

Irrigation water quality and its impact on the physicochemical and microbiological contamination of vegetables produced from market gardening: a case of the Vea Irrigation Dam, U.E.R., Ghana

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ABSTRACT

The rationale for this study was to assess the physicochemical and bacteriological qualities of the Vea irrigation water and resultant effects on the quality of fresh vegetables produced in the area and associated implications for consumers' health. A total of 45 water samples were collected from the reservoir and canals. Also, 16 vegetable samples comprising four samples each of tomatoes, carrots, spring onions, and cabbages were collected from four farms with installed irrigation systems fed by the Vea Dam. The irrigation water samples were analyzed for total coliform (TC) and fecal coliform (FC), *Escherichia coli*, pH, and turbidity, while the samples of vegetables were analyzed for TC and FC, and *E. coli*. The results showed that except for pH, the bacterial loads and turbidity of the sampled vegetables and irrigation water were above the standards of the WHO and the International Commission on Microbiological Specifications for Food. Comparatively, the samples of cabbage recorded the highest levels of microbial contamination. The study suggests that the water should be treated before being used for irrigation; consumers should ensure that vegetables are properly washed and cooked/treated before consumption; and periodic monitoring and assessment should be done to ensure that the adverse effects of these activities are forestalled.

Key words | dam, irrigation, physicochemical and microbiological water quality, vegetable production

HIGHLIGHTS

- Agriculture continuously competes for a limited water supply that is becoming scarcer.
- The microbial quality of irrigation water is vital to the safety of fresh and minimally handled vegetables.
- Pasturing around water bodies affects water quality bacteriologically.
- Washing farm tools and materials and drawing water for watering crops affect water quality.
- Piling dung along water body affects irrigable water through runoff.

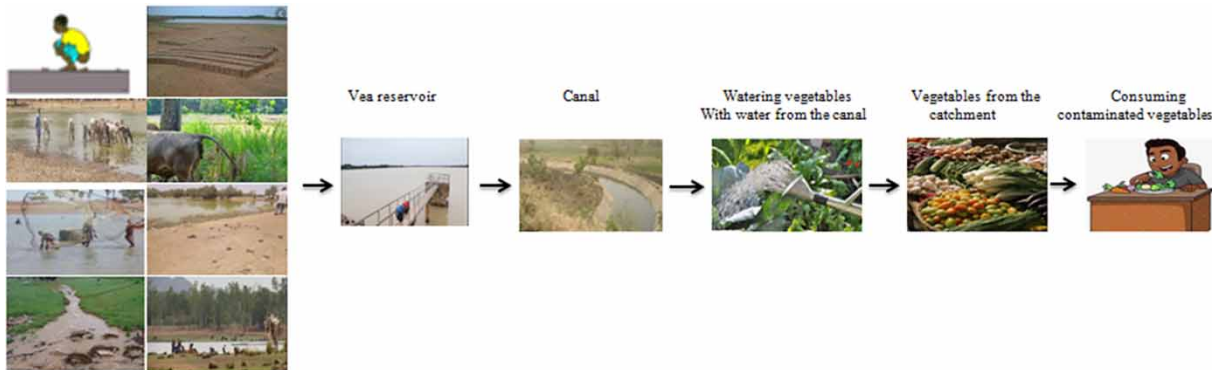
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GRAPHICAL ABSTRACT



INTRODUCTION

The scarcity of water has become a critical concern for global agriculture. It has become prudent that agricultural water users conserve water since agriculture continuously competes for limited water supply that is becoming scarcer. One method of combating food insecurity and water scarcity is irrigation (Ding 2018). Irrigation is globally essential (Howell 2001). According to Jensen (2007), population increase puts pressure on irrigation systems. From canals, wells, and dams, water is made available to support households and livestock, as well as for irrigation purposes. However, a challenging factor in the potential health hazards emanating from the usage of open water sources for the production of vegetables due to contamination cannot be underestimated (World Commission on Dams (WCD) 2000; United Nations 2003). Therefore, in low-income countries, including Ghana, untreated wastewater is predominantly used for farming (Scott *et al.* 2004). According to Westcot (1997), in commercial and small-scale farming, streams, lakes, groundwater, and dams, which do not meet the desired standards of irrigation, are predominantly used. Studies by Keraita & Drechsel (2004) and Scott *et al.* (2004) revealed that in certain cases, wastewater is deliberately used for irrigation because it is cheaper and provides organic nutrients. However, the associated environmental and health risks are ignored.

The microbiological characteristics of irrigation water are prudent predominantly because water polluted with

excreta can introduce pathogens into farm products (FDA/CFSAN 2001). The enteric bacterial load of fresh vegetables is an important concern for all patrons in the food industry, both locally and globally (Chang & Fang 2007). However, according to Scott *et al.* (2004), developing countries are unable to effectively treat wastewater before disposal. Therefore, large volumes of wastewater get into natural water systems, which are further used for irrigation.

