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Fresh Vegetables and Irrigation Water Microbial Quality in One Village and Two Periurban Farms in the Centre Region of Cameroon

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A B S T R A C T

The present study investigated the seasonal variation of microbial quality of irrigation water and vegetables produced at Nkolondom, Ebogo1 and Meyo farms in the Centre region of Cameroon. The physicochemical analysis of irrigation water was also studied. A total of 81 fresh horticultural products were harvested in the three farms and 27 water samples collected. For microbial quality, total aerobic mesophilic bacteria, total coliforms, *E.coli* and *Vibrio spp* were researched. Parameters such as pH, temperature, electrical conductivity, turbidity and total dissolved solids were measured at the water sampling sites. Data collected were analyzed using Statgraphics version 7.1 software. Results showed that total aerobic mesophilic bacteria had the highest count (9.78 log cfu/g) followed by total coliforms (7.5 log cfu/g), while faecal coliforms and *Vibrio* were the least represented. The maximal number of aerobic mesophilic bacteria was counted in parsley during the dry season (9.78 log cfu/g). The microbiological quality of irrigation water and vegetables was unacceptable, exceeding the standards accepted by WHO and International Commission on Microbiology Standards for Foods limits for safe consumption. These results indicate that the microbial hazard of these vegetables is alarmingly high and that consumers should be aware to take correct actions while consuming them.

Introduction

The last decade has seen rapid population growth in cities of developing countries (United nation, 2015). Peri-urban agriculture represents an opportunity to ensure food security, health conditions, the local economy and the social integration of young people (Orsini *et al.,* 2013). In Cameroon, agriculture is the dominant primary activity and it is practised by 80% of the population (Minader, 2012). Millions of tons of fruits and vegetables (processed and fresh) are produced worldwide, with vegetables accounting for 55% of the total production. Vegetables are important sources of vitamins, minerals and antioxidants in human diets and also provide large quantities of vitamin C (Murcia *et al.,* 2000). Despite the advantages of consuming raw fruit and vegetables, quality and safety remain an issue, as these products have an extremely short shelf life, can be rapidly spoiled and represent a potential vector for pathogens (Sequino *et al.,* 2022). As fresh produce is sometimes consumed raw or after minimal processing, pathogen contamination is a potential health risk (Callejón *et al.,* 2015). Cases of food poisoning linked to the ingestion of contaminated vegetables have been identified worldwide (Painter *et al.,* 2013; Tanouti, 2016; Carstens *et al.,* 2019).

Initial microbial contamination can come from close contact with soil, where manure or sewage sludge can represent a primary source of pathogenic microbes, alongside irrigation water (Iwu *et al.,* 2019). Water is therefore a major source of food contamination; for this reason, much attention has been paid to the role of irrigation water in the fresh produce supply chain (Uyttendaele *et al.,* 2015). The microbial quality of irrigation water is therefore essential, as water contaminated with animal or human waste can introduce pathogens into produce before and after harvest (Amale, 2018).

In addition, farmers generally irrigate their produce with water from nearby rivers, streams, ponds and wells which, in many cultivated areas, do not meet the required standard for irrigation. Indeed, studies conducted on groundwater and surface water in urban and peri-urban areas have shown that these waters are of poor quality and harbour pathogenic microorganisms (Mfopou *et al.,* 2014; Ndjama *et al.,* 2017; Kapso, 2018).

Very little research has yet been carried out on vegetables grown in peri-urban areas of Cameroon's Centre Region, and on the relationship between the microbiological and physico-chemical quality of irrigation water and the vegetables obtained from irrigation systems. More specifically, very few data are available on the seasonal variation of the microbiological quality of parsley, leeks and green peppers obtained using surface water irrigation systems. This study aim to assess the quality of water and irrigated vegetables in different localities in the central region over the three seasons of the year.

Materials and Methods

Study sites

This study was carried out at three agricultural sites, Nkolodom, Ebogo1 and Meyo (fig1). Nkolondom is a district of the municipality of Yaoundé (capital of Cameroon) located on the northern outskirts of the city of Yaoundé and a few kilometres from the large Mfoundi market. The main source of irrigation water at Nkolondomis a river; this meanders through the entire area and provides farmers with water to irrigate their farms. Ebogo1 is a district of SOA (MEFOU AFAMBA Department, Centre region). At this site, the main source of water for irrigating the fields is a 1.3 m deep well that has been dug and is located not far from the fields. Meyo is a village located in the SOA district (MEFOU AFAMBA Department, Centre region). The main source of irrigation is a pond. What these three sites have in common is their proximity to the large Mfoundi market, one of the main distribution hubs for vegetables in the Yaoundé city.

Survey

A descriptive study was carried out by interviewing farmers at the Nkolondom, Ebogo1 and Meyo sites. Sociological approaches such as semi-structured questionnaires, interviews and direct observations were used to obtain information on cropping practices from 100 randomly selected farmers in the three study sites. The main information collected concerned socio-demographics (age, gender, social status and main activity), descriptions of farming practices (types of vegetables grown, sources of water supply, irrigation systems, types of fertilizers used), and farmers' perceptions of water and vegetable quality.

