

Occurrence of *Salmonella* spp. and *Shigella* spp. in Irrigation Water and Organic Fertilizers Used in Vegetable Farms in Kindia Prefecture, Guinea

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How to cite this paper: Bah, M., Kolié, B., Diallo, S., Diallo, A.T., Mansare, A.N. and Bah, B.S.S. (2026) Occurrence of *Salmonella* spp. and *Shigella* spp. in Irrigation Water and Organic Fertilizers Used in Vegetable Farms in Kindia Prefecture, Guinea. *American Journal of Plant Sciences*, 17, 1037-1051.

<https://doi.org/10.4236/ajps.2026.1710062>

Received: June 22, 2026

Accepted: October 17, 2026

Published: October 20, 2026

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Abstract

Microbiological contamination of vegetable products constitutes a major public health concern, particularly in vegetable-growing areas where irrigation water and organic fertilizers may serve as vehicles for pathogenic microorganisms. The present study aimed to assess the microbiological contamination of irrigation water and organic fertilizers used in vegetable farms in Kindia Prefecture by bacteria of the genera *Salmonella* and *Shigella*. The study was conducted from June 2024 to March 2025 in Kindia Prefecture. A total of 1073 samples were collected, including 577 irrigation water samples and 496 organic fertilizer samples. Microbiological analyses were performed in accordance with ISO 6579-1:2017 for *Salmonella* spp. and ISO 21567 for *Shigella* spp. Among the irrigation water samples, 68 out of 577 were positive for *Salmonella* (11.79%; 95% CI: 9.40 - 14.67), while only one case of *Shigella* was detected (0.17%). Organic fertilizers showed a *Salmonella* prevalence of 11.90% (59/496; 95% CI: 9.33 - 15.04), with no *Shigella* detected. Runoff water was the most contaminated irrigation source (15.94%). The predominant serotype was *Salmonella enteritidis*, with 75 strains (58.59% of isolates), whereas only one isolate of *Shigella dysenteriae* type 1 was identified in irrigation water (0.78% of isolates). These results indicate that contaminated irrigation water and organic fertilizers may constitute potential sources of *Salmonella* in vegetable production systems.

Keywords

Salmonella, *Shigella*, Irrigation Water, Organic Fertilizers, Microbiological

1. Introduction

Vegetable farming plays an important role in urban and peri-urban food systems in West Africa, contributing to the supply of fruits and vegetables, income generation, and food security. However, the intensification of vegetable production is associated with constraints related in particular to access to good-quality irrigation water, sanitation, organic waste management, and the use of inputs of animal origin. These factors may promote the introduction and circulation of pathogenic microorganisms in production environments.

Fruits and vegetables are an essential component of a healthy diet because of their richness in vitamins, minerals, fiber, and other bioactive compounds. However, when consumed raw or minimally processed, they may serve as vehicles for the transmission of microorganisms of fecal origin. Recent FAO and WHO reports emphasize that fresh plant products are regularly implicated in foodborne disease outbreaks and that the control of microbiological hazards should begin at primary production. Key factors to consider include water quality, organic soil amendments, animal and human intrusion, production-site characteristics, as well as harvesting and handling practices [1].

Water used for irrigation is therefore a determining factor in the microbiological safety of vegetable production. Surface water, runoff water, well water, and other water resources may be exposed to various sources of contamination, including animal and human feces, wastewater, and runoff from residential or livestock areas. FAO and WHO therefore recommend a *fit-for-purpose* approach to water use and the assessment of the microbiological quality of the different water sources used during production [1].

This issue is particularly important in vegetable-growing systems where water resources are limited. Recent international recommendations consider irrigation water as a potential route for the introduction of enteropathogenic bacteria, particularly *Salmonella* spp. and *Shigella* spp., into the production environment. The Codex Alimentarius also emphasizes that water may act as a source of microbiological contamination at different stages of fresh produce production, particularly during irrigation, application of water-soluble fertilizers, harvesting, and post-harvest operations [2].

Runoff water deserves particular attention because it may facilitate the transfer of microorganisms present in soil, animal or human fecal matter, and waste into watercourses and agricultural plots. Changes in land use and climate change may also modify runoff, infiltration, and the transport of microbiological contaminants. In this context, monitoring the quality of water resources used for irrigation is an essential component of contamination prevention in vegetable production systems.