In Ghana, a study carried out between 2007 and 2008 by the Small Grants Programme (SGP) of the UNDP/GLOBAL Environmental Facility (GEF) discovered that vegetables consumed in Accra had additional dozens of chemicals and fecal coliform (FC) above permissive limits. Less than 10% of urban dwellers have access to proper water systems. Thus, wastewater is channeled from gutters to larger drains and streams for irrigation (Keraita *et al.* 2003). In some instances, low-quality water from drains, shallow wells, and streams is used (Amoah *et al.* 2006).

According to Keraita & Drechsel (2004), in Ghana, there is a high demand for fresh produce (vegetables). For instance, though fresh salad is not a major component of Ghanaian diets, in recent times, it has become a common supplement in fast foods. This is predominately due to the awareness of its health benefits (Heaton & Jones 2008). Though Cornish *et al.* (1999), Mensah *et al.* (2001), Keraita *et al.* (2003), and Amoah *et al.* (2006) revealed that low-quality water was used for vegetable production (irrigation) in some urban

cities in Ghana, in Accra, for instance, according to Amoah *et al.* (2007), about 200,000 individuals patronize such supplements daily. This study was, therefore, conducted to assess the irrigation water quality (physicochemical and microbiological properties) of the Veia Dam, and its impacts on the quality of the vegetables produced from market gardening, and consumer health. The research also evaluated the effects of the irrigation water quality on the health risks that the people and the livestock that resort to using the dam as a source of drinking water are exposed to.

METHODS

Description of the study area

The Veia irrigation project is one of the strategic investments in the Upper East Region of Ghana. It is a multipurpose project that supports crop, fish, and livestock production, as well as domestic purposes. The Veia Dam is located in the Bongo District between latitudes $10^{\circ}48'$ and $10^{\circ}56'$ north and longitudes $0^{\circ}44'$ and $0^{\circ}56'$ west (Figure 1). It shares

boundaries with Balungu, Zaare, Gowrie, and Veia townships to the north, south, east, and west, respectively (GSS 2010). The area forms part of the Guinea Savannah Woodland, which is characterized by a single maximum rainfall ranging between 600 and 1,400 mm (Ampadu *et al.* 2015b).

Its catchment communities are Balungu, Bolgatanga, Bongo, Dindubisi, Gowrie, Nyariga, Sumbrungu, Veia, Yikine, and Zaare. However, people outside these catchment communities have access to irrigation facilities, especially for fishing, research, and recreational activities. The focus of the Veia Irrigation Dam was to enhance food production and economic standards through crop production, animal rearing, fishing, and agroforestry. The dam is also a source of drinking water to some areas within the Upper East Region (BONDA 2014; Ampadu *et al.* 2015a).

According to the Irrigation Company of Upper Region (ICOUR) report 1995, the construction of the Veia Dam started in 1965–1980. The dam is fed by the Yarigatanga River. It covers a potential area of 1,197 ha. However, the developed area covers 852 ha, and it was originally constructed to serve 468 ha of irrigation area. It is particularly helpful in the dry season farming of common vegetables/crops, such as rice, tomatoes, pepper, and onions. Small-scale fishing activities are also done within the catchment (GSS 2010).

Sampling site

The research was conducted within the Veia catchment, specifically on the Veia Dam, Nyariga canal, and four vegetable farms irrigated with water from the canal. Vegetables comprising tomato, cabbage, spring onion, and carrot were collected for microbial analyses. A preliminary visit to the study area in the form of a reconnaissance survey was carried out to, among other things, determine the various vegetables cultivated within the catchment.

Sample collection

The catchment was divided into three grids/zones, i.e. the upstream, the middle stream, and the downstream using ArcGIS 9.3©. Within each subdivision, three locations were identified at the entry, middle, and exit points of the subdivision. Three water samples (500 ml each) were collected from these locations at a depth of 5 cm below the surface of the

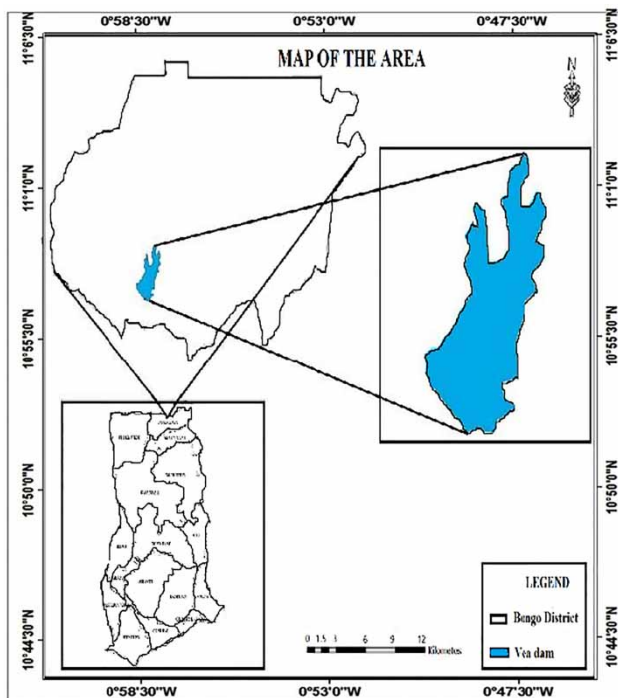


Figure 1 | Map of the study area.