Collection of Water and Vegetables Samples

A total of 27 water samples were taken during each of the three seasons, namely the intermediate season (mid-March 2022), the rainy season (October 2022) and the dry season (December 2022). Water samples included nine samples of water used for irrigation taken from the Nkolondom River, nine samples taken from a well at the EBOGO1 site and nine samples taken from the pond used at Meyo.

The water samples were taken in the vicinity of the farms as used by the farmers. Water samples were collected aseptically from 3 sources (fig 2 (a), (b) (c)) over a 10-month period, from February to December 2022. Irrigation water was collected in sterilized 200 ml glass bottles, preserved with ice during transport to the laboratory of the Microbiology Department of the University of Yaoundé 1 and immediately analyzed for the enumeration of selected bacteria. In addition to the water samples, a total of eighty-one (81) samples of different vegetables irrigated by these water sources were also collected from the three study sites, including twenty-seven (27) parsley samples, twenty-seven (27) leek samples and twenty-seven (27) green bell pepper samples over the three seasons. This was done using sterile plastic bags (Zip bag) and transported for microbiological analysis in the laboratory.

Physicochemical analysis of irrigation water

Hydrogen potential (pH), temperature (T), electrical conductivity (E.C.) and total dissolved solids (TDS) of irrigation water were measured in situ at all selected water points during the three sampling seasons. pH was measured using a WAG-WE30200 pH meter (Wagtech projects, Berkshire, UK), while electrical conductivity and TDS were measured using a WAGWE30210 conductivity meter (Wagtech projects, Berkshire, UK).

Microbiological analysis of irrigation water and vegetables

These analyses were carried out to detect aerobic mesophilic flora, total coliforms, *Escherichia coli* (*E.coli*) and *Vibrio* spp in irrigation water and vegetables. The method used to count these various microorganisms was the surface counting technique. Nutrient agar(CM-PCASP051, UK) was used to detect total mesophilic flora (TAMF). Mac Conkey Agar (CM-MAN257, UK) was used to count presumptive *E.coli*, Thiosulfate Citrate Bile Saccharose (TCBS) agar for *Vibrio* spp and Violet Red Bile Agar (CM-VRBA114, UK) medium for total coliforms. For water analysis, after inoculation of the appropriate dilutions on the respective media, they were inoculated at 45°c for 24 h for *E.coli* enumeration on Mac Conkey Agar and 37°c for 24 h for the other enumerations.

For microbial analysis of vegetables samples, ten (10) grams of each sample (the edible part) were aseptically weighed into a sterile plastic Zip freezer bag, 90 ml of physiological saline solution was added and left immersed for 5 minutes before homogenization. Homogenization was carried out by manual shaking in two phases of five minutes each. After the first shaking, the second was carried out two minutes later. One milliliter of the resulting mixture was taken and dilutions made as for the water samples, inoculated onto a culture medium and then incubated according to the different media presented above.

Microbial load was obtained by using the following formula:

$$C = \frac{N}{V} x F_d$$

C : Microbial concentration in cfu/ml;

N : Some of two successive dilution counts;

F_d : Dilution factor of the sample inoculated.

V : Volume plated in ml;

Statistical analysis

Data analysis involved the use of one-way Analysis of variance (ANOVA) and significance was accepted at ($p<0.05$). Separation of the means involved the use of Tukey's test. All statistical analyses were carried out using SPSS (version 20.0) software.

Results and Discussion

Survey among vegetables growers

Table 1 shows that farming of these vegetables is mainly practiced by men (68%), compared with only 32% of women. These farmers are 43% uneducated. However, 38% of growers declared that they have been educated to a very low level. It also appears that farmers at all sites grow parsley, leeks, green peppers, tomatoes and lettuce. In addition, 74% of farmers said they were unaware of the health risks associated with their farming practices, compared with 26% who said they were aware of these risks. Due to the high cost of living, there has been a surge in the price of synthetic fertilizers, which has directly resulted in farmers switching to the use of natural fertilizers. In our survey, almost 76% of farmers used manure as fertilizer on their fields. The survey also revealed that water used for irrigation also serves for other purposes, such as laundry (65%) and bathing (35%).

Physicochemical characteristics of irrigation water

The results of the analysis of the physicochemical parameters of the irrigation water are shown in Table 2. It is observed that the average temperatures of the surface waters (river and pond) were 30.08°C and 29.82°C respectively during the dry season and 26.06 °C and 25.83 °C during the rainy season. Well water temperatures were 29.05°C in the dry season and 26.53°C in the rainy season (Table 2). Water pH ranged from 5.57 to 8.36. Conductivity fluctuated between 178.6 and 237.1µs/cm. Turbidity values ranged from 13.1 to 26.3 NTU. Total dissolved solids levels in the dry and rainy seasons range from 136 to 196.3 and 114.6 to 187.8 mg/L respectively.