In addition, organic fertilizers of animal origin, particularly poultry manure,

cattle manure, compost, and humus, may constitute potential reservoirs of enteric microorganisms when they are insufficiently treated or composted. FAO and WHO recommend appropriate treatment of fecal waste, including composting, before its use as organic fertilizer, as well as limiting contact between contaminated amendments and edible parts of plants [1].

Microbiological contamination of plant products therefore results from complex interactions among water quality, soil characteristics, organic amendments, animals, climatic conditions, and agricultural practices. Recent evidence shows that *Salmonella* can persist in different environmental compartments and that its survival and transmission to plants depend, among other factors, on environmental conditions, plant characteristics, and production practices [3]. A recent meta-analysis of commercially marketed fresh fruits and vegetables further confirmed the persistence of *Salmonella* as an important food-safety concern and identified irrigation water quality and environmental conditions among the factors associated with its presence. The serotypes *S. typhimurium* and *S. enteritidis* were among those most frequently reported [4].

In the Guinean context, recent data also indicate that microbiological contamination of water resources is a concern in Kindia Prefecture. A study published in 2025 on bathing waters in Kindia detected *Salmonella* spp. at several sites and identified runoff, agriculture, livestock farming, waste, and wastewater as potential sources of environmental contamination [5]. Another recent study conducted in N'Zérékoré highlights the importance of assessing the quality of water used for irrigation of vegetable crops and the need for regular microbiological monitoring [6].

In Kindia, a recent study on the contamination of fruits and vegetables also reported the presence of *Salmonella* in vegetable products and highlighted the potential role of irrigation water and insufficiently composted organic fertilizers. However, this study specified that the associations between these factors and product contamination had not been subjected to specific statistical analysis [7]. The present manuscript specifically analyzes the “irrigation water” and “organic fertilizer” components of a broader sampling campaign that also supported the study of contamination of vegetable products in Kindia. This work addresses a distinct scientific question by characterizing the detection frequency, distribution according to matrices, and serotypes of *Salmonella* and *Shigella* in agricultural inputs.

Accordingly, the present study aimed to assess the microbiological contamination of irrigation water and organic fertilizers used in vegetable farms in Kindia Prefecture by *Salmonella* spp. and *Shigella* spp. More specifically, it sought to determine the contamination frequency of different irrigation water sources and different types of organic fertilizers, as well as to identify the *Salmonella* serotypes and *Shigella* species/taxa present in these matrices.

1.1. General Objective

To assess the microbiological contamination of irrigation water and organic fer-

tilizers used in vegetable farms in Kindia Prefecture by bacteria of the genera *Salmonella* and *Shigella*.

1.2. Specific Objectives

- To determine the detection frequency of *Salmonella* spp. and *Shigella* spp. in irrigation water and organic fertilizers used at vegetable-growing sites;
- To determine the detection frequency of *Salmonella* spp. according to the different irrigation water sources and different types of organic fertilizers;
- To identify the serotypes of *Salmonella* spp. and the species/taxa of *Shigella* spp. detected in the matrices studied.

2. Materials and Methods

2.1. Study Area

The study was conducted in Kindia Prefecture, located in Lower Guinea (Maritime Guinea). It covers an area of approximately 9115 km² and had a population of 439,614 inhabitants according to the 2014 General Population and Housing Census (RGPH), with a density of approximately 52 inhabitants/km². The prefecture includes the urban commune of Kindia and several rural communes, including Bangouyah, Damakania, Friguiagbé, Kolenté, Mambia, Madina-Oula, Molota, Samaya, Souguéta, and Linsan [8] [9].

Kindia has a humid tropical climate characterized by a long rainy season, generally from May to October, and a dry season from November to April. Rainfall is substantial and generally reaches its maximum around August. The landscape is characterized by plateaus, valleys, and lowlands, including Mount Gangan. The prefecture is crossed by several watercourses belonging mainly to the Kolenté and Konkouré river basins [10].

Agriculture is one of the main economic activities in the prefecture. The area is particularly suitable for horticultural and vegetable production. Major vegetable crops include tomato, chili pepper, eggplant, okra, cucumber, watermelon, cabbage, and lettuce. Vegetable farming is practiced during both the rainy and dry seasons, with the latter requiring greater reliance on irrigation [11] [12].

