◉GhIE

CASE STUDY

Assessment of irrigation water quality for vegetable production in the Bono and Bono East regions

Emmanuel Amankwah[1,]*, Prince Antwi-Agyei[2], Emmanuel K. Nyantakyi[2], Isaac M. Bryant[3], Napoleon J. Mensah[4], Godfred E. Sebiawu[5], Samuel Antwi-Akomeah[6]

Abstract

Irrigation water quality is one of the key parameters for healthy plants growth and maintenance of healthy soils for abundant food production. This research examines the physicochemical parameters of irrigation water and its suitability for crop production in the Bono and Bono East regions. The suitability of irrigation water for vegetable production is to ensure that fresh vegetables produced are of good quality, since the vegetables are mostly eaten raw. Four irrigation dams in Subinja, Kaniago, Tanoso and Akrobi from the two regions were selected and water samples from each of the dams were collected during the dry and wet seasons. The samples were analysed for physical parameters, heavy metals and soluble cations and anions at the GWCL laboratory using standard laboratory procedures and techniques. The various parameters examined showed that EC, SAR, TDS, pH and the ionic concentrations (Ca^{2+}, K^+, Mg^{2+}, Na^+, Cl^-, NO_3^-) were found within the WHO recommended limits and therefore, suitable for irrigation of vegetables. However, Na^+ values for dry and wet seasons were found to be above the permissible limits and therefore, can only be suitable for salt tolerant crops. K^+ was also found to be higher across all the dams. Elements such as Cu, Pb and As ions, which might cause toxicity of the irrigation water were low except Cr, which had no effect on the quality of the irrigation water. The study recommends further studies on the quality of vegetables produced from the dams and its impact on consumers.

Keywords: Irrigation Dams, Physicochemical Parameters, Water Quality, Bono Regions

Introduction

Water is a basic requirement for life and a key resource for domestic, agricultural, industrial and other human activities. Water has no close substitute making it an indispensable commodity and thus its quality should not be compromised. Drought, acute water scarcity and excessive water demand has necessitated the use of wastewater for irrigation and other purposes (Misra, 2014)

Water quality is a very important parameter for human health, the environment and for the production of quality crops in large quantity (Hoek *et al.*, 2001). The quantity and quality of irrigation water available to farmers and other irrigation activities have considerable impact on the health and productivity of farm produce and general agricultural practices. Due to the impact of climate variability and change and other factors, water will become one of the most fiercely challenged resources on earth (Hertel and Liu, 2019) for domestic and agricultural applications. Proper irrigation management is becoming critically important as demand and competition for water quality and quantity is needed for high crop growth. Water quality indices provide a simple and understandable tool for the suitability of water quality for irrigation but that factor alone is not enough as it may be influenced by soils, crop management and drainage. The use of surface water for irrigation as a source of water supply during wet periods, and ground water during drought (Faunt, 2009) are very essential in the midst of water scarcity in arid and semi-arid areas. Proper agronomic practices, social and economic factors must also be adopted to increase the quantity and quality of irrigation water for crop production. Irrigation water derived from rainfall, surface and underground sources may contain appreciable quantities of chemical substances in solution that may decrease crop yield and deteriorate soil fertility. Irrigation water quality can have effects on the management of soils, crop growth and food safety and thus the need for such assessment (Allende and Monaghan, 2015).

Irrigation water always carries substances derived from its natural environment or from the product of man's activities. The quality of irrigation water varies with its sources. The chemical constituents of irrigation water can affect plant growth directly through deficiency or toxicity, or indirectly by changing plant available nutrients (Ayres and Westcot, 1985; Rowe and Abel-Magid, 1995). Irrigation water can also vary, to a great extent, in quality depending upon the type and quantity of dissolved salts. Extended use of irrigation water could cause deterioration in the soil physical properties, and thereby results in the decrease of crop yield due to accumulation of dissolved salts (Oladeji *et al.*, 2012). The quality of irrigation water is often characterized by Sodium Adsorption Ratio (SAR), Electrical Conductivity (EC), Residual Sodium Carbonate (RSC), Soluble Percentage (SP), and Kelly's ratio (Golekar *et al.*, 2013). Research has shown that wastewater is used for irrigation especially in peri-urban vegetable production and this eventually results in many health challenges (Hamilton *et al.*, 2007). Continuous use of poor irrigation water from varied sources may results in excess salinity (salts) and toxic elements such as boron, nitrogen and iron that will affects plants growth and influence the osmotic relationship between roots and soil moisture (Malash *et al.*, 2005). For effective agricultural production, water availability, quality and quantity will play a key role in proper plant growth and yield, animal watering, milk

