resources

Article

Spring Water Quality in a Flood-Prone Area of Kampala City, Uganda: Insights Furnished by Sanitary and Limnochemical Data

Ronald Tenywa [1], Timothy Omara [2,*], Gerald Kwikiriza [3], Christopher Angiro [4] and Emmanuel Ntambi [1,*]

1 Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology, Mbarara P.O. Box 1410, Uganda; tenywaronald8@gmail.com
2 Department of Chemistry, College of Natural Sciences, Makerere University, Kampala P.O. Box 7062, Uganda
3 Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI), National Agricultural Research Organisation (NARO), Kabale P.O. Box 421, Uganda; gkwikiriza2@gmail.com
4 Centre for Water, Environment and Development-School of Water, Energy and Environment, Cranfield University, Cranfield Road, Cranfield, Bedfordshire MK43 0AL, UK; christopher.angiro.602@cranfield.ac.uk
* Correspondence: prof.timo2018@gmail.com (T.O.); emmantambi@must.ac.ug (E.N.)

Abstract: For millennia, springs have provided water for drinking, domestic use, balneological treatment, liminality rites as well as tourist attractions. Amidst these uses, anthropogenic activities, especially urbanization and agriculture, continue to impair the functionality of springs. With the looming decadal climate change, freshwater springs could be a sustainable source of clean water for the realisation of Sustainable Development Goal 6. This paper presents the results of the sanitary inspection and assessment of limnochemical characteristics and quality of water samples ($n = 64$) from four freshwater springs (coded SPR1, SPR2, SPR3, and SPR4) in Kansanga, a flash flood-prone area in the African Great Lakes region of Uganda. Each sample was analysed for 17 parameters (temperature, pH, electrical conductivity, turbidity, fluorides, sulphates, chlorides, nitrates, orthophosphates, total dissolved solids, dissolved oxygen, total alkalinity, potassium, sodium, total, magnesium and calcium hardness) following the standard methods. Water quality index (WQI) was calculated to establish the quality of the water samples based on the physicochemical parameters measured. Based on the sanitary risk assessment results, the springs had medium- to high-risk scores, but most water parameters were within the WHO guidelines for potable water, except for nitrates (in SPR1 and SPR2), hardness levels (in SPR2), and dissolved oxygen (in all the samples). Sampling season and location had significant effects on the limnochemistry of the freshwater springs ($p < 0.05$). The water quality indices calculated indicated that the water from the springs was of good quality (WQI = 50–57), but there was a reduction in water quality during the wet season. The best water quality was recorded in samples from SPR4, followed by those for SPR3, SPR1, and SPR2. These results provide insights into the contribution of floods and poor sanitation facilities to the deterioration of spring water quality in Kansanga, and the need to leverage additional conservation strategies to support vulnerable communities in the area. Further studies are required to establish the risk posed by trace metals and microbes that may contaminate freshwater in the studied springs, especially following flood events.

Keywords: potable water; physico-chemical quality; water quality index

Citation: Tenywa, R.; Omara, T.; Kwikiriza, G.; Angiro, C.; Ntambi, E. Spring Water Quality in a Flood-Prone Area of Kampala City, Uganda: Insights Furnished by Sanitary and Limnochemical Data. *Resources* **2024**, *13*, 133. https://doi.org/10.3390/resources13100133

Academic Editor: Barbara Ruffino

Received: 7 August 2024
Revised: 19 September 2024
Accepted: 23 September 2024
Published: 25 September 2024

1. Introduction

Universal access to clean and safe water and hygiene services is one of the core targets to be realised by 2030 (Sustainable Development Goal 6) to achieve the central and transformative mantra of "Leave No One Behind" [1]. According to the United Nations, increasing population pressures has exacerbated water insecurity, with several millions of people having limited access to clean and safe water, which is otherwise considered to be a basic human right [2]. While we have less than a decade to 2030, the complexity of achieving universal water security has become more apparent [3]. Several challenges that are beyond basic water infrastructure, supply, and utility are being identified [4,5]. For example, disease epidemics and climate risks in combination with water insecurity creates a triple threat to the realisation of the Sustainable Development Goals [5,6]. Thus, there is a need to adopt a holistic approach including integrated water conservation techniques, real-time water quality monitoring, and water pollution control to offset the current innovation deficit in water resource management [4,7].

Natural freshwater resources such as lakes, rivers, swamps, and springs are the most important sources of water that support life on Earth, and are critical for sustainable future developments [3]. Despite this, there is irrational use and pollution of freshwater resources, and the situation is much more deplorable in developing countries due to weak regulatory infrastructures and monitoring systems [8]. In Africa, the water insecurity predicament seems to be largely driven by poor management (economic scarcity) rather than overexploitation or overextraction (physical scarcity) [9].

Considering the various sources of fresh water, springs are unique because they connect the lithosphere, hydrosphere, biosphere, and atmosphere [10]. Springs result when water pressure induces a concentrated natural discharge of groundwater onto the Earth's surface via fractures, contact zones, or other such openings [11]. In most cases, they represent headwaters or low-order tributaries. The calcareous nature of aquifers gives spring water its calcium-bicarbonate hydrochemical signature, along with other dissolved ions such as magnesium, sulphates, and sodium [12]. Since all spring water initially originates from precipitation, external factors can influence the quality of the final water [13]. Thus, monitoring the limnochemical and microbial characteristics of water from springs is an important step towards the realisation of sustainable development and in enhancing their use [14,15].