Vegetable farms use different water sources, including rivers, streams, wells, dams, and runoff water. Plots are generally established near water points, lowlands, or watercourses to facilitate irrigation. This configuration, combined with the proximity of certain residential and livestock areas and the use of organic fertilizers of animal origin, may facilitate the introduction and circulation of microorganisms of fecal origin in the production environment. These characteristics motivated the selection of Kindia Prefecture as the study area (Figure 1).

2.2. Working Materials

The working materials consisted of equipment, laboratory glassware, and specific culture media.

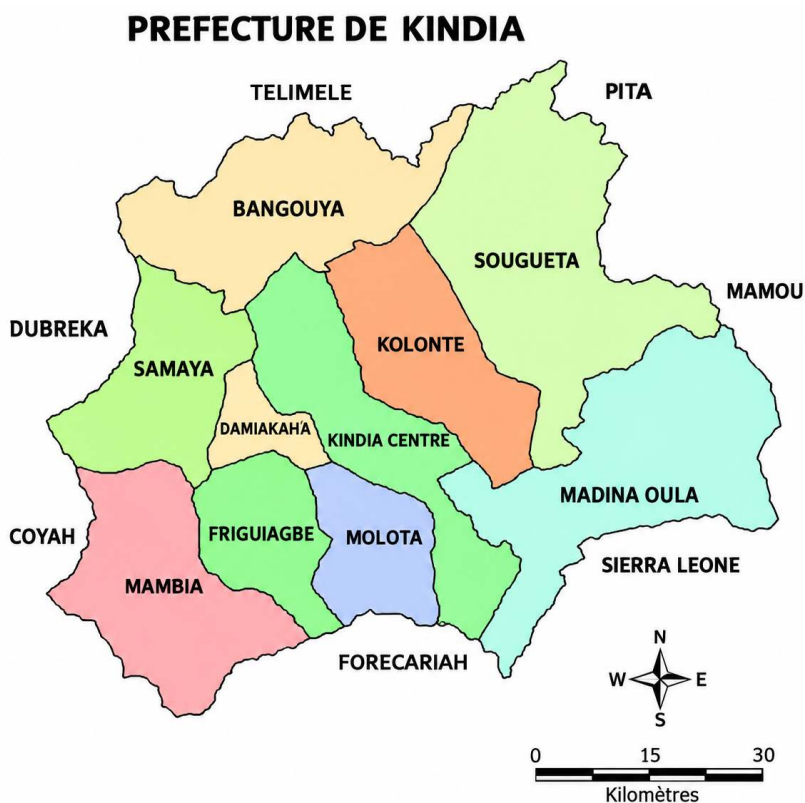


Figure 1. Kindia prefecture (Kindia Urban Commune, 2015).

2.3. Biological Matrix

Irrigation water and organic fertilizers served as the biological materials for the study.

2.4. Methodology

2.4.1. Study Design and Study Period

This was a descriptive observational study conducted from June 2024 to March 2025 in the main vegetable-growing sites of Kindia Prefecture, Republic of Guinea. The study aimed to assess the microbiological contamination of irrigation water and organic fertilizers used in vegetable farms by *Salmonella* spp. and *Shigella* spp.

2.4.2. Study Sites and Sampling Strategy

The study was conducted at 17 vegetable-growing sites distributed across the main agricultural production areas of Kindia Prefecture. The sites were selected in communes where vegetable farming was an important activity and where producers used different water sources for irrigation as well as different types of organic fertilizers.

Site selection was based on the following criteria: (i) the importance of vegetable production activities; (ii) regular use of water resources for irrigation; (iii) use of

organic fertilizers, particularly compost, humus, poultry manure, and cattle manure; and (iv) farmers' agreement to participate in the study.

The 17 vegetable-growing sites were selected using purposive sampling based on predefined criteria. Within the selected sites, sampling points were randomly selected according to a predefined protocol. A total of 1073 samples were collected, including 577 irrigation water samples and 496 organic fertilizer samples. Water samples originated from five types of sources: rivers, streams, wells, runoff water, and dams. The organic fertilizers analyzed consisted of compost, humus, poultry manure, and cattle manure.

2.5. Sample Collection and Preservation

The sampling unit consisted of a 500 mL composite sample for irrigation water (wells, rivers, and reservoirs) and a 250 g sample for organic fertilizers (compost, chicken manure, and cattle manure). Across the 17 vegetable-growing sites surveyed in the Kindia Prefecture, a total of 1073 samples were collected ($n = 577$ water samples and $n = 496$ organic fertilizer samples). Sample allocation was performed using proportional stratified sampling based on the number of farms at each site, corresponding to an average of 34.0 water samples and 29.2 organic fertilizer samples per site. Variations in sample numbers among sites were attributable to the operational availability of active water sources. Each sample was identified using a unique code containing information on the site, sampling date, and type of matrix.