Contamination of the irrigation water and vegetables samples

Tables 3shows the results obtained during the three seasons for irrigation water. These results indicate that there was no significant difference between the samples of the different water points in the rainy season. Total aerobic mesophilic flora (TAMF) showed a maximum of 6.38 log /ml in site 3 (pond water) and a minimum of 5.67 log cfu/ml in site 2 (river water). It thus appears that all the samples tested have a TAMF greater than 3 log cfu/ml, the standard accepted by the WHO for water intended for the irrigation of plants which can be consumed raw (WHO, 2003). Consequently these waters are not suitable for irrigation. In the intermediate season and the dry season (tables 3), there is an increase in the concentration of TAMF in irrigation water, surface water being more contaminated than well water, with the highest concentration found in pond water 9.78log cfu/ml. Total coliforms are present in all water samples tested with concentrations ranging from3.73 logcfu/g (river water) to 4.43 logcfu/ml (pond water). We also noted the presence of *Escherichia coli* in all the vegetables samples irrigated with these water sources. Irrigation water is also more contaminated with Total Coliforms and *Escherichia coli* during the dry season, with the highest concentrations in pond water (6.52 log cfu/ml and 4.59 log cfu/ml respectively). *Vibrio spp*. were detected in well and pond water at 1.18 log cfu/ml and 1.14 log cfu/ml respectively, only during the rainy season. No *Vibrio spp*. was detected in any of the water samples tested in the dry season, whereas the concentrations of *Vibrio spp*. in vegetables collected the same season were very high.

Regarding the TAMF quality of vegetables, in general, The results reported in tables 4, 5 and 6 show that none of the vegetables have a TAMF lower than 4log cfu/g. Similarly, we found that the TAMF obtained for the leek and parsley samples are higher than those of the green pepper, which has the lowest TAMF (5.13 logcfu/g). All researched microorganisms or group of microorganisms were enumerated in all the types of samples. The lowest concentrations of microorganisms per season were observed in green pepper (for TAMF 5.13 log cfu/g, for total coliforms 4.22 log cfu/g, for *E.coli*3.48 log cfu/g and *Vibrio spp.* 2.92 log cfu/g). The leek samples irrigated with pond water were the most contaminated with a TAMF of 9.83 log cfu/g in the dry season. In the dry season, we noted an increase in microbial contamination independently of vegetables, with Total aerobic mesophilic flora ranging from 6.53 log cfu/g (green pepper) to 9.83 log cfu/g (leek).

In order to assess a possible relation between water quality parameters, a correlation analysis was performed. Table 7 shows the correlations between the assessed quality parameters of water used for irrigation. It can be observed that pH, is significantly correlated to conductivity (r=0, 93; P<0,01) and total dissolved solids (r= 0,75; P<0,05). Total dissolved solids are positively correlated to conductivity (r=0,63). Temperature showed a negative correlation with turbidity (r= -0,64). TAMF is significantly positively correlated with total coliforms (r= 0,68) and with temperature (r=0,662). Total dissolved solids are positively correlated to *E.coli* (r=0,52).

In order to explain part of the variability observed in vegetable samples analysed, a principal component analysis was performed. The PCA analyses permitted to explain using the first two factors, from 92 to 98 % of the variability depending of the sampling site. In general it can be observed that microbial descriptive were not significant in explaining the grouping of green pepper in none of the sites (Fig 4, A, B and C). At the contrary, independently of the season leek and parsley were positively affected by microbial descriptive. In fact *E. coli* and total coliforms were the most representing variables of factor 1 in all the PCA analyses of the three sites. TAMF was an important variable for factor 1 only in the PCA analysis of samples in Nkolondom and Meyo.

From the results obtained in all the water samples, TAMF exceeded the concentrations authorized for irrigation water by most organizations including the World Health Organization (WHO). This high contamination up to 9.81log Cfu/ml in irrigation water can be explained in several ways. Indeed, the results of the survey revealed that 76% of farmers used the droppings as fertilizers. This could be a source of water contamination. The survey also revealed that river water was collected using a bucket or any rusty container left on the ground, which could be considered another source of contamination. As for surface water, in addition to irrigate the fields, the populations used them for bathing and washing and also discarded their domestic effluent into them. These results are in line with those of the studies of Tariq *et al.,* (2020); Ollo *et al.,* (2021) who have shown that human-induced water pollution contributes to the poor bacteriological quality of surface waters. Independently of the season considered, the results indicate that among the surface waters used, there is a significant difference ($P < 0.05$) between the Total Aarobic Mesophilic Flora from the pond and that coming from the river water. These results are similar to those obtained by Luana *et al.,* (2017), but different from those obtained by Sultana *et al.,* (2020) showed in their study that the water of the river was more charged than that of the pond.

Table.1 Socio demographic characteristics and cultural practices of farmers in the study area.

Descriptive	Farmers site1 (Nkolondom)	Farmers site2 (Ebogo1)	Farmers site3 (Meyo)
Sex			
male	25	23	**20**
female	15	12	**5**
Marital status			
single	10	25	**11**
married	30	10	**14**
Level of studies			
unschooled	15	te	**13**
primary	16	10	**12**
secondary	7	9	**0**
High education	2	1	**0**
Cultivated vegetables			
parsley	36	12	**15**
leek	35	25	**15**
Green pepper	22	24	**12**
tomato	40	0	**22**
lettuce	38	35	**0**
Knowledge of risks			
awareness	14	10	**2**
unawareness	25	18	**23**
Types of fertilizers used			
synthetic	11	10	**3**
naturals	25	25	**25**
Irrigation mode			
surface	0	0	**0**
sprinkler	40	35	**25**
Other uses of irrigation water			
laundry	30	15	**20**
bath	10	20	**5**
Total famers surveyed	40	35	**25**