water. The centered value of each sampling location was computed, showing an average of nine water samples. From the Nyariga canal, 18 water samples (two at each point) were collected at an interval of about 10 m, and the mean of each point was calculated. This translates to an average of nine water samples. A total number of 45 water samples were collected from the reservoir (27 samples) and the canal (18 samples). The centered value of each grid was calculated. The water samples were contained in 500 ml sterile plastic bottles, which were preconditioned under washing with a detergent and de-ionized water to prevent external contamination (Anim-Gyampo et al. 2013).

Following Cobbina et al. (2013), the samples of fresh vegetables (tomatoes, cabbages, spring onions, and carrots) were randomly collected from four farms with installed irrigation systems from the Nyariga canal, which is fed by the Vea Dam. A total of 16 vegetable samples comprising four samples of each of the vegetables under study were collected. This study involved samples that had been grown for more than 60 days. Each vegetable sample was divided into four, and two opposite quadrants were further divided and weighed to 10 g. This was to cater for both outer and inner contamination. The weighed samples were rinsed vigorously in 500 ml of distilled water in clear plastic containers, which were preconditioned under sterilization with a detergent, warm water, and then distilled water. Afterwards, following Cobbina et al. (2013), 200 ml of the water used in rinsing each of the vegetable samples was measured into sterile screw-capped glass bottles analyzed for FC, total coliform (TC), *Escherichia coli*, and *Salmonella*. The water samples were contained in an ice chest at a temperature around 4 °C (Cobbina et al. 2013). The spatial locations of all the water and vegetable sampling points on the digitized grid map were recorded in an eTRex Garmin GPS and used in the field (catchment and randomly selected farms) to locate these points and collect the corresponding water and vegetable samples (Figure 2).

Laboratory analyses

Bacteriological method

The membrane filtration technique was employed to determine TC, FC, *E. coli*, and *Salmonella*. Bacteriological

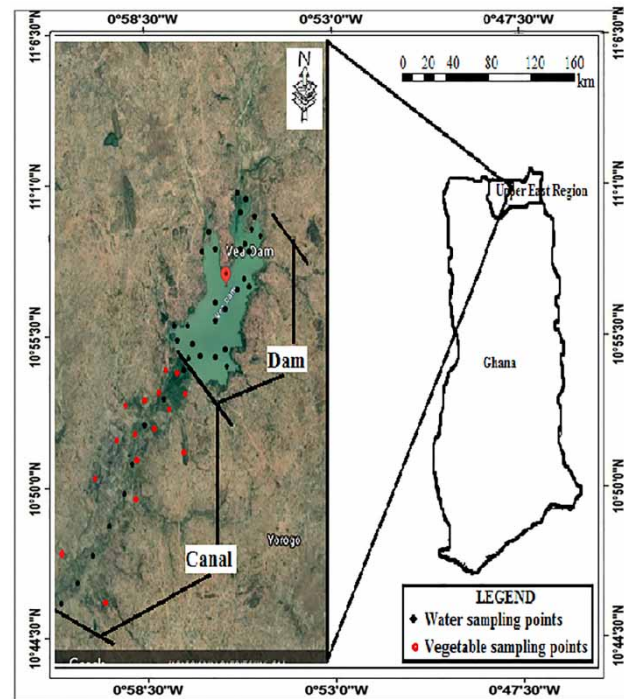


Figure 2 | Map showing water sampling sites.

parameters were determined by filtering 100 ml of the water samples through 0.45 µm pore-size cellulose membrane filters. The membrane filters were then plated on media for faecal coliform (mFC) agar and incubated at 44 ± 2 °C for 18–24 h for FC, m-Endo, and *Salmonella–Shigella* agar media at an incubated temperature of 37 ± 2 °C for 18–24 h to enumerate TC and *Salmonella*, respectively (APHA 1998), while membrane infiltrating (MI) agar media at an incubated temperature of 35 ± 0.5 °C for 24 h were used for *E. coli* (USEPA 2002).

Determination of physicochemical parameters

The pH and the turbidity of the water samples were also determined. The pH was measured with a 211 Chip pH meter (Hanna Instruments Inc., Woonsocket, RI, USA), whereas turbidity was determined using an H1 93703 Microprocessor turbidity meter.

Analysis of data

The descriptive statistics were computed using Microsoft Excel 2016 version. The enteric bacteria loads of TC, FC,

and *E. coli* (CFU/100 ml) were normalized by log transformation for the analysis of variance using the Microsoft Excel 2016 version and R software. The significance level (one-way ANOVA) of the analyzed results was quoted at $P < 0.05$. An empirical orthogonal function (EOF) was done on the obtained data and the cumulative proportions were used in the interpretation of the results, whereas the interrelationships of the variables were determined using covariance–variance analysis. pH and turbidity were not considered in the EOF and covariance–variance analysis since they were not included in the assessment of vegetable quality.