*Corresponding author: emmanuel.amankwah@uenr.edu.gh

[1]Department of Environmental Management, UENR, Sunyani, Ghana.

[2]Department of Civil and Environmental Engineering, UENR, Sunyani, Ghana.

[3]Department of Environmental Science, UCC, Cape Coast, Ghana.

[4]Department of Science Laboratory Technology, Wa Technical University, Wa, Ghana.

[5]Department of Dispensing Technology, Wa Technical University, Wa, Ghana

[6]Forensic Science Laboratory, Ghana Police Service, Accra, Ghana

yields and beef production (Tolgyessy, 1993). Water from lakes, dams and groundwater aquifers with varying geology may also influence the water quality (and Westcot, 1994; Nahid *et al.*, 2008).

To assess irrigation water quality, the parameters such as percentage sodium (Na %) and Sodium Adsorption Ratio (SAR) will be calculated based on the chemical variables of water samples (Singh *et al.*, 2005). The irrigation water assessment indices include:

All the ionic concentrations are expressed in milliequivalents per litre (meq/L) of the respective ions. This research therefore examines the physicochemical parameters of irrigation water quality and its suitability for crop production in the Bono and Bono East regions. This will ensure that quality vegetable are produced to warrant public safety and health.

$$\text{Percentage sodium} = \frac{Na^+}{Na^+Ca^{2+}Mg^{2+}K^+} * 100\% \quad (1)$$

$$\text{Sodium Adsorption Ratio, SAR} = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+}Mg^{2+})}} \quad (2)$$

Materials and Methods
Description of the study area
The research was carried out in four farming communities in the Wenchi and Techiman Municipalities where the irrigation dams are located. The communities are Subinja, Akrobi, Kaniago and Tanoso. The Wenchi Municipality lies within latitudes 7° 30′ and 8° 05′ North and longitudes 2° 15′ West and 1° 55′ East and covers 3,494 km² of land. The Techiman Municipality lies between longitude 1° 49′ East and 2° 30′ West and 8° 00′ North and 7° 35′ South with a total land area of 1,119 km² and an estimated population of 243, 334 (GSS, 2021). The Wenchi Municipality being the largest district in the Bono region shares borders with Techiman Municipality to the west. The two Municipalities have similar characteristics in terms of climate, agricultural productivity and vegetation.

The predominant occupation in both Municipalities is agriculture (GSS, 2010). The average temperature of the area is 24.5 ℃ with maximum temperature being 30.9 ℃ and a minimum of 21.2 ℃ and the hottest season being February and March. The annual amount of rainfall ranges from 1,140 to 1,270 mm. The four selected communities in the Municipality have similar weather conditions and agricultural productivity. The major crops produced are maize, groundnut and garden eggs, yam, cassava and other crops. The irrigations in the selected communities are mainly used for crop production such as water melon and vegetables. Subinja and Akrobi farming communities are located in Wenchi Municipality with total land area of 121 and 40 hectares under cultivation respectively. Tanoso and Kaniago are located in the Techiman Municipality with a total land area of 60 and 100 hectares of land also under cultivation.

Methods of data collection and analysis
Water for irrigation can come from different sources but must meet the technological and quality requirements. The criterion for analysis is not as stringent as those for drinking purposes but it must satisfy the WHO / FAO standard for drinking water since it is used to produce vegetables which are sometimes eaten raw. Ensuring water quality is of great significance especially in areas where there is high level contamination from excreta-related diseases and infrequent water treatment systems (WHO, 2006).