During the rainy season, the results showed that well water was more contaminated than river water, which is in line with the results of the study carried out by Tryland *et al.,* (2014) in which surface waters were more vulnerable to contamination than groundwater reservoirs due to the lack of natural soil protection. This could be due to the infiltration of run-off water into shallow water tables through soil porosities, as well as its run-off (as these wells do not meet construction standards). Another explanation is the direct contamination of objects in contact with water, such as containers used to transport water and which are also used for other activities. This result is similar to that of the study carried out by Magha *et al.,* (2021). During the dry season and during intermediate season, well water was less contaminated than surface water (pond and river). All vegetables which were irrigated with contaminated water (river, well, pond) were also contaminated with coliforms, *E.coli* and *Vibrio spp*. over the three sampling seasons. The results showed high concentrations of *E.coli*, total coliforms and aerobic mesophilic bacteria in leeks, parsley and green peppers.

Table.2 Comparison of averages of physicochemical parameters with available WHO standards

Seasons	Type of water	T (°C)	Ph	Turbidity (NTU)	Conductivity (μS/Cm)	TDS (mg/l)
2011 WHO standard			**6.5-8.5**		**12**	**500**
Rainy	well	26.53±0.3[a]	5.57±0.04[a]	17.6±0.44[e]	178.5±0.56[a]	**115±0.36[a]**
	river	25.83±0.23[a]	7.78±0.04[e]	35.3±0.63[h]	218.4±0.40[d]	**187.8±0.2[g]**
	pond	26.06±0.16[a]	7.56±0.7[d]	24.6±0.10[f]	231.5±0.72[f]	**119.4±0,65[b]**
Intermediate	well	27.86±0.2[b]	6.49±0.05[a]	12.4±0.53[a]	183.6±0.26[b]	**123.7±0.26[c]**
	river	28.45±0.7[bc]	8.02±0.06[f]	26.3±0.44[g]	225.8±0.75[e]	**191.5±0.46[h]**
	pond	29.04±0.2[cd]	8.08±0.09[f]	17.5±0.53d[e]	234.2±0.20[g]	**145.8±0.44[e]**
Dry	well	29.05±0.9[cd]	7.33±0.05[c]	13.1±0.36[a]	198.2±0.36[c]	**136.5±0.64[d]**
	river	30.08±0.6[de]	7.95±0.03[f]	14.6±0.46[c]	231.62±0.39[f]	**180.4±0.36[f]**
	pond	29.82±0.6[e]	8.36±0.03[g]	16.3±0.10[d]	236.7±0.59[h]	**196.3±0.26[i]**

Values with different letter exponents in the same column are significantly different ($p < 0.05$). T°C = temperature of water; TDS = Total Soluble Solids; NTU = Nephelometric Turbidity Unit

Table.3 Microbial quality of three types of irrigation water during rainy, intermediate and dry seasons

Seasons	Type of water	TMAF	E. coli	Total coliform	*Vibrio* spp
Rainy	well	6.36±1.06 [a]	4.11±1.63 [a]	4.19±0.96 [a]	**1.18±0.96 [a]**
	river	5.67±0.70 [a]	4.74±0.90 [a]	3.73±0.89 [a]	**ND**
	pond	6.38±0.71 [a]	4.88±0.42 [a]	4.43±0.26 [a]	**1.14±0.95 [a]**
Intermediate	well	7.7±0.66 [a]	3.43±1.23 [a]	5.85±0.77 [b]	**7.7±0.66 [a]**
	river	5.48±0.75 [b]	3.82±0.63 [a]	4.19±0.68 [a]	**5.48±0.75 [b]**
	pond	9.04±0.81 [c]	4.23±0.28 [a]	5.99±0.32 [b]	**9.04±0.81 [c]**
Dry	well	5.78±0.53 [a]	4.35±0.07 [a]	5.83±0.04 [a]	**ND**
	river	8.3±0.11 [b]	4.19±0.04 [b]	4.44±0.05 [b]	**ND**
	pond	9.78 ±0.3 [c]	4.59±0.04 [c]	6.52±0.04 [c]	**ND**

Values with different letter exponents in the same column are significantly different ($p < 0.05$). (TC=Total Coliform, *E.coli*= *Escherichia coli*, TAMF= Total Aerobic Mesophilic Flora

The contamination of these crops is undoubtedly closely linked to the pollution of irrigation water (surface water and well water) and soil. It appears that, whatever the season considered, leeks and parsley are always more contaminated than green peppers. Amale *et al.,* (2018); Salamandane *et al.,* (2021) and Kowalska *et al.,* (2022) obtained similar results where green pepper was less contaminated than leek. This result could be explained by the fact that the outer surface of leafy vegetables offers a larger contact surface with irrigation water and therefore a greater possibility of fixing microorganisms. In addition, the surface of the fruit (green pepper) is not conductive to biofilms formation, due to its smooth texture. On the other hand, plants whose edible parts are close to the ground, such as parsley, will be exposed to microorganisms that come into contact with them through splashes of droplets from the soil (Liu *et al.,* 2013).