RESULTS

The bacteriological quality of water samples

Table 1 and Figure 3 present the summarized results of the enteric bacterial load of the irrigation water from the reservoir and the canal. The results of the water samples from the dam showed that the population of TC ranged between 3.56 and 3.98 (log CFU/100 ml), while the FC results ranged from 3.20 to 3.96 (log CFU/100 ml). The results of *E. coli* analysis ranged between 3.00 and 3.95 (log CFU/

Table 1 | The enteric bacteria load of water from the reservoir and the canal (log CFU/100 ml)

Parameter	Samples									Min.	Max.	Med.	Avg.	SD	Skew	Kurt.	
	S1	S2	S3	S4	S5	S6	S7	S8	S9								
Dam																	
TC	3.92	3.97	3.98	3.77	3.74	3.86	3.65	3.56	3.77	3.56	3.98	3.77	3.80	0.14	-0.32	-0.79	
FC	3.92	3.96	3.39	3.20	3.41	3.39	3.81	3.17	3.74	3.17	3.96	3.41	3.55	0.31	0.14	-1.80	
<i>E. coli</i>	3.96	3.95	3.75	3.04	3.41	3.25	3.39	3.0	3.0	3.00	3.96	3.39	3.42	0.39	0.40	-1.50	
<i>Salmonella</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Canal																	
TC	3.78	3.86	3.87	3.79	3.89	3.91	3.74	3.8	3.88	3.74	3.91	3.86	3.84	0.06	-0.37	-1.38	
FC	3.62	3.70	3.82	3.39	3.46	3.66	3.78	3.74	3.54	3.39	3.82	3.66	3.63	0.15	-0.50	-0.85	
<i>E. coli</i>	3.17	3.39	3.17	3.41	3.04	3.25	3.54	3.45	2.27	2.27	3.54	3.25	3.19	0.38	-2.04	4.92	
<i>Salmonella</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

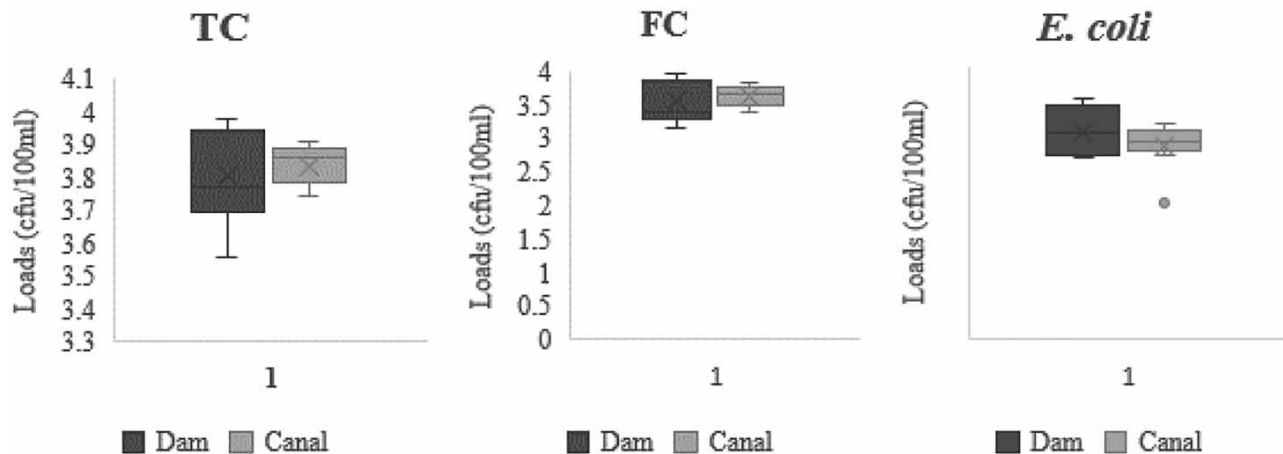


Figure 3 | Comparative box plots of enteric bacteria loads of samples from the dam and the canal.

100 ml). Meanwhile, the water samples recorded no concentration of *Salmonella*. Sampled water from the canal (Table 1) revealed that the population of TC and FC ranged between 3.74 and 3.92 (log CFU/100 ml) and 3.39 and 3.82 (log CFU/100 ml), respectively. The results of *E. coli* ranged from 3.17 to 3.54 (log CFU/100 ml), whereas the *Salmonella* load was negative.