Twenty-four water samples were collected from four irrigation dams in clean plastic bottles of 500 mL each during the wet and dry seasons for physicochemical analysis with 6 samples from each irrigation dam. The sample bottles of 500 mL were properly cleaned and sterilised with distilled water to avoid contamination (Anim-Gyampo *et al.*, 2013). Wet season samples were collected during the raining season in late June, 2020 while the dry season samples were collected in the dry season in early February, 2020 when the dams' levels were low. This is because the quality of water sources may change significantly with time and season and thus taking samples from different seasons at regular basis for analysis is highly recommended (Islam and Shamsad, 2009). Three samples were collected at two different points of each of the dam (3 meter into the water and at opposite sides of the dam) at different depths and stored in cooled boxes at a temperature of 4 ℃ (to inhibit the bacteria growth and retention of volatile materials in the sample) and transported to the Ghana Water Company Limited (GWCL), Sunyani laboratory for analyses (Cobbina *et al.,* 2013). The samples were taken in triplicates, properly capped and labelled for easy identification before transporting to the Laboratory for analyses.

Analysis of water parameters
On the field, physicochemical parameters such as pH, TDS and EC were determined using pH meter, digital TDS meter and EC meter, and the results recorded instantly while the other parameters such as Ca, Mg, Na % and heavy metals were sent to the laboratory for analysis.

The water samples collected were analysed for pH, EC, TDS, Na%, Na, Ca, Mg, Cl, K, NO3, Cu, Pb, As and Cr. All these parameters were determined according to International Standards and Laboratory Procedure (APHA/AWWA/WEF, 2017). Each of the samples were performed three times and the average values calculated for the records (Tables 1 and 2). Standard laboratory instruments employed in the analysis includes Atomic Absorption Spectrophotometry (AAS) to determine heavy metals, Nephelometric Turbidity Units (NTU) to measure turbidity, Membrane filtration method for determining the total and faecal Coliforms.

Results and Discussion
The results of the water samples collected from the four irrigation dams during the dry and wet seasons in Subinja, Akrobi, Tanoso, and Kaniango areas were analysed for various physicochemical properties as shown in Tables 1 and 2. Both dry and wet seasons showed variations in most of the parameters due to changes in the water levels. The results of the experiment showed that all the physical parameters such as pH, EC and TDS were all within the acceptable range. The heavy metals also showed higher values for Chromium, Arsenic and Copper at different ranges with Cr recording higher values for all the dams. The graphical presentation of heavy metals of the different irrigation sites is presented in Figure 1. The Potassium levels were also found to be above the recommended limit with 10.82 for Akrobi in the wet season. The bacteriological loads of the total and faecal coliform are also presented in Figure 2.

The use of irrigation water for vegetable production is very important due to the fact that untreated wastewater is mainly used for vegetable production which raises health and safety concerns (Gatto *et al.*, 2015). As opposed to the use of wastewater for irrigation of vegetables, irrigation water seems to command better quality and thus the need to examine its quality in relation to vegetable production. From Table 3, the pH from the experiment ranges from 6.5-8.2 indicating that the waters are slightly acidic and slightly basic which values are within the permissible range of irrigated agriculture. A pH range of 6.0 to 9.0 is said to provide protection for aquatic life especially fish and other bottom dwelling invertebrates as well

as plants growth (Kumar and Puri, 2012). The highest pH values were recorded in Tanoso and Nkaniago. The SAR figures are within the permissible limits including Calcium (Ca^{2+}) and Magnesium (Mg^{2+}). Ca^{2+} values ranges between 18 to 74 mg/l with Kaniago recorded the least value while Subinja recorded the highest value. Mg^{2+} concentration also range from 7 to 29 mg/l with Subinja recording the highest value and Nkaniago also recorded the least value. However, Ca^{2+} and Mg^{2+} have all their concentrations within the WHO acceptable limits of 800 and 120 mg/L, respectively (WHO, 2005). During the wet sea-

son, all the Na^+ parameter values of the irrigation dams were below the recommended limits except Subinja which value exceeded the limit. Also in the dry season, the value of Akrobi was rather high and above the limit and this could pose challenge to crop production. Irrigation water that has high sodium content can bring about a displacement of exchangeable cations Ca^{2+} and Mg^{2+} from the clay minerals of the soil, followed by the replacement of the cations by sodium. Sodium-saturated soil also peptizes and loses their permeability so that their fertility and suitability for cultivation decreases (Matthess, 1992).