Table.4 Microbiological quality of vegetables in Nkolondom during all seasons

Type of Vegetable	Seasons	TAMF	E. coli	Total coliforms	*Vibrio*. spp
Leek	rainy	7.88±0.31[bc]	5.53±0.44[de]	6.43±0.12[de]	5.18±0.14[d]
	intermediate	8.30±0.25[cd]	6.41±0.13[d]	7.32±0.07[c]	4.34±0.28[a]
	dry	8.58±0,28[cd]	6.66±0,6[d]	7.56±0.21[cd]	4.62±0.13[cd]
Parsley	rainy	7.43±0.18[bc]	4.45±0.46[bc]	5.68±0.57[cd]	3.33±0.2[a]
	intermediate	7.59±0.58[bc]	5.98±0.46[cd]	6.37±0.16[b]	4.80±0.66[a]
	dry	8.19±0,21[cd]	6.23±0,17[cd]	6.63±0.70b[cd]	4.76±0.14[d]
Green pepper	rainy	5.13±0.09[a]	3.48±0.42[a]	4.22±0.27[a]	3.52±0.35[a]
	intermediate	6.48±0.12[a]	5.050±0.12[b]	5.63±0.12[a]	5.32±0.22 [a]
	dry	6.53±0.30[a]	5.12±0.13[b]	5.80±0.16[a]b	5.32±0.15[e]

Values with different letter exponents in the same column are significantly different ($p < 0.05$). (*E.coli*= *Escherichia coli*, TAMF= total aerobic mesophilic flora)

Table.5 Microbiological quality of vegetables in Ebogo 1 during all seasons

Type of Vegetables	Seasons	TAMF	E. coli	Total coliforms	*Vibrio*. spp
Leek	rainy	7.26±0.38[a]	5.65±0.45[a]	6.24±0.28[a]	5.18±0.14[a]
	intermediate	8.55±0.18[b]	5.62±0.12[a]	6.36±0.48[a]	3.99±0.57[b]
	dry	8.96±0,47[b]	5.81±0.12[a]	6.78±0.47[a]	4.19±0.50[b]
Parsley	rainy	7.51±0.08[a]	4.25±0.07[a]	5.38±0.26[a]	3.46±0.25[a]
	intermediate	7.49±0.80[ab]	6.56±0.39[b]	7.16±0.12[b]	4.32±0.12[b]
	dry	7.89±0,14[b]	6.62±0,80[b]	7.32±0.75[b]	4.54±0,6[b]
Green pepper	rainy	5.26±0.47[a]	3.48±0.18[a]	4.74±0.11[a]	2.92±0.78[a]
	intermediate	6.62±0.26[b]	4.32±0.47[b]	5.46±0.10[b]	4.61±0.61[b]
	dry	6.75±0.21[b]	4.60±0,15[b]	5.65±0,40[b]	4.61±0.50[b]

Values with different letter exponents in the same column are significantly different ($p < 0.05$). (*E.coli*= *Escherichia coli*, TAMF= total aerobic mesophilic flora)

International standards are not available for non-transformed vegetables and fruits. Notwithstanding, in literature some microbial limits are given by the Hazard Analysis and Critical Control Points-Total Quality Management (HACCP-TQM) cited by Aycicek *et al.,* (2006). According to this reference, foods containing less than 4, between 6 and 6.69, between 6.69 and 7.69 and more than 7.69 log cfu/g (aerobic bacterial count) are considered good, fair, poor and spoiled, respectively. Based on these characteristics, the results obtained in the present study showed that green bell pepper samples can be considered as poor quality plant foods, while parsley and leek can be considered as spoiled plant foods. In this respect, the parsley and leek analyzed are not suitable for raw consumption. If we consider raw vegetables eaten after minimal transformation, the limit concentrations for *E. coli* and total coliforms recommended by the International Commission on Microbiology Standards for Foods (ICMSF) and by the WHO are 2 log cfu/g for *E. coli* and 3 log cfu /g for total coliforms (TC) for ready-to-eat vegetables. In our samples total coliforms and *E.coli* in vegetables had the lowest value at 4.22 log cfu/g for total coliform and 3.48 log cfu/g for *E.coli* (in green pepper) which were higher than these recommendations. It is important to stress that microbial contamination levels on harvested vegetables are likely to be reduced with the level of transformation applied before eating.

The results showed that *Vibrio* spp. was not detected in the water samples in intermediate season and in the dry season. Based on the (WHO, 2011) norms for irrigation water, it appears that *Vibrio* spp load in irrigation water is safe. Studies carried by Magha *et al.,* (2021) made similar observations in Bamenda where *Vibrios spp* were not detected in irrigation water in the dry season, but their presence was confirmed during the rainy season. This could be due to water runoff infiltration into shallow water tables, and also to the fact that wells are not protected. During the rainy season, run-off water flows easily to contaminate wells, carrying along any bacteria that may have been trapped in the soil particles. In contrast to the water samples, *Vibrio*s were detected in all the vegetables, regardless of season and site, indicating the ability of these microorganisms to resist on plants through the different seasons.