The bacteriological quality of vegetable samples

Table 2 and Figure 4 show the bacteriological quality and the statistical derivations of the results obtained from the analysis of the sampled vegetables. *E. coli*, TC, and FC were found in tomato, carrot, spring onion, and cabbage samples. However, *Salmonella* was not detected during this study. The average CFU/g wet weights of the tomato samples were 3.83 ± 0.10 , 3.29 ± 0.05 , and 3.27 ± 0.03 for TC, FC, and *E. coli*, respectively. Also, the average CFU/g wet weights of the carrot samples were 3.74 ± 0.04 ,

3.35 ± 0.14 , and 3.33 ± 0.07 , respectively, for TC, FC, and *E. coli*, while those of spring onion and cabbage were 3.67 ± 0.05 , 3.32 ± 0.07 , and 3.26 ± 0.05 and 3.92 ± 0.05 , 3.5 ± 0.05 , and 3.34 ± 0.08 for TC, FC, and *E. coli*, respectively.

The enteric bacteria analyses of the sampled vegetables revealed that the TC load in the tomato samples ranged between 3.75 and 3.90 (log CFU/10 g), whereas the carrot, spring onion, and cabbage samples recorded TC ranging between 3.70 and 3.79 (log CFU/10 g), 3.60 and 3.71 (log CFU/10 g), and 3.85 and 3.96 (log CFU/10 g), respectively. Additionally, the laboratory analysis showed that FC in the tomato, carrot, spring onion, and cabbage samples ranged from 3.25 to 3.35 (log CFU/10 g), 3.25 to 3.45 (log CFU/10 g), 3.25 to 3.35 (log CFU/10 g), and 3.50 to 3.54 (log CFU/10 g), respectively. Though the vegetable samples showed no traces of *Salmonella*, *E. coli* levels for tomato, carrot, spring onion, and cabbage ranged from 3.25 to 3.32 (log CFU/10 g), 3.25 to 3.40 (log CFU/10 g), 3.20 to 3.32 (log CFU/10 g), and 3.25 to 3.41 (log CFU/10 g), respectively. The highest levels of contamination of TC, FC, and *E. coli* of vegetables were detected on cabbage. The analysis of variance showed that there was no significant difference ($P > 0.05$) in TC counts in the vegetables and irrigation water. There was, however, a significant difference ($P < 0.05$) in FC and *E. coli* loads in fresh vegetables (cabbage and tomatoes) and irrigation water.

Table 2 | Statistical summary of bacteria loads of sampled vegetables (log CFU/10 g)

Vegetable	TC	FC	<i>E. coli</i>
Tomatoes	3.83 ± 0.07	3.29 ± 0.05	3.27 ± 0.03
Spring onion	3.67 ± 0.05	3.32 ± 0.07	3.25 ± 0.05
Carrot	3.74 ± 0.04	3.35 ± 0.09	3.33 ± 0.07
Cabbage	3.92 ± 0.05	3.50 ± 0.04	3.34 ± 0.08

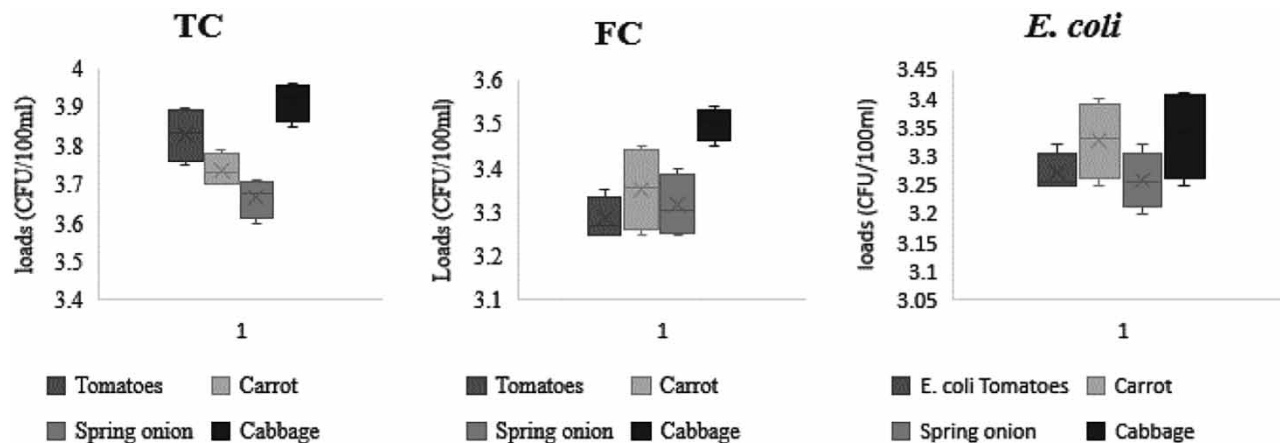


Figure 4 | Comparative box plots of enteric bacteria counts of vegetable samples.