Table 1 Water sampling analysis for wet and dry seasons

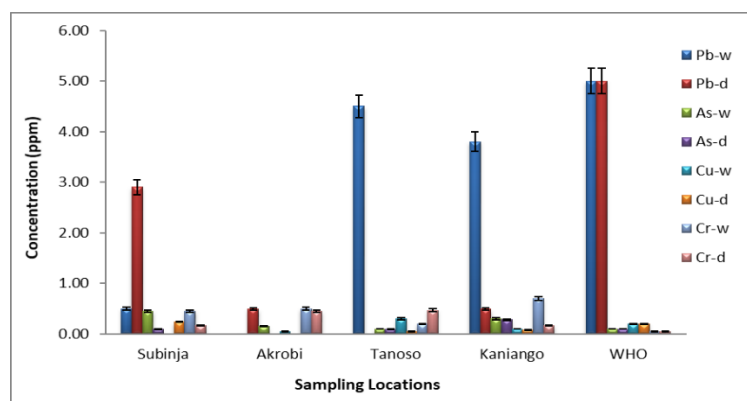| Heavy Metal (ppm)	Season	Sampling Location				WHO Permissible Limits
		Subinja	**Akrobi**	**Tanoso**	**Kaniango**	
Pb	Wet	0.50	Nil	4.50	3.80	5.00
	Dry	2.90	0.49	Nil	0.49	
As	Wet	0.45	0.15	0.10	0.30	0.10
	Dry	0.09	BDL*	0.09	0.28	
Cu	Wet	Nil	0.05	0.30	0.10	0.20
	Dry	0.24	BDL*	0.05	0.08	
Cr	Wet	0.45	0.50	0.20	0.70	0.05
	Dry	0.17	0.45	0.47	0.17	

Figure 1 Heavy metals at the different irrigation sites

Table 2 Water sampling analysis for extractable cations and anions

Extractable Ions (mg/L)	Season	Sampling Location				WHO Permissible Limits
		Subinja	**Akrobi**	**Tanoso**	**Kaniango**	
Ca^{2+}	Wet	74.00	20.00	36.00	18.00	800
	Dry	26.00	68.80	21.00	18.00	
Mg^{2+}	Wet	29.00	13.00	18.00	7.00	120
	Dry	16.40	17.80	13.50	12.00	
Na^+	Wet	328.00	102.00	86.00	117.00	200
	Dry	88.40	219.40	86.00	101.70	
K^+	Wet	4.50	10.82	3.50	1.00	2
	Dry	4.02	3.90	9.01	1.20	
NO_3^-	Wet	0.50	0.90	0.43	1.20	10
	Dry	0.45	0.62	0.59	0.72	
Cl^-	Wet	201.00	109.00	174.00	132.00	250
	Dry	118.00	109.50	78.00	92.80	

Table 3 Other physico-chemical parameters

Parameter	Season	Sampling Location				WHO Permissible Limits
		Subinja	Akrobi	Tanoso	Kaniango	
TDS (mg/L)	Wet	80.00	49.00	53.50	61.00	500 - 2000
	Dry	179.50	35.00	40.00	16.00	
SAR (meq/L)	Wet	3.22	1.75	1.17	2.33	51
	Dry	1.36	2.33	1.47	1.87	
Na%	Wet	75.32	69.95	59.93	81.82	-
	Dry	65.57	70.79	66.40	76.52	
EC (uS/m)	Wet	162.00	97.00	107.00	121.00	3000
	Dry	360.00	70.00	82.00	30.00	
pH	Wet	7.98	7.82	8.20	6.47	6.50 - 8.50
	Dry	7.32	7.03	6.82	7.19	
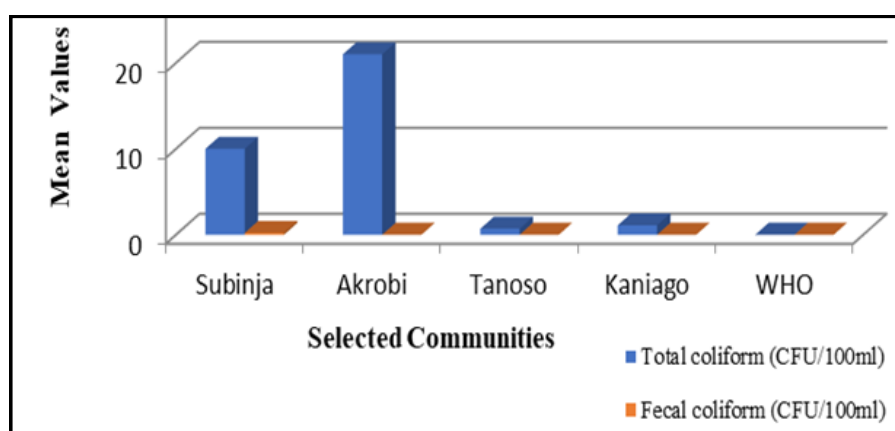
Figure 2 Biological samples analysed for total and faecal coliforms