Table.6 Microbiological quality of vegetables in Meyo during all seasons

Type of Vegetable	Seasons	TAMF	E. coli	Total coliforms	*Vibrio* spp
Leek	rainy	7.98 ± 0.23^{a}	6.18 ± 0.38^{a}	6.52 ± 0.34^{a}	4.76 ± 0.47^{a}
	intermediate	9.01 ± 0.27^{b}	6.48 ± 0.25^{a}	7.50 ± 0.22^{b}	4.23 ± 0.95^{a}
	dry	9.83 ± 0.17^{c}	6.59 ± 0.10^{b}	7.82 ± 0.40^{b}	$4.36\pm0,23^{a}$
Parsley	rainy	8.12 ± 0.46^{a}	5.00 ± 0.18^{a}	5.97 ± 0.21^{a}	3.79 ± 0.21^{a}
	intermediate	7.49 ± 0.80^{a}	6.56 ± 0.39^{b}	7.16 ± 0.12^{b}	4.32 ± 0.12^{b}
	dry	8.43 ± 0.18^{a}	5.97 ± 0.37^{b}	7.06 ± 0.31^{b}	3.61 ± 0.44^{a}
Green pepper	rainy	5.80 ± 0.05^{a}	3.97 ± 0.06^{a}	4.77 ± 0.16^{a}	3.20 ± 0.15^{a}
	intermediate	6.89 ± 0.40^{b}	4.90 ± 0.54^{b}	5.67 ± 0.24^{b}	4.49 ± 0.92^{b}
	dry	6.92 ± 0.10^{b}	5.20 ± 0.25^{b}	5.72 ± 0.10^{b}	4.49 ± 0.60^{b}

Values with different letter exponents in the same column are significantly different ($p < 0.05$). (*E.coli*= *Escherichia coli*, TAMF= total aerobic mesophilic flora)

Figure.1 Samples collection sites as distributed in two Department of the Centre region