After collection, samples were immediately placed in a cooler containing ice packs and transported at a temperature ranging from 4°C to 8°C. They were transported to the microbiology laboratory of the Institute for Applied Biological Research of Guinea (IRBAG) in Kindia and to the Laboratory of Applied Research in Natural Sciences (LARASCINA) for microbiological analyses.

Microbiological analyses were conducted jointly by IRBAG (samples from the eastern/northern area of Kindia) and LARASCINA (western/southern area) to ensure sample viability during transportation (transit time < 4 h at 4°C - 8°C). Inter-laboratory quality assurance included the systematic use of positive controls (*Salmonella enteritidis* ATCC 13076 and a reference *Shigella* strain), negative medium/reagent blanks, and blinded duplicate cross-analysis of 5% of the samples by both laboratories. An inter-laboratory agreement rate of 96.5% was observed.

2.6. Microbiological Analyses

Microbiological analyses were carried out in accordance with the recommendations of ISO 6579-1:2017 for the detection of *Salmonella* spp. and ISO 21567 for the detection of *Shigella* spp. Following pre-enrichment in buffered peptone water, the samples underwent selective enrichment in Rappaport-Vassiliadis and Selenite-Cystine broths. The cultures were then inoculated onto Xylose Lysine Deoxycholate (XLD) and Hektoen Enteric Agar media.

Suspect colonies were identified using conventional biochemical tests (Triple

Sugar Iron, urease, Simmons' citrate, motility and indole production), and then confirmed by serotyping according to the Kauffmann-White scheme.

The screening for *Shigella* spp. followed ISO 21567, modified by the use of *Shigella* broth supplemented with novobiocin for selective enrichment at 42°C for 24 hours. Suspect colonies on XLD and MacConkey agar were subjected to biochemical identification (API 20E) and serotyped by slide agglutination using specific polyvalent and monovalent antisera (Bio-Rad), enabling the unambiguous identification of the single isolate of *Shigella dysenteriae* type 1.

2.7. Statistical Analysis

The raw data were entered into Microsoft Excel and analysed using SPSS software (version 25). The frequencies and proportions of positive results were calculated for all variables, together with their exact 95 per cent confidence intervals (95% CI) using the Clopper-Pearson method. As repeated samples taken over time from the same site or water source were not structured using a hierarchical random-effects model (taking into account the clustering effect), the bivariate comparisons of prevalence between water sources and types of organic fertiliser are strictly descriptive in nature.

3. Results

As shown in **Table 1**, a total of 1073 samples were analyzed, including 577 irrigation water samples (53.77%) and 496 organic fertilizer samples (46.23%).

Table 1. Distribution of Samples according to the matrix studied.

No.	Biological matrix	Number of samples	Percentage (%)
2	Irrigation water	577	53.77
3	Organic fertilizers	496	46.23
Total		1073	100

As shown in **Table 2**, among the 577 irrigation water samples analyzed, 68 were positive for *Salmonella* spp., corresponding to a prevalence of 11.79% (95% CI: 9.40 - 14.67). *Shigella* spp. was detected in only one sample, corresponding to a prevalence of 0.17% (95% CI: 0.03 - 0.98). Overall, 69 samples were positive for at least one of the two bacterial genera, corresponding to an overall prevalence of 11.96%.

Table 2. Prevalence of *Salmonella* and *Shigella* in irrigation water.

No.	Microorganism	Samples analyzed	Positive cases	Prevalence (%)	95% CI
1	<i>Salmonella</i> spp.	577	68	11.79	9.40 - 14.67
2	<i>Shigella</i> spp.	577	1	0.17	0.03 - 0.98
Total			69	11.96	

As shown in **Table 3**, among the 496 organic fertilizer samples analyzed, 59 were positive for *Salmonella* spp., corresponding to a prevalence of 11.90% (95% CI: 9.33 - 15.04). No sample was positive for *Shigella* spp.

Table 3. Prevalence of *Salmonella* and *Shigella* in organic fertilizers.