The K^+ values also ranges between 1 to 10.82 mg/l and all the parameters are above the recommended WHO values with Akrobi having the highest K^+ and Nkaniago having the least in both seasons. High concentration of K^+ may be as a result of excessive use of chemical fertilizer in the study area and this could lead to the introduction of magnesium deficiency and chlorosis. An imbalance of Mg^{2+} and K^+ may be toxic, but the effects of both can be reduced by high calcium levels (Fipps, 2003). Chloride, an essential micronutrient, plays a key role in cell hydration and turgor maintenance during cation transportation in the plant. Cl^- and NO_3^- values fall within the acceptable limits. Also Lead values were also below the WHO limits for both wet and dry seasons which is good for plant growth. Too much lead can contaminate soils and eventually accumulate in plants through plant uptake which will cause toxicity such as stunted growth, chlorosis as well as photosynthesis distraction in plants (Drechsel, 2008). Copper values were all below the permissible limits except Subinja and Tanoso with high values in both dry and wet seasons respectively. Chromium values were found to be higher in all the four irrigation dams which could emanate from leaching from rocks into the water. Too much Cr will affect plant germination, growth and development of the physiological process of plant (Shanker *et al.*, 2005). Nitrate and Potassium are very important for plant growth but the values for Nitrate are within the acceptable limits while that of Potassium is above the WHO recommended values. Most fertilizers contain NPK which are used to improve crop production. However, higher levels of nitrate and phosphate could

cause eutrophication in water bodies (Anim-Gyampo *et al.*, 2012). It is therefore necessary that the potassium content in fertilizer application is taken note of. Key parameters useful for crop production are given attention below.

Electrical conductivity
The electrical conductivity (EC) of water is one of the important parameters for determining the quality of irrigation water and it's defined as the capacity of water to transmit electric current. It gives an indication of the salinity hazard which is the most important water quality parameter for crop production. Water with high salinity is toxic to plants and holds a salinity hazard (Fipps, 2003). EC values from the study area ranges from 97 to 162 µs/cm where Subinja recorded the highest value and Nkaniago has the least. From the classification suggested by Ayres and Westcot (1985) irrigation waters in the study area can be termed as excellent and good.

Sodium adsorption rate
Irrigation water containing large amount of sodium is of special concern due to sodium effect on the soil which poses a sodium hazard. SAR is the estimation of the degree to which sodium will be absorbed. Continued used of water having a high SAR leads to breakdown in the physical structure of the soil and a build-up of high soil sodium levels overtime which can adversely affect soil permeability. Calcium and magnesium, if present in the soil in large quantities, will counter the effects of the sodium and help maintain good soil properties (Fipps, 2003). SAR

values less than 10meq/L (SAR < 10meq/L) are classified as "Excellent, those with SAR values between 10 and 18meq/L are termed "Good" and "Doubtful" if the SAR value is between 18 and 26 meq/L. "Unsuitable" refers to the SAR values greater than 26meq/L (SAR > 26meq/L) (Maas, 1990; Sadashivaiah *et al*, 2008). Based on SAR values for the study areas ranging from 1.17 to 3.22 meq/L, all the irrigation water could be classified as excellent and would be suitable for vegetable production.