The African Great Lakes region (the focal point of this study, henceforth referred to as AGLR) refers to the region lying in the Western and East African Rift (including the Albertine Rift) with a series of tropical lakes (Albert, Edward, Kivu, Malawi, Tanganyika, Turkana, and Victoria) [16]. These lakes, collectively called the "African Great Lakes", are shared by ten African countries, namely Uganda, Burundi, the Democratic Republic of the Congo (DRC), Rwanda, Ethiopia, Tanzania, Kenya, Malawi, Mozambique, and Zambia [17]. For example, Lakes Albert and Edward are shared by Uganda and the DRC while Tanganyika is shared among four countries: Tanzania, DRC, Burundi, and Zambia. The geological formations of AGLR have favoured the formation of springs [18–20]. In Uganda, springs are cherished as sources of water for drinking and domestic uses, balneological treatment, sites of liminality, and the protection of unique landscapes as well as tourist attractions [14,15,19–23]. However, studies investigating the limnochemical and microbial characteristics of springs have been confined to the Rwenzori, Kitagata, Kibenge, Katanga, Nyakirango, and Ihimbo hot springs [15,22,24–28], Chuho springs [14], and protected springs in the Mbarara and Kasese Districts [29–31] of Western Uganda. In contrast, fewer reports exist on the quality of freshwater from springs in other parts of Uganda [21,23,28,32–37]. These limited studies make it challenging to understand the factors that influence the quality of water from the springs. Additionally, policymakers and responsible institutions in charge of water resource management including the Ministry of Water and Environment are constrained in making informed decisions related to the use and regulation of water quality from springs.

Herein, we examined the temporal variations in the limnochemistry of water from four freshwater springs in Kansanga, a flood-prone area in the Greater Kampala Metropolitan Area of the AGLR, Uganda. In addition to calculating the water quality index (WQI), we adapted the recommended guidelines by the World Health Organisation to perform a sanitary inspection of the springs for the identification of possible risks of microbial contamination. This information is essential for ensuring water quality, protecting public health, and addressing environmental challenges related to spring water.

2. Methods

2.1. Study Area and Choice of the Sampled Springs

The study was conducted in Kansanga (0°17′14.0″ N, 32°36′28.0″ E; Figure 1), Makindye Division of the Greater Kampala Metropolitan Area (GKMA), Uganda. Kansanga shares common frontiers with Kabalagala and Kisugu in the north, Muyenga to the northeast, Bukasa to the east, Bbunga to the southeast, Konge to the south, Lukuli to the southwest, and Nsambya to the west. Initially a middle or otherwise mediocre class residential neighbourhood of Kampala, Kansanga is a cosmopolitan, rapidly growing residential area [38]. The area is highly accessible, being only 7 km to the city centre of Kampala.

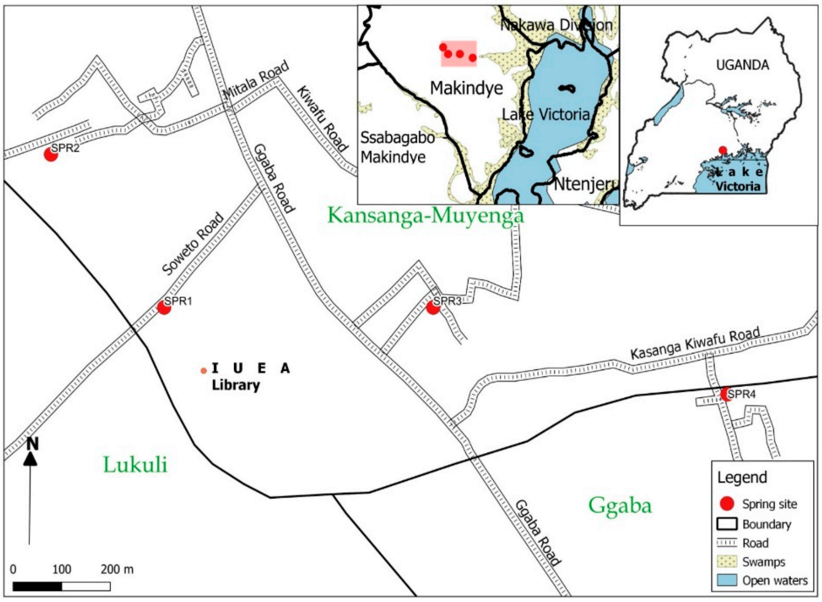

Figure 1. Map showing the location of the sampled springs in Kansanga, Greater Kampala Metropolitan Area. SPR1 to SPR4 refers to the four springs considered.

Despite the impressive business and residential facades in Kansanga, there is a section of highly populated low-income areas of Kampala city suburb situated in a flood plain marked by the Kampala Capital City Authority [39,40]. The majority of the 40,000 residents in this area rely on freshwater from eight springs for drinking and other domestic uses [41]. With regard to climate, Kansanga has bimodal rainfall, with two wet seasons running from March to May, and then from September to November every year. The dry months are January to February and July to August. The mean annual rainfall is 1320 mm.