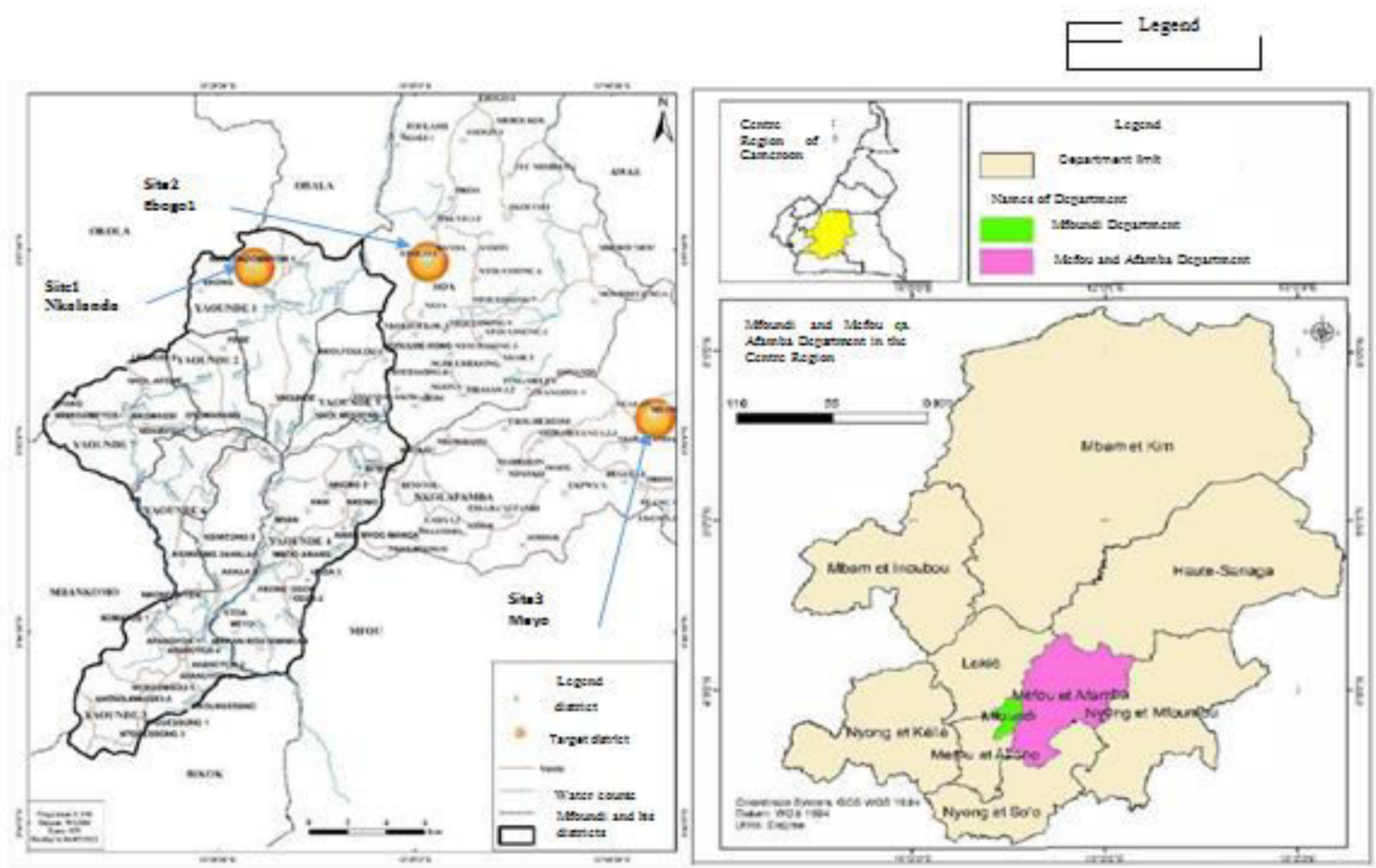


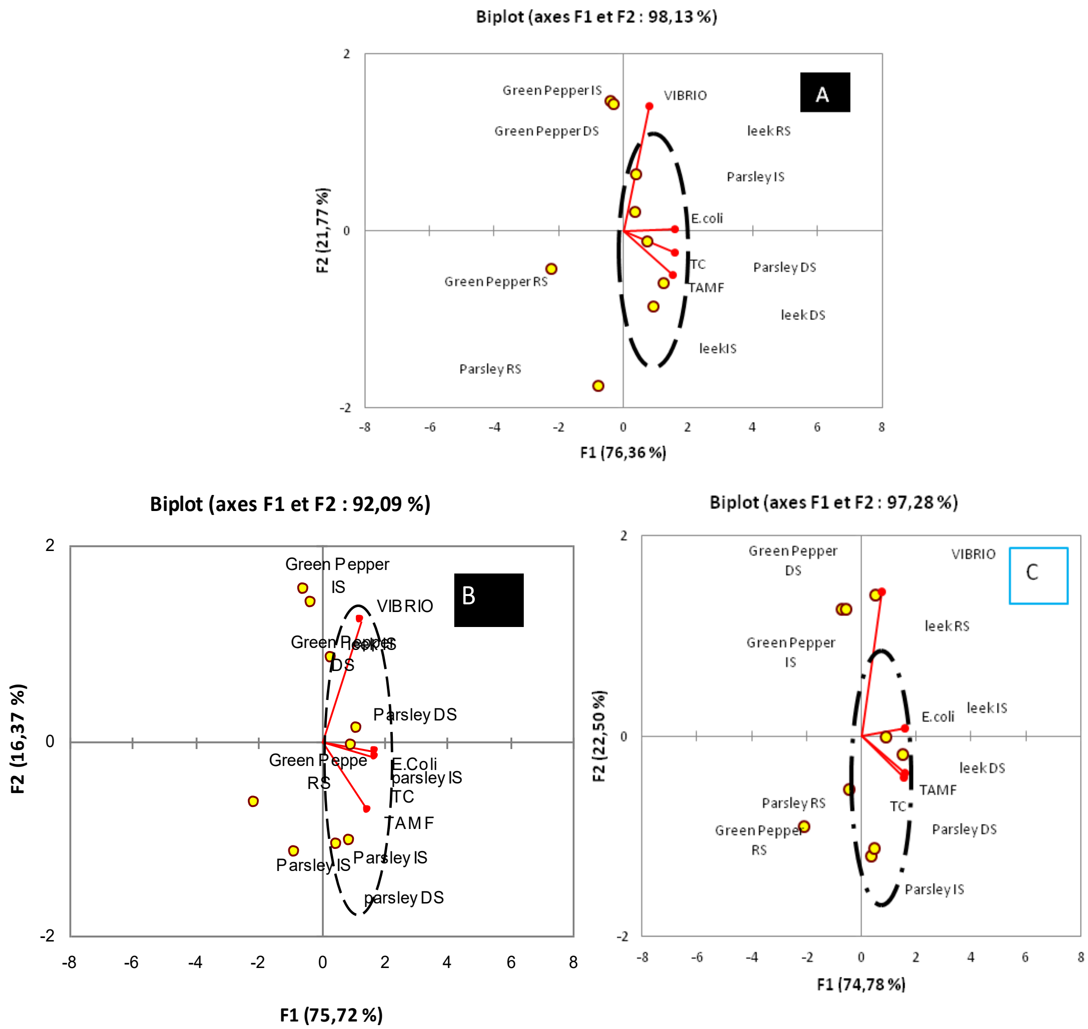
Table.7 Correlation between physicochemical and microbiological parameters of irrigation water

	T°C	pH	Turbidity	conductivity	TDS	TAMF	E coli	Total coliforms
T°C	1	0.474	-0.644	0.342	0.409	0.624	-0.273	**0.617**
pH		1	0.263	**0.925****	**0.748***	0.331	0.398	**0.191**
turbidity			1	0.308	0.377	-0.524	0.465	**-0.692***
cond				1	0.625	0.386	0.518	**0.049**
TDS					1	0.183	0.165	**-0.077**
TAMF						1	-0.032	**0.686***
E.coli							1	**-0.164**
CT								**1**

T°C= temperature of water; TDS= Total Soluble Solids; *E.coli*= *Escherichia coli*, TAMF= total aerobic mesophilic flora; * $p<0.05$; ** $p> 0.01$

Figure.2 Irrigation water sources; river water (A), pond water (B) and well water (C)

Figure.3 Representation of PCA factorial maps: A) factorial map for the nkolondom site; B) factorial map for the ebogo1 site; C) factorial map for the meyo site; IS=Intermediate season; Ds= dry season; Rs=rainy season



During the dry season, analyses also showed an increase in coliform concentration in both irrigation water and vegetables. This result is similar to previous studies, which have shown that the highest levels of *E. coli* and pathogen prevalence in water and on produce is observed during periods of the year when ambient and irrigation water temperatures are high (Park *et al.,* 2015).