The SAR is an index that quantifies the proportion of sodium ions (Na^+) to calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}) in a sample. Calcium will flocculate (hold together), while sodium disperses (pushes apart) soil particles. This dispersed soil will readily crust which will cause infiltration and permeability challenges. Sodium in irrigation water can also cause toxicity problems for some crops and rusting of the metals pipes used for irrigation. Crops vary in their susceptibility to sodium toxicity damage (Maas, 1990). However, large amount of calcium and magnesium in soil will reduce the effects of the sodium and help maintain good soil properties (Cobbina *et al.*, 2013). Good proportion of Ca^{2+} and Mg^{2+} is favourable for good permeability.

Sodium percentage
The Na% is an indication of the soluble sodium content of the irrigation water and also used to evaluate Na hazard. In all-natural waters, Na% is a common parameter to assess its suitability for irrigation purposes since sodium reacts with the soil to reduce permeability (Janardhana *et al.*, 1992; Wilcox, 1955). According to Fipps (2003), water with Na% greater than 69 % may result in sodium accumulation that will cause a breakdown in the soil's physical properties. Excess Na combining with carbonate, leads to formation of alkali soils, whereas with chloride, saline soils are formed and neither soil will support plant growth (Rao, 2005). A salinity problem exists if salt accumulate in the crop root zone to a concentration that could cause a loss in yield. If water uptake is appreciably reduced, the plant slows in growth rate (Ayres and Westcot, 1985). The Na% of the irrigation waters in the study area ranges from 59.93 to 81.82. Detailed classification of irrigation water quality parameters and their impact on crop yield and quality can be found in the work of Üzen (2016). The results show that all the irrigation waters from the study areas fall under the tolerant range (Alan, 1994). This makes the dams in the study area suitable for irrigation and for the production of healthy vegetables.

Biological analysis for water samples
In many microbiological surveys, the presence of pathogenic microorganisms has been demonstrated on fruits and vegetables and numerous disease outbreaks have been linked to contaminated fruits and vegetables. This is due to the poor and below standards water quality used for vegetable irrigation in urban cities of Ghana (Antwi-Agyei, 2016). These incidence suggest that contaminated produce can have impact on human health. The risk of disease transmission is increased when fruits and vegetables are consumed raw. Fruits and vegetables may become contaminated with pathogenic microorganism when there is contact with the soil or improperly composted manure and also when washed with contaminated water, or by contact with infected food handlers. Pathogenic microorganism in irrigation water is closely associated with faecal contamination. Faecal contamination is commonly detected by the use of water quality indicators. In this study, two types of microbial quality indicators were examined; total coliforms and faecal coliforms.

Total coliforms are a heterogeneous group of bacteria that

are used to evaluate the general hygiene level of water but are not directly related to faecal contamination. Faecal coliforms are a subset of coliform bacteria that are used to estimate the concentration of *Escherichia* coli that can be observed in water samples. E. coli is a thermo tolerant coliform bacterium that is closely associated with faecal contamination of water. The total coliform values from the four irrigation sites (Subinja, Akrobi, Tanoso and Kaniago) are within the excellent class and that makes the water suitable for irrigation. The presence of Coliforms in the irrigation water samples which is higher than the recommended limit may be attributed to open defecation and poor sanitation within the farming areas which could contaminate vegetable products and make them unwholesome for consumption.

Conclusion
The assessment of irrigation water quality of selected farming communities in the Bono and Bono-East regions has been done with reference to internationally accepted standards. Results obtained from the areas show that the irrigation dams in the study areas can be classified as excellent and good, therefore, suitable for irrigation of vegetables. The irrigation dam in the study areas were also within the class of "None" based on the TDS classification. The pH, Ca, K, Cl, Na, Mg, and NO_3^- also fall in the class of 'excellent to good', therefore, vegetables produced in those communities can be consumed with less or no health implication.