In this study, four springs labelled SPR1 to SPR4 were chosen (Figure 1). They were purposely selected based on the intensity of human activities and poor waste disposal practices that could be potential causes of water contamination. Spring-head material (whether polyvinyl chloride, i.e., PVC or steel) and construction design were the other factors considered (Figure 2). SPR1 is located in the Mutesasira zone (0°17′4.73012″ 32°36′20.29513″), with its source inside the walls of Wonderworld Amusement Park. Its water flows through an open concrete drainage channel that ends in a PVC spring-head. SPR2 is located in the Simbwa zone (0°17′14.63532″ 32°36′12.762″) and possesses a steel spring-head. It is bordered by the Kampala City Council Authority Primary School to the north, a slum settlement uphill, and a drainage channel to the south. SPR3 is in the Kiwafu A zone (0°17′4.73012″ 32°36′38.20104″) and is inside a motor garage that has a well-planned private residence uphill with the landmark being the Gospel Light Baptist Primary School. The last spring (SPR4) is situated in the Kiwafu B zone (0°16′59.11716″ 32°36′57.78504″), which is close to Windchimes Kindergarten School. It is surrounded by well-planned residences uphill, and a busy murram road to the west. It has a steel spring-head. Based on the coordinates, SPR1 is 384.4 m from SPR2, while SPR3 is 629.2 m from SPR4.

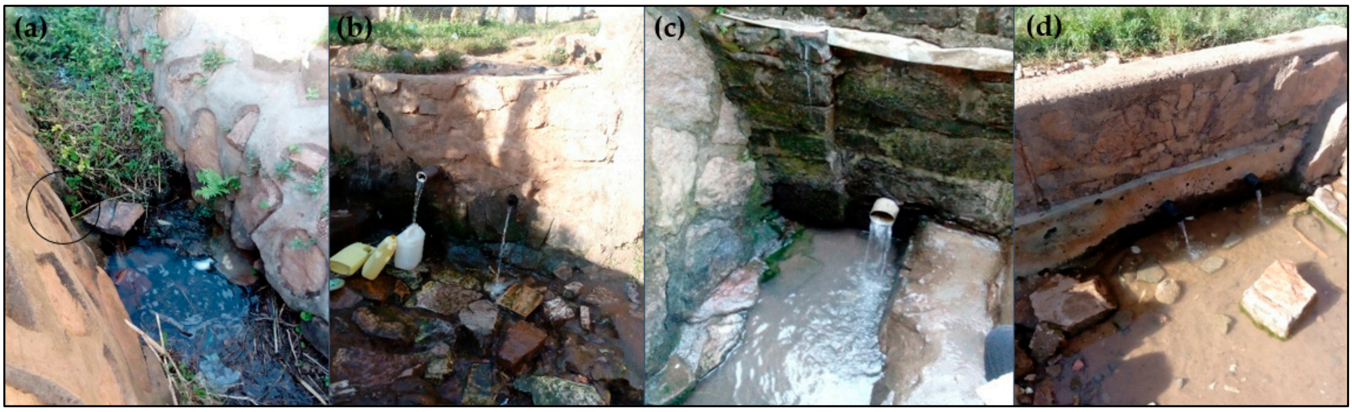

Figure 2. Characteristics of the springs considered in this study: (**a**) SPR1 with the outlet pipe broken and here shown with a circle in the open concrete drainage channel; (**b**) SPR2 with two outlet pipes, (**c**) SPR3 with a single outlet pipe, and (**d**) SPR4 with two outlet pipes. Photos taken by Ronald Tenywa.

2.2. Sanitary Inspection of the Springs

A sanitary assessment survey was conducted at the selected springs to identify the risks for contamination. The study employed an approach previously used in Uganda [21,23,30,33] that is also very similar to the recently developed sanitary inspection package (drinking water) for springs provided by the World Health Organisation [42]. Our inspection involved filling in a ten-point standardised data form consisting of questions with yes/no options for ten designated risks. A score of one point was awarded for each "yes" answer (risk observed) and zero points for each "no" answer (no risk observed). By way of summing up all of the "yes" scores, a final risk score was obtained, which gave the overall assessment of the risk profile of a spring. The total sanitary risk score was manipulated into a percentage, and the aggregate risk score was graded as nil (0%), low (1% to 30%), medium (31% to 50%), high (51–80%), or very high (81–100%) [21].

2.3. Water Sampling Protocol

Water samples were collected from the four springs in the morning, afternoon, and evening every fortnight from July to October 2023 following the procedures described by Omara et al. [23] with slight modifications. The seasons were stratified into the dry spell (July and August 2023) and wet or rainy season (September 2023 and October 2023) to discern whether there were any potential impacts of rain on the limnochemical characteristics of spring water. Samples for the same day per spring were combined into a composite sample, resulting in 16 samples per month (i.e., 32 samples per season and 64 samples in total). Sterilised 500 mL polyethene bottles were used in the sampling campaigns. After removing any attachments that could cause the splashing out of water at the mouth of the springs, water was allowed to flow for one minute, and with the bottle held at the mouth of the spring with one hand, the bottle was opened with the other hand, placed below the pipe, and filled with water while ensuring that there was an allowance (air space). Samples were immediately taken to the laboratory for analysis.