No.	Microorganism	Samples analyzed	Positive cases	Prevalence (%)	95% CI
1	<i>Salmonella</i> spp.	496	59	11.90	9.33 - 15.04
2	<i>Shigella</i> spp.	496	0	0	0.00 - 0.74
Total		496	59	11.90	9.33 - 15.04

Analysis of the different types of organic fertilizers showed that compost had the highest observed detection frequency of *Salmonella* (15.07%), followed by cattle manure (12.50%), humus (10.09%), and poultry manure (9.94%). No organic fertilizer sample was positive for *Shigella* spp. (**Table 4**).

Table 4. Detection frequency of *Salmonella* and *Shigella* according to the type of organic fertilizer.

Type of organic fertilizer	Number analyzed	<i>Salmonella</i> n	Prevalence (%)	<i>Shigella</i> n	Prevalence (%)
Compost	146	22	15.07	0	0.00
Humus	109	11	10.09	0	0.00
Poultry manure	161	16	9.94	0	0.00
Cattle manure	80	10	12.50	0	0.00
Total	496	59	11.90	0	0.00

The prevalence of *Salmonella* spp. was highest in runoff water (15.94%), followed by river water (11.64%), dam water (10.00%), streams (8.94%), and well water (6.17%) (**Table 5**).

Table 5. Detection frequency of *Salmonella* according to irrigation water source.

Water source	Number analyzed	Positive cases	Prevalence (%)	95% CI
River	146	17	11.64	6.96 - 17.90
Stream	123	11	8.94	4.95 - 15.59
Well	81	5	6.17	2.67 - 13.55
Runoff water	207	33	15.94	11.63 - 21.47
Dam	20	2	10.00	2.79 - 30.10
Total	577	68	11.79	9.40 - 14.67

This descriptive distribution indicates a higher detection frequency in runoff water than in the other sources studied. Well water had the lowest prevalence among the sources investigated.

Serotyping of the isolates identified 128 bacterial isolates, including 127 *Salmonella* spp. isolates and one *Shigella dysenteriae* type 1 isolate. These isolates originated from 128 positive samples among the 1073 samples analyzed, corresponding to an overall prevalence of 11.93% (Table 6).

Table 6. Distribution of *Salmonella* serotypes and *Shigella* according to sample type.

Sample type	Number analyzed	<i>S. typhi</i> n (%)	<i>S. typhimurium</i> n (%)	<i>S. enteritidis</i> n (%)	<i>Shigella dysenteriae</i> type 1 n (%)	Total positive n (%)
Irrigation water	577	3 (0.52)	29 (5.03)	36 (6.24)	1 (0.17)	69 (11.96)
Organic fertilizers	496	0 (0.00)	20 (4.03)	39 (7.86)	0 (0.00)	59 (11.90)
Total	1073	3 (0.28)	49 (4.57)	75 (6.99)	1 (0.09)	128 (11.93)

The predominant serotype was *Salmonella enteritidis*, with 75 strains, representing 6.99% of the samples analyzed and 58.59% of the isolated strains. It was followed by *Salmonella typhimurium*, with 49 strains, corresponding to 4.57% of the samples analyzed and 38.28% of the isolates. *Salmonella typhi* was detected in only three irrigation water samples, representing 0.28% of the samples analyzed and 2.34% of the isolates. Only one strain of *Shigella dysenteriae* type 1 was isolated from irrigation water, corresponding to 0.09% of the samples analyzed and 0.78% of the isolates.

Irrigation water accounted for 69 samples positive for *Salmonella* spp. and/or *Shigella* spp. (11.96%), compared with 59 positive samples among organic fertilizers (11.90%). The isolates were predominantly represented by *S. enteritidis* (58.59%) and *S. typhimurium* (38.28%), whereas *S. typhi* and *Shigella dysenteriae* type 1 accounted for 2.34% and 0.78% of the isolates, respectively. *S. typhi* and *Shigella dysenteriae* type 1 were detected exclusively in irrigation water, whereas *S. enteritidis* and *S. typhimurium* were found in both matrices studied.

4. Discussion

The prevalence of *Salmonella* observed in irrigation water was 11.79%, highlighting a non-negligible level of microbiological contamination in this matrix. This observation is consistent with studies reporting that water used for irrigation can constitute a route for the introduction of enteropathogenic bacteria into vegetable production systems [6]. The presence of *Salmonella* in irrigation water therefore highlights its potential role as a source of exposure for crops, particularly when the water comes into direct contact with edible plant parts. However, since the present study did not investigate vegetable products, the transfer of *Salmonella* from water to vegetables cannot be directly established.