The four irrigation dams in the study areas (Akrobi, Subinja, Tanoso, Nkaniago) for both dry and wet seasons had some salinity problem based on the Na % values, which were found to be doubtful and would be tolerable to crops that can withstand saline environment and sensitive to others but on the basis of SAR values for dry and wet season, the values were in excellent and had no salinity problem in the study areas. The values of toxic heavy metals Cu, Pb, and As were also found within the permissible limit except Cr. The values of biological parameters from the four irrigation sites were found in the excellent class, which make the water suitable for the production of vegetables. Overall, irrigation dam in the study areas are good for vegetable production except the parameters with high value which may require further attention. Based on the findings, it is very important to investigate the quality of vegetables produced with the irrigation water to be certain that they are completely free from contamination and health hazards.

Conflict of Interest Declarations
The authors declare that there is no potential conflict of interest.

References
Alan, D. B. (1994). Soil salinity, salt tolerance and growth potential of horticultural and landscape plants. Department of Soil and Plant and Insect Science, University of Wyoming, http://ces.uwyo.edu/PUBs/Wy988.PDF.

Allende, A., and Monaghan, J. (2015). Irrigation water quality for leafy crops: a perspective of risks and potential solutions. International Journal of Environmental Research and Public Health, 12(7), pp. 7457–7477. https://doi.org/10.3390/ijerph120707457

Anim-Gyampo, M., Kumi, M. and Zango S. M. (2013). Heavy metals concentrations in some selected fish species in Tono

Irrigation Reservoir in Navrongo. Journal of Environment and Earth Science. 3(1), pp. 109-119

Anim-Gyampo, M., Ntiforo, A. and Kumi, M. (2012). Assessment of heavy metals in wastewater irrigated lettuce in Ghana: The case of Tamale Municipality. Canadian Centre of Science and Education, Richmond Hill.

Antwi-Agyei, P., Cairncross, S., Peasey, A., Price, V. et al. (2016). A farm to fork risk assessment for the use of wastewater in agriculture in Accra, Ghana. PLoS ONE 10 (11), e0142346.

APHA/AWWA/WEF (2017). Standard methods for the examination of water and wastewater. 23rd Edition, American Public Health Association, American Water Works Association, Water Environment Federation, Denver.

Ayers, R. S. and Westcot. D. W. (1994). Water quality for agriculture, university of California. FAO, California, USA.

Ayres, R. S. and Westcot, D. W. (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, Food and Agriculture Organization of the United Nations, Rome. pp. 1-117.

Cobbina, S., Kotochi, M. C., Korese, J. K. and Akrong, O. M. (2013). Microbial contamination in vegetables at the farm gate due to irrigation with wastewater in the tamale metropolis of Northern Ghana. Journal of Environmental Protection 4, pp. 676–682.

Drechsel, P., Keraita, B., Amoah, P., Abaidoo, R. C., Raschid-Sally, L. and Bahri, A. (2008). Reducing health risks from wastewater use in urban and peri-urban sub-Saharan Africa: Applying the 2006 WHO Guidelines. Water Science Technology, 57 (9), pp. 1461–1466.

Faunt, C. C. (2009). Groundwater availability of the central valley aquifer, US Geological Survey, California.

Fipps, G. (2003). Irrigation water quality standards and salinity management strategies. Texas Farmer Collection, pp. 1-19.

Gatto, D. M. L, Salas Barboza, A. G. J., Garcés, V., Rodriguez-Alvarez, M.S., Iribarnegaray, M. A., et al. (2015). The use of (treated) domestic wastewater for irrigation: current situation and future challenges. International Journal Water and Wastewater Treatment 1(1), https://dx.doi.org/10.16966/ijwwwt.107.

Ghana Statistical Service (GSS) (2021). Ghana 2021 population and housing census: General report; volume 3A. Ghana Statistical Service, Accra, Ghana.

GSS (2010). Population and housing census 2010. Ghana Statistical Service (GSS), Accra, Ghana.

Golekar, R. B., Baride, M. V. and Patil, S. N. (2013). Assessment of surface and wastewater quality for irrigation suitability. A case study of Jalgaon Urban area, Maharashtra (India). Der. Chemica Sinica, 4(2), pp. 177-181. (Online). www.pelagiaresearchlibrary.com

Hamilton, A. J., Stagnitti, F., Xiong, X., Kreidl, S. L., Benke, K. K., et al. (2007) Wastewater irrigation: the state of play. Vadose Zone Journal, 6, pp. 823-840

Hertel, T. and Liu, J. (2019). Implications of water scarcity for economic growth. In Economy-Wide Modeling of Water at Regional and Global Scales (pp. 11-35). Springer, Singapore.