2.4. Determination of Physicochemical Parameters of Water

2.4.1. Non-Conservable Parameters

Electrical conductivity (±0.5%), pH (±0.002), and temperature (±0.2 °C) were measured using a Duo pH/Ion/Cond meter SG78 (Mettler Toledo, Oakland, CA, USA). The total dissolved solids (TDSs) were measured using a waterproof HI 98129-HI 98130 pH/TDS/temperature/conductivity meter (Hanna Instruments Inc., Woonsocket, RI, USA).

2.4.2. Turbidity and Total Alkalinity

The turbidity was determined by shaking each water sample to obtain a homogeneous mixture. The water samples (2 mL) were transferred into a cuvette, and the turbidity was measured using an HACH turbid meter 2100P in nephelometric turbidity units (NTUs). The double indicator method was used for total alkalinity determination [43].

2.4.3. Nitrate-Nitrogen and Water Hardness

Nitrate nitrogen (NO_3-N) was determined by following the *Standard Methods for the Examination of Water and Wastewater* [43,44]. The ethylenediaminetetraacetic acid (EDTA) titration method was used to determine the total, calcium, and magnesium hardness [43]. Briefly, 2 mL of ammonia buffer solution was added to the water samples (25 mL), and the resultant solutions were titrated in triplicate against a 0.01 M EDTA solution using Eriochrome black T. The end point of the titration was indicated by a sharp colour change from wine red to blue. The total hardness as calcium carbonate (mg/L) was calculated using Equation (1) [45].

$$\text{Total hardness (mg/L)} = \frac{\text{V} \times \text{M} \times 10,000}{v} \quad (1)$$

where V = volume of EDTA used, M = molarity of EDTA, v = volume of sample used, and 10,000 was the factor used to convert the results from millimoles (mmol) to milligrams per litre (mg/L) of calcium carbonate equivalent, which is the standard unit for expressing water hardness.

For magnesium (Mg) hardness, titration was conducted by employing a pH 10 borax buffer. Eriochrome black T indicator (2 drops) was added, and the mixture was heated for 5 min. The resultant solution was then titrated against a standard solution of 0.01 M EDTA until the appearance of a permanent blue colour. The volume of EDTA used to reach the end point was recorded. The titre values were used to compute the concentration of magnesium in the water samples using Equation (2). Calcium (Ca) hardness was computed as the difference between the total and Mg hardness [46].

$$\text{Mg hardness} = \frac{\text{V} \times \text{M} \times 24,305}{\text{v}} \quad (2)$$

From which V, M, and v follow from Equation (1). The value of 24,305 is a conversion factor specific to magnesium. The factor represents the molecular weight of magnesium expressed in mg/mol. This was used to convert the amount of magnesium (in moles) into milligrams per litre (mg/L), which is the standard unit for water hardness.

2.4.4. Determination of Sulphates, Phosphates, Fluoride, Sodium, and Potassium Contents

The sulphate (SO_4^{2-}) content of the spring water samples was quantified based on the *Standard Methods for the Examination of Water and Wastewater* [47]. Briefly, samples (25 mL) were transferred into Erlenmeyer flasks followed by the addition of a conditioning reagent (50 mL of glycerol, 30 mL of 2 M of concentrated hydrochloric acid, 100 mL of 95% ethanol, and 75 g of sodium chloride). The mixture was agitated for 3 min. After 10 min, the absorbance of the resultant solution was measured spectrophotometerically at 420 nm using deionised water as a blank. The analysis utilised a Thermoscientific Gallery Plus Discrete Analyzer, and the SO_4^{2-} concentration was obtained from a calibration curve constructed from standard sodium sulphate solutions (10 to 50 mg/L) plotted against absorbance [43].

Similarly, phosphates (as total phosphorus) were quantified using the vanadomolybdophosphoric acid method [43]. Briefly, nitric and sulphuric acids (2 M, 2 mL each), ammonium molybdate (0.052 M, 5 mL), and ascorbic acid (0.15 M, 2 mL) were added to 50 mL of the sample in an Erlenmeyer flask. The absorbance of the blue coloured solution was determined spectrophotometrically on a Thermoscientific Gallery Plus Discrete Analyzer at 650 nm utilising deionised water as a blank. Phosphate concentrations were determined from a calibration curve of a standard solution of potassium hydrogen phosphate [43].

For the determination of fluorides, 50 mL of the water samples was transferred into 250 mL beakers followed by 50 mL of Total Ionic Strength Adjustment Buffer (TISAB). A fluoride ion-selective electrode was rinsed, dried, and placed in the sample, followed by stirring until a stable reading was obtained. The stable reading was taken from the meter and calibrated again every one hour. Direct measurement results were verified by a known addition procedure, which involved adding a standard solution (2 mg/L) to each sample solution. From the change in electrode potential before and after addition, the original sample concentration of the fluoride was determined, and the mean value was obtained from three replicates [43].

To quantify the chloride content of the water from the springs, 50 mL of the samples was pipetted into a conical flask and titrated against a standard solution of 0.0141 M silver nitrate in the presence of a 5% potassium chromate indicator. The end point was indicated by the appearance of a red-brown precipitate of silver chromate. A blank was also treated in the same way, and the concentration of chloride was computed using Equation (3).

$$\text{Chlorides (mg/L)} = \frac{(X - Y) \times M \times 35.45}{V} \quad (3)$$

where X = volume of silver nitrate used in the titration, Y = volume of silver nitrate required for blank titration, V = volume of the sample, and M = molality of the silver nitrate solution. The value 35.45 represents the mass of one mole of chloride ions, which was used to convert the titrant amount into the mass of chloride in the water sample (mg/L of chlorides).

