applied Water Science,* vol. 7, pp. 2385-2396, 2017.

[2] J. Xavier and A. K. Varghese, "Effect of Treated and Untreated Domestic Sewage Water Irrigation on Tomato Plants," *Asian Journal of Plant Sciences,* vol. 19, no. 3, pp. 252-260, 2020.

[3] S. Chaoua, S. Boussaa, A. El Gharmali and A. Boumezzough, "Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco," *Journal of the Saudi Society of Agricultural Sciences,* vol. 18, pp. 429-436, 2019.

[4] N. Al-Ansari, W. Aldardor, D. Siergieiev and S. Knutsson, "Effect of trated wastewater irrigation on vegetables," *Journal of Environmental Hydrology,* vol. 21, no. 5, pp. 1-13, 2013.

[5] H. I. Mustapha and O. B. Adeboye, "Heavy metals accumulation in edible part of vegetables irrigated with untreated municipal wastewater in tropical savannah zone, Nigeria," *African Journal of Environmental Science and Technology,* vol. 8, no. 8, pp. 460-463, 2014.

[6] Z. A. Bazai, A. k. K. Achakzai and S. Gul, "Bioaccumulation of micro elements in spanish (Spinacea oleraceac L.) irrigated with wastewater from Quetta City," *International Journal of Botany,* vol. 1, no. 2, pp. 219-222, 2006.

[7] F. M. Kiziloglu, M. Turan, U. Sahin, Y. Kuslu and A. Dursan, "Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (Brassica olerecea L. var. botrytis) and red cabbage (Brassica olerecea L. var. rubra) grown on calcareous soil in Turkey," *Agricultural Water Management,* vol. 95, pp. 716-724, 2008.

[8] H. R. Alzahrani, H. Kumakli, E. Ampiah, T. Mehari, A. J. Thornton, C. M. Babyak and S. O. Fakayode, "Determination of macro, essential trace elements, toxic heavy metal concentrations, crude oil extracts and ash composition from Saudi Arabian fruits and vegetables having medicinal values," *Arabian Journal of Chemistry,* vol. 10, pp. 906-913, 2017.

[9] American Public Health Association (APHA), American Water Works Association, Water Environment Federation., Standard methods for the examination of water and wastewater, E. W. Rice and L. Bridgewater, Eds., Washington, D.C.: American Public Health Association, 2012.

[10] R. Ayers and D. Westcot, "Water Quality for Agriculture," *FAO Irrigation and Drainage Paper 29 Rev. 1* , 1994.

[11] WHO, "A compendium of standards for wastewater reuse in the Eastern Mediterranean Region," World Health Organization , , Cairo , 2006.

[12] S. S. Singwane and P. Malinga, "Impacts of pine and Eucalyptus forest plantations on soil organic matter content in Swaziland - Case of Shisel Weni Forests," *Journal of Sustainable Development in Africa* , vol. 14, no. 1, pp. 137-151, 2012.

[13] M. R. Motsara and R. N. Roy, Guide to Laboratory Establishment for Plant Nutrient Analysis, vol. , Rome: FAO , 2008, pp. 17-50, 77-87 and 91-122..

[14] K. J. Umar, L. Hassan, S. M. Dangoggo and M. J. Ladan, "Nutritional composition of water spinach (Ipomoea aquatica Forsk.) leaves," *Journal of Applied Sciences,* vol. 7, no. 6, pp. 803-809, 2007.

[15] J. O. Unuofin, G. A. Otunola and A. J. Afolayan, "Nutritional evaluation of Kedrostis africana (L.) Cogn: An edible wild plant of South Africa," *Asian Pacific Journal of Tropical Biomedicine,* vol. 7, no. 5, pp. 443-

449, 2017.

[16] M. B. Arora, R. Kiran, A. Shweta, B. Rani and N. M. Kaur, "Heavy metal accumulation in vegetables irrigated with water from different sources," *Food Chemistry*, vol. 111, no. 4, pp. 811-815, 2008.