Hoek, W. V. D., Konradsen, F., Ensink, J. H. J., Mudasser, M. and Jensen, P. K., (2001). Irrigation water as a source of drinking water: is safe use possible? Tropical Medicine and International Health 6(1), pp. 46-54.

Islam, S. M. and Shamsad, M. K. Z. (2009). Assessment of irrigation water quality of Bogra District in Bangladesh. Bangladesh Journal of Agricultural Research, 34(4). pp. 597-608

Janardhana, R., Reddy, T. V. K. and Kotaiah, B. P. T. (1992). A study on seasonal variations of ground water quality in Upper Gunjanaeru River basin, Cuddapah District, Andhra Pradesh. Fresenius Environ Bullettin, 1, pp. 98–103.

Kumar, M. and Puri, A. (2012). A review of permissible limits of drinking water. Indian journal of occupational and environmental medicine, 16(1), pp. 40–44. https://doi.org/10.4103/0019-5278.99696

Maas, E.V. (1990). Crop salt tolerance. In: Tanji, K., Ed., Agricultural Salinity Assessment and Management, ASCE Manuals & Reports on Engineering Practice No. 71, ASCE, pp. 262-304.

Malash, N., Flowers, T. J. and Ragab, R. (2005). The effect of irrigation systems and water management practices using saline and non-saline water on tomato production. Agricultural Water Management, 78, pp. 25-38. Department of Agriculture Engineering, University of Cape Coast, Ghana.

Matthess, G. (1982). The properties of groundwater. Wiley, New York.

Misra, A. K. (2014). Climate change and challenges of water and food security. International Journal of Sustainable Built Environment 3, pp. 153-165.

Nahid, S., Aminul, M. H. and Elahi, S. F. (2008). Evaluation of surface irrigation water quality in Muktagacha Upazila of Bangladesh. Bangladesh Journal of Agricultural Research, 34(4), pp. 597-608.

Oladeji, O. S. Adewoye, A. O. and Adegbola, A. A. (2012). Suitability assessment of groundwater resources for irrigation around Otte Village, Kwara State, Nigeria, International Journal of Applied Sciences and Engineering Research. 1(3), pp. 437-445.

Rao, N. S. (2005). Seasonal variation of groundwater quality in a part of Guntur district, Andhra Pradesh, India. Environmental Geology 49, pp. 413–429 http://www.ghanadistricts.com/reg-info.asp?RegionID=6.

Rowe, D. R. and Abel-Magid, I. M. (1995). Handbook of wastewater Reclamation and Reuse. CRC press, Inc. p550.

Sadashivaiah, C., Ramakrishnaiah, C. R. and Ranganna, G. (2008). Hydro-chemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka State, India. International Journal of Environmental Research and Public Health, 5(3), pp. 158–164.

Shanker, A. K., Cervantes, C., Loza-Tavera, H., and Avudainayagam, S. (2005). Chromium toxicity in plants. Environment International, 31(5), pp. 739–753. https://doi.org/10.1016/j.envint.2005.02.003

Singh, A. K., Mondal, G. C., Singh, P. K., Singh, S., Singh, T. B. and Tewary, B. K. (2005). Hydrochemistry of reservoirs of Damodar River bain, India: Weathering process and water quality assessment, Environmental Geology, 48 (8), pp. 1014-1028.

Tolgyessy, J. (ed) (1993). Chemistry and Biology of Water, Air and Soil; Environmental Aspects. Volume 53 of Studies in Environmental Science, Elsevier.

Üzen, N. (2016). Use of water for agriculture irrigation and infectious diseases, Journal of Environment Protection and Ecology, 17(2), pp. 488-497.

WHO (2005). International standards for drinking water. World Health Organization, Geneva.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture, Geneva, Switzerland

Wilcox, L.V. (1955). Classification and use of irrigation water. USD circular No 969, Washinton D.C.