Table 3 | Physicochemical properties of the water samples

Variables	Samples															
	S1	S2	S3	S4	S5	S6	S7	S8	S9	Min.	Max.	Med.	Avg.	SD	Skew	Kurt.
Dam																
Turbidity	87.50	101.00	103.00	85.00	87.50	75.5	85.10	71.00	73.00	71.00	103.00	85.10	85.38	11.29	0.39	-0.76
pH	7.89	8.42	7.67	7.60	8.32	7.56	7.83	7.95	8.25	7.56	8.42	7.89	7.94	0.32	0.35	-1.45
Canal																
Turbidity	75.50	110.00	110.00	95.00	90.00	95.00	75.00	102.00	85.00	75.00	110.00	95.00	93.06	13.09	-0.10	-1.13
pH	6.96	7.64	7.85	7.45	7.35	7.40	7.75	7.64	7.55	6.96	7.85	7.55	7.51	0.26	-1.01	1.58

Physicochemical properties of the irrigation water

Table 3 and Figure 5 show the physicochemical properties of the water samples taken from the dam and the irrigation canal. The turbidity of the dam and the canal ranged from 71 to 103 Nephelometric Turbidity Units (NTUs) and 75 to 110 NTUs, respectively. Also, the pH of the water sampled from the dam and the canal ranged from 7.56 to 8.42 for the former and from 6.96 to 7.85 for the latter.

Variance-covariance matrix and EOF

The results for the computed correlation analysis showed that except for FC and TC that showed a negative association ($r = -0.31$), and *E. coli* and TC ($r = 0.15$) and *E. coli* and turbidity ($r = 0.45$) that indicated no significance, the other variables were significantly related. TC had a positive association with turbidity ($r = 0.57$) and pH ($r = 0.56$), whereas FC was directly related to *E. coli* ($r = 0.50$), turbidity ($r = 0.51$), and pH ($r = 0.50$). *E. coli* showed no relationship with pH ($r = 0.51$). A strong relationship of $r = 0.99$ was established between turbidity and pH. The EOF analysis showed two components: EOFs 1 and 2. EOF 1 eigenvectors that explained 50.74% of the total variance and correlation were attributed to a weighted sum of *E. coli* and FC (Table 4). Meanwhile, EOF 2 eigenvectors that explained 34.497% of the total variance and correlation were governed by a weighted sum of TC (Table 4).

DISCUSSION

Properties of the irrigation water and vegetables

The microbial value of irrigation water is vital to the safety of fresh and minimally handled vegetables (Bihn & Gravani 2006). Table 1 and Figure 3 show the results of TC, FC, and *E. coli* in the water samples from the dam and the irrigation canal. Though the interquartile range of the obtained results presented in Figure 3 showed a close relationship, they exceeded the WHO (2001) recommendation of 3.0 (log CFU/10 ml) for unrestricted irrigation water. The obtained enteric bacteria loads are similar to findings of a previous study by Ninkuu *et al.* (2015), where above-threshold loads

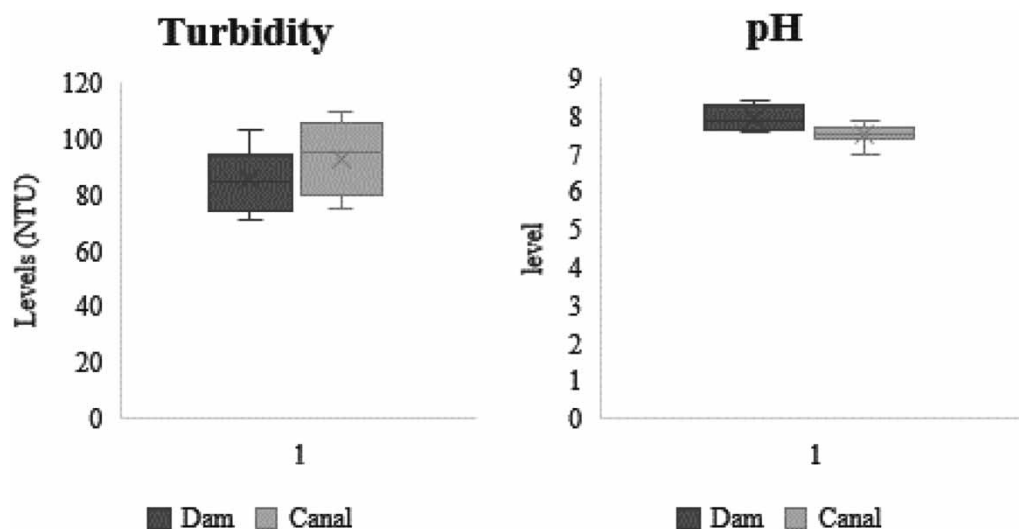


Figure 5 | Comparative box plots of physical parameters of samples from the dam and the canal.