A flame photometer was employed to determine the sodium and potassium concentrations. The photometer was calibrated using standard stock solutions of sodium and potassium with a 30 mg/L concentration. Water (100 mL) from each collected sample was filled in standard laboratory plastic bottles and then analysed.

2.5. Assessment of Water Quality

Since spring water is considered to be potable, we harnessed the WQI as an established straightforward, practical, and inexpensive approach for ascertaining the overall quality of surface and groundwater and its acceptability for human consumption (Equation (4)) [48].

$$\text{WQI} = \sum \left(W_i \times \left(\frac{C_i}{S_i}\right) \times 100\right) \quad (4)$$

where C_i denotes the concentrations of the factors used in the computation, S_i symbolises the WHO standard levels for drinking water [49], and W_i is the relative weight expressed as a ratio of w_i to $\sum w_i$ in relation to their relevance of the parameters to human health as well as water quality. The relative weight takes values between 1 and 5 [48]. Subsequently, the quality of freshwater from the springs was categorised as excellent, good, poor, very poor, or unfit for use, depending on whether the calculated WQI was <50, 50–100, 100–200, 200–300, or >300, respectively [33].

2.6. Statistical Analysis

The sanitary inspection and water parameter data were captured in Microsoft Excel 2019. Descriptive statistics were used to analyse the data, which were subsequently averaged and presented with standard deviations of the replicates for the different water parameters. One-way analysis of variance (ANOVA) was used to establish the significant differences in the means of the water parameters among the springs and between seasons. Statistical evaluations (at $p < 0.05$) and data visualisation were executed in GraphPad Prism for Windows (version 9.3.1 GraphPad Software, San Diego, CA, USA).

3. Results and Discussion

3.1. Sanitary Risk Assessment Results

Sanitary inspection is a pivotal analytical asset for the evaluation of the quality and safety of spring water sources. It points out potential hazards that could compromise water quality and pose health risks to consumers [42]. In this study, four springs were assessed, and their qualitative risk profiles indicated that there were medium to high risks, and the highest score of 70% was for SPR2 (Table 1; Figure 2). Two springs (SPR1 and SPR4) had high scores of 60%. Only SPR3 exhibited a medium risk profile, which is in agreement with the sanitary risk assessment results for the Bwanika I, Kasule, and Maama Betty springs of Kampala [21] and springs in Kiswahili and Kisenyi, Mbarara Municipality [30]. Some springs in Kampala (Nakatanza, Kazungu, Musoke, Kakajo, Kiteeso, Luzige, and Bwanika II) [21] and Bwaise (Nabukalu, Bishop Mukwaya, Kiggundu, and Jace School) [50] had high to very high sanitary risk scores (60–90%), which were higher than those observed in the present study.

Table 1. Risk assessment scores of the selected springs in Kansanga, Kampala, Uganda.

Spring	Potential Risks Noted [a]	Risk Score (%)	Aggregate Risk Score
SPR1	1, 2, 3, 4, 9, 10	60	High
SPR2	1, 2, 3, 5, 6, 9, 10	70	High
SPR3	2, 3, 4, 9, 10	50	Medium
SPR4	1, 2, 4, 5, 8, 10	60	High

[a] Risk definitions: (1) unprotected spring, (2) faulty spring masonry, (3) eroded backfill area, (4) spilt water floods collection area, (5) non-existent perimeter fence, (6) animals can freely access the spring within a radius of 10 m; (7) pit latrine uphill and/or within 30 m of water source, (8) surface water collects upstream of the spring, (9) diversion ditch situated uphill absent/non-functional, and (10) other potential contamination sources uphill of the water source such as solid waste dumps, faeces, stagnant water, and drainage channels.

3.2. Temporal Variations in the Hydrochemistry of Spring Water

Table 2 provides a statistical summary of the physicochemical parameters of the spring water samples measured during the dry and wet seasons. The individual parameters, which are water performance quality indicators, are discussed in the following.

Table 2. Hydrochemical profile of the spring water sampled from Kansanga, Kampala, Uganda.