Contamination of organic fertilizers was also substantial, with a *Salmonella* prevalence of 11.90%. The bacterium was detected in all four types of fertilizers

studied: compost (15.07%), cattle manure (12.50%), humus (10.09%), and poultry manure (9.94%). This distribution indicates that different organic matrices used in vegetable farming may constitute potential sources of microbiological contamination. These findings are consistent with those of [12], which emphasize the importance of treatment, storage, and handling practices for organic amendments in controlling bacterial contamination. However, since the degree of composting or hygienization of the fertilizers was not assessed in our study, it is not possible to directly attribute the observed contamination to inadequate treatment.

The prevalence of *Salmonella* varied according to the irrigation water source. Runoff water had the highest prevalence (15.94%), followed by river water (11.64%), dam water (10.00%), streams (8.94%), and wells (6.17%). The higher frequency observed in runoff water could be explained by its direct exposure to runoff from different areas of the watershed, which may transport microbiological contaminants originating from domestic, agricultural, or livestock activities [2]. However, this interpretation remains hypothetical because the specific sources of contamination were not characterized in the present study. Similarly, the lower prevalence observed in well water does not allow us to conclude that there is less fecal contamination in the absence of measurements of specific microbiological indicators.

Serotyping revealed a predominance of *Salmonella enteritidis*, with 75 isolates representing 58.59% of the 128 isolates obtained, followed by *S. typhimurium* with 49 isolates (38.28%). *S. typhi* accounted for 2.34% of the isolates (3/128), while a single strain of *Shigella dysenteriae* type 1 was identified, representing 0.78%. The predominance of *S. enteritidis* and *S. typhimurium* is consistent with their frequently reported importance in food contamination and agricultural environments [4]. The presence of these serotypes in irrigation water and organic fertilizers highlights their circulation within the matrices studied. However, in the absence of molecular characterization and analyses capable of tracing contamination sources, the animal, human, or environmental origin of the isolates cannot be established with certainty.

Overall, the detection of *Salmonella* in irrigation water and organic fertilizers demonstrates the presence of this bacterium in two important matrices of vegetable production systems in Kindia Prefecture. These findings highlight the need to strengthen microbiological monitoring of irrigation water and improve the treatment, storage, and handling practices of organic fertilizers. Further studies incorporating microbiological analysis of vegetable products, molecular characterization of isolates, and assessment of seasonal variations would help better determine contamination pathways and estimate the potential risk to consumers.

5. Study Limitations

- The purposive selection of sites limits the generalizability of the results to all vegetable farms in Guinea.
- The study was conducted in only one prefecture.
- There was no additional molecular characterization of the isolates, particularly

for genetic typing and analysis of phylogenetic relationships.

- No specific indicator of fecal contamination, particularly *E. coli*, was measured.
- Other enteric pathogens (*E. coli* O157, *Campylobacter*, *Listeria*) were not investigated.
- Although the study period covered part of both the rainy and dry seasons, no season-stratified analysis was performed.
- No quantitative health risk assessment for consumers was conducted.
- The degree of maturation, composting, or hygienization of the fertilizers was not documented.

6. Conclusions

The results of this study demonstrate the detection of *Salmonella* and/or *Shigella* in some of the irrigation water and organic fertilizers used on the market garden holdings surveyed. Runoff water showed the highest detection rates among the irrigation sources examined, while the use of inadequately treated poultry manure was identified as a potential source of microbial hazards. These findings indicate that certain production inputs may constitute reservoirs of enteric pathogens and therefore represent potential upstream sources of contamination within the production environment.

However, the detection of pathogens in irrigation water or organic fertilizers does not, in itself, demonstrate their transfer to the surfaces or internal tissues of vegetables. Nor does it establish the magnitude of contamination of harvested produce or provide a direct estimate of the microbiological or health risk to consumers. Demonstration of such transfer and assessment of consumer health risk would require direct microbiological examination of the vegetables, together with information on pathogen concentrations, environmental persistence, irrigation and harvesting practices, post-harvest handling, and the amount of contaminated produce potentially consumed.