Table 4 | Total variance explained

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	1.522	50.737	50.737	1.522	50.737	50.737
2	1.035	34.497	85.235	1.035	34.497	85.235
3	0.443	14.765	100.000			

of TC and FC were obtained ranging between 150 and 1,600 CFU/100 ml (2.2–3.2 log CFU/100 ml) and 70 and 920 CFU/100 ml (1.9–3.0 log CFU/100 ml). Similarities with *Salmonella* spp. were also identified. Though *Salmonella* spp. was not detected in this study, Ninkuu *et al.* (2015) had a nearly close result of 2×10^5 CFU/100 ml. This could be attributed to the anthropogenic activities within the catchment. A survey conducted by the GSS (2010) revealed that sanitation was poor within the area of study. Open defecation and improper waste disposal were studied and these were said to have affected the quality of the irrigation water. Runoffs from defecation sites were observed to find their way into the main river channel. Also, animal rearers were observed using the dam as a source of water for their livestock, especially cattle. Since animal droppings have been found to negatively impact water quality, deposited animal droppings along the banks of the dam may have added to the above-threshold microbiological

contamination in the dam. This inference was consistent with the findings of research studies conducted by Tiedemann *et al.* (1988) and Söderström *et al.* (2005). Variations in FC and TC counts were observed in the water samples from the dam and the canal, with the results of the latter being higher than those of the former. This revealed that the observed activities, such as washing farming tools and other useful farming materials and drawing water for other activities, could have affected the water quality negatively. Although *Salmonella* was not detected in this study, if the aforementioned anthropogenic activities are not curtailed, there is a future possibility of its occurrence due to continuous anthropogenic activities such as washing and defecating into the irrigation dam.

According to Beuchat (1999), vegetable contamination by pathogenic microbes occurs during cultivation, harvesting, transportation, processing, marketing, or at home. The ingestion of fruits and vegetables is usually identified as a

potential health risk factor related to enteropathogens including *Salmonella* and *E. coli* (Heaton & Jones 2008). All vegetables sampled in this study recorded above-threshold TC and FC, and *E. coli*. The study showed that the microbial loads of vegetables in the area were all above the International Commission on Microbiological Specifications for Food (ICMSF), and the WHO recommended limits of 2 CFU/g for *E. coli* and 3 CFU/g for both TC and FC for ready-to-eat vegetables. Since the occurrence of *E. coli* in animal manure is inevitable as mentioned by Kudva *et al.* (1998), the presence of *E. coli* in the vegetables was suspected to have emanated from the application of animal manure to promote growth (Heaton & Jones 2008). Hilborn *et al.* (1999) attribute an outbreak of *E. coli* O157:H7 to mesclun lettuce, which was studied to be irrigated with water contaminated by cattle grazing. Similarly, Söderström *et al.* (2005), in a study in Sweden, revealed the contribution of cattle feces to stream contamination, which extends to vegetables. Also, Wachtel *et al.* (2002) traced the contamination of *E. coli* at the roots of cabbage to the use of sewage-contaminated stream water for irrigation. The significantly high records of microbial count above permissible limits were observed to have adversely impacted the quality of the vegetables grown in the catchment, as farmers were using raw water without any form of treatment for irrigation. Additionally, to improve crop yield, farmers within the catchment resorted to animal dung/manure since it is perceived to be a cheaper and healthier form of fertilizer. These processes contributed to the introduction of TC, FC, and *E. coli*.

The analysis of variance showed that there was no significant difference in TC bacteria counts in vegetables and irrigation water. There was, however, a significant difference ($P < 0.05$) in FC and *E. coli* loads in vegetables (cabbage and tomatoes) and irrigation water, implying that irrigation water is not the only possible source of contamination. Open defecation and the deposition of dung on marginal lands along the reservoir and the application of manure on the farms, as observed by Amoah *et al.* (2006), could also contribute to enteric bacteria contamination in water and vegetables. The presence of these fecal contaminant-indicative organisms in large quantities in vegetables is a major health concern to consumers. The presence of FC and TC pathogens could cause diseases such as stomachache, diarrhea, and skin

rashes, as discussed by Ercumen *et al.* (2017). Though most *E. coli* strains have been generally described as harmless, some serotypes are pathogenic and can contribute to serious food poisoning and urinary tract infections in human beings (Ferdosi-Shahandashti *et al.* 2015).

Sivaplasingham *et al.* (2004) indicated that *Salmonella* spp. are the most commonly identified etiological pathogens associated with fresh produce-related infections. A range of fresh fruits and vegetables, including tomatoes, lettuce, watermelon, and sprouted seeds, have been implicated in *Salmonella* infection, most commonly (Heaton & Jones 2008). However, in this study, all water samples were negative for *Salmonella* spp. The close deviations, skewness, kurtosis, lopsidedness, and tailedness presented in Table 1 indicate a close relationship between the enteric bacteria loads of samples taken from the reservoir and the canal. This signifies that they were from the same source and impacted by similar geogenic and anthropogenic activities. The results of the microbiological quality of irrigation water confirm earlier assertions that low-quality water is being used for urban vegetable production in most Ghanaian cities (Cornish *et al.* 1999; Mensah *et al.* 2001; Keraita *et al.* 2003; Amoah *et al.* 2006).