Parameter	SPR1	SPR2	SPR3	SPR4	WHO Guidelines [51]	*p*-Value
Electrical conductivity (µS/cm)	233 ± 0.82 (231 ± 0.74)	285 ± 1.50 (288 ± 3.14)	220 ± 0.81 (221 ± 1.32)	198 ± 0.77 (199 ± 1.30)	1500	0.000 ** (0.000**)
pH	6.10 ± 0.02 (6.30 ± 0.01)	6.15 ± 0.31 (6.00 ± 0.05)	6.13 ± 0.01 (6.10 ± 0.03)	6.02 ± 0.15 (6.01 ± 0.04)	—	0.746 (0.430)
Temperature (°C)	23.0 ± 0.85 (22.4 ± 0.65)	22.9 ± 1.20 (22.4 ± 0.75)	22.7 ± 0.60 (22.3 ± 0.53)	22.8 ± 0.25 (22.5 ± 0.51)	—	0.847 (0.962)
Turbidity (NTU)	3.2 ± 0.25 (3.8 ± 0.03)	3.4 ± 0.30 (3.9 ± 0.42)	3.3 ± 0.02 (3.7 ± 0.31)	3.4 ± 0.20 (3.9 ± 0.25)	5	0.501 (0.474)
Total alkalinity (mg/L)	38.00 ± 0.35 (36.50 ± 0.77)	5.10 ± 0.30 (3.81 ± 0.62)	38.00 ± 0.42 (35.92 ± 0.40)	34.00 ± 0.25 (32.63 ± 0.41)	200	0.000 ** (0.000 **)
Total dissolved solids (mg/L)	90.20 ± 0.38 (90.60 ± 0.41)	90.40 ± 0.25 (90.60 ± 0.40)	89.70 ± 0.35 (90.00 ± 0.31)	89.90 ± 0.20 (90.10 ± 0.40)	1000	0.040 (0.315)
Nitrate-nitrogen (mg/L)	30.89 ± 0.05 (38.60 ± 0.15)	30.63 ± 0.04 (31.31 ± 0.04)	17.00 ± 0.06 (20.00 ± 050)	5.14 ± 0.04 (5.80 ± 0.03)	10	0.410 (0.000 **)
Total hardness (mg/L)	75.00 ± 0.30 (76.30 ± 0.51)	110.00 ± 0.76 (111.00 ± 0.65)	83.20 ± 0.40 (84.00 ± 1.21)	48.20 ± 0.52 (49.61 ± 0.53)	500	0.000 ** (0.000 **)
Calcium hardness (mg/L)	43.00 ± 0.25 (44.70 ± 0.64)	60.10 ± 0.22 (61.80 ± 0.52)	51.10 ± 0.52 (51.80 ± 0.25)	30.00 ± 0.48 (32.20 ± 0.32)	150	0.000 **(0.000 **)
Magnesium hardness (mg/L)	32.00 ± 0.58 (33.30 ± 0.78)	50.00 ± 0.68 (52.10 ± 0.62)	32.00 ± 0.40 (33.90 ± 0.22)	18.00 ± 0.20 (20.10 ± 0.01)	250	0.000 ** (0.000 **)
Sulphates (mg/L)	13.50 ± 0.30 (13.90 ± 0.20)	33.20 ± 0.21 (33.70 ± 0.90)	19.00 ± 0.29 (19.30 ± 0.40)	15.00 ± 0.50 (15.10 ± 0.25)	—	0.000 * (0.000 **)
Total phosphorus (mg/L)	0.23 ± 0.00 (0.07 ± 0.01)	0.05 ± 0.01 (0.02 ± 0.01)	0.05 ± 0.01 (0.02 ± 0.01)	0.05 ± 0.01 (0.03 ± 0.02)	—	0.000 ** (0.006 *)

Table 2. *Cont.*

Parameter	SPR1	SPR2	SPR3	SPR4	WHO Guidelines [51]	*p*-Value
Sodium (mg/L)	23.00 ± 0.05 (23.50 ± 0.04)	48.20 ± 0.03 (49.10 ± 0.35)	26.20 ± 0.24 (26.80 ± 0.45)	17.20 ± 0.04 (17.51 ± 0.05)	200	0.000 ** (0.000 **)
Potassium (mg/L)	6.80 ± 0.01 (7.00 ± 0.25)	22.00 ± 0.02 (22.80 ± 0.04)	8.10 ± 0.01 (8.50 ± 0.05)	4.20 ± 0.03 (4.30 ± 0.06)	12	0.000 ** (0.000 **)
Fluorides (mg/L)	0.29 ± 0.02 (0.28 ± 0.01)	0.17 ± 0.02 (0.17 ± 0.01)	0.16 ± 0.03 (0.15 ± 0.02)	0.39 ± 0.01 (0.39 ± 0.01)	1.5	0.004 * (0.012)
Chlorides (mg/L)	28.80 ± 0.50 (31.70 ± 0.41)	61.20 ± 0.48 (62.80 ± 0.45)	25.50 ± 0.55 (27.20 ± 0.31)	18.00 ± 0.45 (20.10 ± 0.35)	250	0.000 ** (0.000 **)
Dissolved oxygen (mg/L)	5.68 ± 0.18 (5.55 ± 0.21)	5.70 ± 0.20 (5.80 ± 0.31)	5.90 ± 0.21 (6.00 ± 0.22)	6.20 ± 0.35 (6.00 ± 0.35)	4	0.822 (0.657)

Note: Results are presented as the means ± standard deviation of triplicates. Values in parentheses are for the wet season. — means "No health-based guideline value established as per WHO (2022) guidelines for drinking water [51]". * Statistically significant at $p < 0.05$, ** also significant at $p < 0.01$. The significant differences were among the means of the specific parameter measured for water samples from the four springs.

3.2.1. Electrical Conductivity

The highest seasonal mean electrical conductivity (EC) recorded during the wet and dry seasons was 288.00 ± 3.14 µS/cm and 285.00 ± 1.50 µS/cm for SPR2, while the lowest conductivities were 199.00 ± 1.30 µS/cm and 198.00 ± 0.77 µS/cm, respectively, for SPR4 (Table 2). There were significant differences in the EC among the four streams ($p < 0.05$). Conductivity values of the water sources were below the WHO regulatory guideline of 1500 µS/cm for drinking water [51]. The EC of water provides good estimates of the amount of solids dissolved in water (its TDS), is proportional to the water's temperature [10]. The high EC of the water samples indicates the presence of a higher content of salts, and organic and inorganic ions such as alkalis, chlorides, sulphides, and carbonates.