Contrary to previous authors, (Atidegla and Agbossou, 2010) who indicated that it is in the rainy season that coliform concentration is increased due to rainfall and runoff, which are responsible for the dissemination of pollutants in the environment. Analysis of variance showed that there was no significant difference between total coliforms in irrigation water and in green pepper. Furthermore, there was a significant difference ($P < 0.05$) between the total coliforms in the irrigation water and in the leek and parsley samples analyzed.

This means that irrigation water could not be the only possible source of contamination. Moreover, microbial presence on vegetables could be considered as the result of progressive accumulation trough biofilms formation after each irrigation. In the present study, the average temperature values of the irrigation water obtained ranged from 25.68°C to 30.66°C, representing the optimum temperature range for the growth of mesophilic bacteria (25°C- 30°C). This could explain the positive correlation observed between temperature and total aerobic mesophilic flora. The significant difference found between surface water (river and pond) and well water could be explained by the fact that well water benefits from the shade generated by the shrubs present on the site, whereas surface water is directly exposed to the sun's rays. These temperatures are similar to those obtained by Djegbe *et al.,* (2018) in irrigation water.

The results revealed pH values oscillating between 5.57 and 8.36. This would certainly be linked to the existence of several water effluents likely to increase the pH of the water, such as laundry, dishwashing and toilet water, as revealed during the surveys carried out. This high pH of surface water during the rainy season has already been reported by Gemmell and Schmidt (2010). The pH values obtained during our analyses (6.5-7.5). represent optimal values for the development of many bacteria This could explain the positive correlation between pH and TAMF.

Analysis of the correlation between physicochemical water parameters and microbiological parameters (table 7) shows a good correlation between factors such as total dissolved solids and electrical conductivity, which would be due to the fact that these parameters both describe inorganic salts present in solution.

Natural water parameters can influence the biological quality of water. Indeed, several studies have established correlations between increased concentrations of microorganisms and increased turbidity (Snead *et al.,* 2011; Goshko *et al.,* 2011; Haas *et al.,* 2011).

On the other hand, strong correlations have been observed between temperature, pH, total dissolved solids, total coliforms and total flora. In other words, high-temperature environments with high pH contain high numbers of aerobic mesophilic bacteria and total coliforms. This result is similar to that obtained by Lapworth *et al.,* in 2012. This indicates that these simple physicochemical parameters can help predict water quality used for irrigation. Turbidity and dissolved solids could be constantly measured in these water sources.

The PCA factorial maps (A, B and C) for vegetables sampled at the three sites over the three seasons show that, on the one hand, most vegetables cluster around axis 1, which can be defined here as the axis that best reflects microbiological parameters such as total flora and total coliforms. Axis 2, on the other hand, is more representative of vegetables with low concentrations of microorganisms. On the other hand, it was observed that among the vegetables well represented on axis 2, most were sampled in the rainy season, and green bell pepper samples were in the majority. This means that the dry and mid-season seasons are those with the highest contamination of microorganisms.

The present study investigated the seasonal variations of the physicochemical and microbiological quality of irrigation water and the microbial quality of vegetables produced at Nkolondom, Ebogo1 and Meyo farms in the Centre Region of Cameroon.

The data collected during this study enabled us to draw up a profile of the physicochemical and microbiological quality of irrigation water and fresh vegetables harvested in the three localities. The microbiological quality of both the irrigation water and the vegetables was unacceptable, as microbial loads exceeded the standards accepted by the WHO and other bodies such as the INSCF.

It can therefore be considered unsuitable for irrigating crops likely to be eaten raw, such as leeks, parsley, green peppers whose watering brings the irrigation water to come into direct contact with the edible part of the crop.

Faecal pollution indicators were isolated during all sampling campaigns. Overall, pond water was the most contaminated. Concentrations of aerobic mesophilic bacteria were highest during the dry season both in irrigation water and in vegetables, with the exception of well water. *Vibrio spp* were not found in irrigation water. The high concentrations obtained, above international standards, imply a high demand for quality water both for small-scale agriculture and for clothes washing.

Vegetables irrigated with contaminated water also showed high level of contamination. The total aerobic mesophilic flora of all vegetables exceeded WHO accepted standards, irrespective of the seasons considered. Leeks and parsley were the most contaminated, both in the dry season and in the rainy season. The highest coliform concentrations were observed during the dry season. This high level of contamination in vegetables may be associated with the quality of the irrigation water although other factors such as the excrement used as fertilizer by many farmers may also be taken into account.

Author Contribution

Minka Joseph Dalambert: Investigation, formal analysis, writing—original draft. Fongang Foko Desoeuvres: Validation, methodology, writing—reviewing. Mobou

Estelle Yolande:—Formal analysis, writing—review and editing. Sado Kamdem Sylvain Leroy: Investigation, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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