Physicochemical properties of irrigation water

pH is the degree of acidity or alkalinity of an aqueous solution. The WHO recommends a pH value between 6.5 and 8.5 for human consumption of water. According to the results shown in Table 3, the pH values of sampled water fell within the permissible limits stipulated by the WHO (2017). This showed that the irrigation water from the dam, which is channeled through the canal, was good for vegetable production. The pH results obtained are beneficial because no negative effects emanating from pH may affect the aquatic system, as stated by Chapman (1996), crops, environment, and health. The buffered state of the water in the dam and the water channeled through the canal may be due to the consistent movement of water in and out of the catchment. There is a regular introduction of freshwater into the dam, which can promote pH neutralization.

Turbidity describes the cloudiness of fluids resulting from suspended solids. It is primarily a measure of the

concentration of finely divided matter (colloidal solids) (Alfred & Prosper 2014). The WHO (2008) recommended levels for water turbidity ranging between 0 and 5 NTUs. However, the recorded results were about 17 times higher than the recommended standard. This also reflects the high records of microbial pollution recorded in Tables 1 and 2. Runoff from farmlands within the catchment and tourists' activities, large solid particles, farm-derived wastes, and natural debris along the banks of the dam were studied as contributing factors to the introduction of soil particles into the dam. The variation in turbidity between the samples taken from the dam and the canal (Table 3) showed that water movement increases turbidity, as unintended solid particles are carried along the canal. The close deviations, skewness, kurtosis, lopsidedness, and tailedness presented in Table 3 indicate a close relationship between the physical characteristics of the samples collected from the reservoir and the canal. This signifies that they were from the same source and impacted by similar geogenic and anthropogenic activities. The high levels of turbidity may not only inhibit aquatic animals and plant growth but can also increase the risk of gastrointestinal diseases (USEPA 2005).

Covariance–variance matrix and EOF

Pearson's correlation (r) analysis for normality provides a quick method to visualize the association between two variables to draw inferences (Loh et al. 2020). Also, the EOF reduces the dimensionality of a dataset through a linear combination to generate new latent variables that are orthogonal and uncorrelated (Zamani et al. 2012). The Varimax method with Kaiser normalization based on the eigenvalues was adopted for the rotation of the principal components (Magesh et al. 2017). The inverse and no relationships established between TC and FC ($r = -0.31$), and *E. coli* ($r = 0.15$) are affirmed by the EOF analysis where TC was insignificant in component 1 (Table 5), whereas FC and *E. coli* were identified as the main pathogens impacting the quality of the irrigable water. The inverse relationship established between TC and FC correlates with the findings by Ogawa et al. (1986), whereas the no association between TC and *E. coli* differs from the assertion by Khan & Gupta (2019), who described *E. coli* as an indicator to fecal contamination.

Table 5 | Component matrix

Variables	Components	
	1	2
<i>E. coli</i>	0.886	0.028
FC	0.728	-0.563
TC	0.455	0.847

This relationship appears to be dependent on factors such as the sources and nature of the contamination and the presence of psychrotrophic coliform, as indicated by Kagalou et al. (2002). No significant association was identified between *E. coli* and turbidity ($r = 0.45$), while both, respectively, established a direct relation to pH ($r = 0.51$ and 0.99). This was dissimilar to the findings by Smith et al. (2008). The other variables were significantly related, as TC had a positive relation with turbidity ($r = 0.57$) and pH ($r = 0.56$), unlike the findings by Chigor et al. (2010) in a similar assessment in the Kubanni River in Nigeria, whereas FC was directly related to *E. coli* ($r = 0.50$), turbidity ($r = 0.51$), and pH ($r = 0.50$) (Ortega et al. 2009; Khan & Gupta 2019; Seo et al. 2019). EOF 1 and 2 eigenvectors were attributed to a weighted sum of *E. coli* and FC and TC, respectively, and indicated the factors that predominantly influenced the quality of the reservoir. The presence of coliforms in the pond suggests poor sanitation practices such as open defecation within the catchment (Okullo et al. 2017). Findings by Jongman & Korsten (2018) indicate that consuming contaminated water and vegetables contributes to hemolytic–uremic syndrome. This situation is more worrying, as the occurrence of FC suggests the presence of other microbes, as indicated by the WHO (2003). Discharging domestic wastewater, heaping animal waste within the catchment for manure, and using the dam as a drinking-water source or pastureland for livestock, especially for cattle, could also impact the enteric load.

CONCLUSIONS

The poor water quality in the irrigable water can be attributed to human-inducing activities, including the application of manure as a cheap but potent source of fertilizer, the

deposition of human and animal waste within the catchment, open defecation, and runoffs into irrigation water. The occurrence of FC as an indicator organism in the sampled vegetables suggests that the fresh vegetables could have been contaminated with other pathogens. Generally, the microbial loads of irrigation water and vegetables reveal that consumers of vegetables grown within a particular area are at high risk of cholera, typhoid, and intestinal disease caused by worms. Based on the findings of the study, the following recommendations are suggested: (1) further research should be done to determine whether there are resistance strains and other pathogenic organisms associated with the irrigation dam; (2) water should be treated before being used for irrigation; and (3) consumers should ensure that vegetables are properly washed and cooked/treated before consumption and report any post-consumption health complications to the nearest community health center.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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