Accordingly, the findings should be interpreted primarily as evidence of the presence of potential microbial hazards in production inputs, rather than as evidence of confirmed contamination of vegetables or demonstrated illness risk among consumers. Nevertheless, the presence of these pathogens in inputs provides a scientific basis for preventive measures aimed at reducing the possibility of their transfer to crops and limiting potential downstream exposure.

The results therefore support the strengthening of preventive agricultural hygiene measures, particularly the improvement of irrigation-water quality and the proper treatment and management of organic fertilizers. Routine monitoring of relevant production inputs, combined with training in Good Agricultural Practices (GAP), may help reduce the occurrence of microbial hazards at the production stage. Future studies should include direct microbiological testing of vegetables and, where appropriate, quantitative assessment of pathogen levels and exposure pathways in order to determine whether contamination of produce occurs

and to better characterize any associated consumer health risk.

7. Recommendations

Based on the findings of this study, the following recommendations are proposed primarily to control potential microbial hazards identified in production inputs and to prevent their possible transfer to fresh produce. These recommendations should not be interpreted as evidence that contamination of vegetables or adverse health effects in consumers were demonstrated by the present study.

7.1. Recommendations to Government Authorities

- Strengthen awareness and training programmes for vegetable producers on Good Agricultural Practices (GAP), with particular emphasis on irrigation-water quality, manure treatment and management, and hygienic handling of produce.
- Develop and implement food-safety awareness programmes targeting stakeholders involved in the production, transportation, marketing, preparation, and handling of fruits and vegetables.
- Establish or strengthen routine microbiological surveillance of production inputs, particularly irrigation water and organic fertilizers, in addition to surveillance of fresh produce where resources and regulatory frameworks permit.
- Prioritize microbiological monitoring of surface and runoff water, given the relatively high detection rates observed in these sources in the present study.
- Develop appropriate guidelines for the safe treatment, storage, and application of organic fertilizers intended for vegetable production, including criteria for adequate composting or other validated treatment processes.
- Support future studies that directly assess the presence and concentration of *Salmonella* and *Shigella* in vegetables produced under the conditions represented in this study, in order to determine whether contamination of produce occurs.
- Where sufficient data become available, support quantitative microbiological risk assessment to characterize potential consumer exposure and associated health risks.

7.2. Recommendations to Stakeholders Involved in Fruit and Vegetable Production

- Comply with applicable hygiene requirements and adopt Good Agricultural Practices throughout cultivation, harvesting, transportation, storage, and handling.
- Give particular attention to the microbiological quality of irrigation water and, whenever feasible, avoid water sources that may be affected by domestic, agricultural, or animal waste.
- Improve the collection, storage, treatment, and handling of organic fertilizers before their application to vegetable crops, ensuring adequate treatment before

use.

- Where technically and economically feasible, adopt irrigation methods that minimize direct contact between irrigation water and edible portions of crops, such as drip irrigation.
- Avoid unnecessary irrigation immediately before harvest and establish an appropriate interval between the last irrigation and harvesting according to local agricultural conditions and applicable guidance. A one-day interval should not be presented as a universally validated measure unless supported by local or experimental evidence.
- Prevent cross-contamination during harvesting, washing, packing, transportation, and marketing through appropriate hygiene and sanitation practices.
- Strengthen training of farmers, vendors, and other food handlers on personal hygiene, equipment sanitation, cross-contamination prevention, and safe handling of fresh produce.
- Where washing or disinfection of produce is undertaken, use safe water and appropriate food-grade procedures in accordance with applicable guidance and manufacturer instructions.

7.3. Recommendations to Consumers

- Wash fruits and vegetables thoroughly with safe, potable water before consumption.
- Where disinfection of fresh produce is recommended or appropriate, use a suitable food-grade disinfectant strictly according to the manufacturer's instructions regarding concentration and contact time.
- Prevent cross-contamination between raw produce and potentially contaminated foods, surfaces, utensils, or hands during preparation.
- Maintain appropriate hygienic conditions during the preparation, storage, and serving of fruits and vegetables.
- Where possible, purchase fresh produce from vendors who maintain clean handling and storage conditions.

These consumer recommendations are preventive measures and should not be interpreted as indicating that the present study demonstrated contamination of marketed vegetables or a quantified health risk to consumers.

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Acknowledgements

The authors would like to thank the Government of the Republic of Guinea, particularly the Ministry of Higher Education, Scientific Research and Innovation, the University of Kindia (UK), and the Institute for Applied Biological Research of Guinea (IRBAG/Kindia) for their support.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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