Previous studies in Uganda have reported an EC of 104–248 µS/cm, 158–201 µS/cm, 155–821 µS/cm, 218.80–621.00 µS/cm, and 349.13–516.13 µS/cm for water from springs in the Mbarara and Kasese Districts [29], Kyambogo University vicinity [23,37], and Kampala and its environs [32,33]. Other research efforts into the Chuho springs of Kisoro [14], springs in Kisenyi and Katwe (Kampala) [21], springs in Kampala and Lira [34], and Kiswahili spring (Mbarara) [31] found higher ECs (425.33–455.47 µS/cm, 95–705 µS/cm, 28–760 and 685.00–715.00 µS/cm, respectively) than we recorded. Elsewhere in Cameroon, Germany, and the Natuv Catchment (Palestine), higher ECs of 306 and 317 µS/cm, 182–892 µS/cm, and 410–1307 µS/cm for spring water have been documented [52–54]. As a measure of water quality, significant variations in the EC of water between two seasons, as observed in this study, are indicative of discharge or some other source of pollution entering the spring aquifers.

3.2.2. pH

This study also measured the variations in the acidity and alkalinity of the spring water samples. The pH levels of the water sources ranged from 6.00 ± 0.05 in SPR2 to 6.30 ± 0.01 in SPR1 during the wet season, and 6.02 ± 0.15 in SPR4 to 6.13 ± 0.01 in samples from SPR3 during the dry season (Table 2). All of the mean pH values were below the generally acceptable range of 6.5–8.5 [51], and there was no statistically significant difference in the mean pH values measured across the springs in both seasons

The pH values reported in this study were lower than 7.73–8.40 for the Chuho springs in Kisoro [14] and 4.40–7.27 for the water from springs in other districts of Uganda [21,23,28,29,32–34]. However, they were comparable to the 4.71–6.26, 6.19, and 6.52 reported for some springs in Banda, Katanga spring, Uganda [28,37], and the Damas spring of Cameroon, respectively [52]. Tourism springs in western Kazakhstan were found to be slightly alkaline, with pH values of 7.0–8.3, which are higher than those reported for the Kansanga springs in the current study [55]. Seasonal variations in the pH values of the water samples, as observed in the Kansanga springs, have also been reported in springs on plateaus in Giresun Province, Türkiye in the range of 6.35–10.14 [48]. In the

Yarlung Zangbo River Basin of China, a study reported that the pH of the spring water was 6.7–9.7 [56], which is higher than what we have recorded herein. In the Natuv Catchment in Palestine, freshwater spring samples were found to have pH values of 6.4 to 8.3 [53]. Weber and Kubiniok [54] hinted that pH values of spring waters between 6 and 8 (neutral range), as observed in the current study, are indicative that such springs are influenced by anthropogenic (agricultural) activities. No health-based guideline value for pH has since been indicated by the WHO. It should be emphasised that although insignificant pH variations may not have direct impacts on health, higher pH values can induce unpleasant smells and gastrointestinal tract irritations [57].

3.2.3. Temperature

The highest mean temperatures of 22.40 ± 0.75 °C and 23.00 ± 0.85 °C were registered in SPR2 and SPR1 during the wet and dry seasons, respectively. The lowest mean temperatures (22.30 ± 0.53 °C and 22.70 ± 0.60 °C) were registered in SPR3 in the wet and dry seasons, respectively (Table 2). Statistically, there was a significant difference ($p < 0.05$) in the mean temperature among the water sources and between most of the pairs of different water sources during the dry season, but this was not significant ($p > 0.05$) during the wet season. All of the temperatures recorded were above the recommended limit of 15 °C. Temperature is an important physical property of water because it influences other parameters used to evaluate the quality of drinking water. It affects many phenomena including the rate of chemical reactions in water, a reduction in the solubility of gases, and the amplification of taste and colour. For example, a high water temperature enhances the growth of pathogenic microorganisms, and may increase problems related to corrosion, taste, odour, and turbidity or colour [51].

In reference to previous studies on Ugandan springs, temperatures of 20.33–28.80 °C have been reported [14,21,23,29,31,32], some of which are comparable to the values obtained in this study. In the Chinese Yarlung Zangbo River Basin [56] and Germany [54], spring water was reported to have temperatures of 7.38–7.84 °C and 7.7–12.0 °C, which were lower than those observed in the current study. Tourism springs in western Kazakhstan have also been reported to mainly be of the cold type (water temperature = 7.38–20 °C), except for Ystyk Su spring, which is a hot spring with an average temperature of 52 °C [55]. The Damas and Obili springs in Cameroon have recorded temperatures of 26 °C and 27 °C, which are higher than those observed in this study [52]. The differences in the temperature values observed in this study and the literature reports are because the study area is located near the Equator, which makes the land relatively hotter compared to colder regions.

3.2.4. Turbidity

The provision of drinking freshwater that is not only safe, but also acceptable in appearance, taste, and odour is of utmost priority. Thus, one of the most apparent physical parameters used as an indicator of groundwater quality is turbidity or colour. Turbidity describes the cloudiness of water caused by chemical precipitates (for example, manganese and iron), total suspended particles (such as silts and clay), organic particles (such as plant debris), and microorganisms [51].

In this study, the highest average turbidity values for both the wet and dry seasons of 3.88 ± 0.42 NTU and 3.40 ± 0.30 NTU were registered for samples from SPR2. The lowest value of 3.65 ± 0.31 NTU was for SPR3 in the wet season and 3.20 ± 0.25 NTU for SPR1 in the dry season. Interestingly, these turbidity values were not statistically different across seasons and springs ($p > 0.05$), and the average values never surpassed the permissible guideline limit of 5 NTU (Table 2). Preceding authors [23,33,34,37] have reported turbidity values of Ugandan springs to be less than 5 NTU, which is in agreement with the results of the current study. Apecu et al. [29] and Elambo et al. [52] disclosed turbidity values of 5 NTU and 12 NTU for four protected springs in Mbarara and Kasese (Uganda) and Damas spring (Cameroon), respectively, which were higher than the values we apprise din this study.

3.2.5. Total Dissolved Solids and Total Alkalinity

The measured TDS values ranged from 90.00 ± 0.31 mg/L in SPR3 to 90.60 ± 0.40 mg/L in SPR2 during the wet season and 89.70 ± 0.35–90.40 ± 0.25 mg/L in the same springs during the dry season (Table 2). The TDS values were less than the WHO regulatory guideline of 500 mg/L in both seasons, suggesting that the presence of ionic species of calcium, magnesium, sodium, bicarbonates, chlorides, and sulphates that contribute to the TDSs were not a threat. There were no significant differences in the average TDS values recorded in all of the water samples ($p > 0.05$).

Considering Ugandan springs, TDS readings have been registered in the ranges of 366.07–460.32 mg/L in Chuho springs [14], 55–125 mg/L and 345–579 mg/L for springs in Kasese and Mbarara, respectively [29,31], 59–212 mg/L for springs in Kampala [34], and 111.90–323.20 mg/L for springs in Banda [37]. Two Cameroonian springs (Damas and Obili) had TDSs of 153 mg/L and 159 mg/L [52], which were lower than for the Kansanga springs. The total dissolved solids as a generic measure of the quantity of the dissolved salts and thus water quality is known to impact the taste of drinking water if the readings surpass 1000 mg/L [58], but the U.S. EPA's secondary regulations indicate that TDS readings should be well below 500 mg/L [59]. In addition, high TDSs reportedly hinder washing operations, and can readily corrode plumbing fixtures [44].

The highest average total alkalinity values (38.00 ± 0.35 mg/L and 36.50 ± 0.77 mg/L) in the dry and wet seasons, respectively, were for SPR1. The lowest average values in the dry and wet seasons (5.10 ± 0.30 mg/L and 3.81 ± 0.62 mg/L) were recorded in SPR2. All of the mean alkalinity values were within the acceptable limit of 200 mg/L, and displayed significant differences in both seasons ($p < 0.05$). Compared to a previous report (131.465–165.16 mg/L, 10.35–60.40 mg/L, 10.00–345.00 mg/L) on the Chuho springs [14], springs in Banda [37], and Giresun Province, Türkiye [48], the total alkalinity observed in the Kansanga springs is lower.

3.2.6. Nitrate-Nitrogen

The NO_3-N concentration of the water samples ranged from 5.80 ± 0.03 mg/L in SPR4 to 38.60 mg/L in SPR1 during the wet season. In the dry season, the range was 5.14 ± 0.04 mg/L to 30.89 ± 0.05 mg/L in the same springs. Only the NO_3-N concentrations of spring water sampled from SPR4 were lower than the regulatory guideline of 10 mg/L provided by the WHO.

In Kampala, Nsubuga et al. [36] reported that NO_3-N concentrations varied between 20–50 mg/L and 19.9–31.1 mg/L for water sampled from springs in the Makindye and Kawempe Divisions of Kampala, respectively, during the dry season, while in the wet season, the NO_3-N levels were 19.8–49.5 mg/L and 4.3–11.1 mg/L, respectively. Other comparable NO_3-N contents of spring water examined in this study were reported by Haruna et al. [21] (21–140 mg/L) and Kiwanuka et al. [33] (13.69–43.13 mg/L) for some springs in Kampala. The NO_3-N concentrations obtained by Okot-Okumu et al. [34] for springs in the Kampala and Lira Districts of Uganda (0.01–1.3 mg/L), were, however, far lower than those found in the present study. Lower NO_3-N contents (0.09–3.52 mg/L) were also highlighted for the wet and dry season spring water samples sourced from Giresun Province, Türkiye [48]. Weber and Kubiniok [54] quantified NO_3-N levels of 2.2–52.6 mg/L in 22 springs in Saarland, Germany, which were higher than in the Kansanga springs. From a health perspective, nitrate ions may pose a risk to humans through endogenous nitrosation (the formation of N-nitroso compounds), which are potent human carcinogens [60].

3.2.7. Magnesium, Calcium, and Total Hardness

Water hardness, defined as a measure of two major divalent cations (Ca^{2+} and Mg^{2+}), is basically used to classify water for its usability [61]. Water can be classified as hard or soft; water with more than 300 mg/L total hardness (TH) is considered to be hard and water with <75 mg/L TH is classified as soft. Hard water has a tendency to attract and potentially bind to the skin's natural oils, leaving the skin feeling stiff. Aesthetically, hard water possesses a characteristically unpleasant taste [62], and may form precipitates that encrust or clog water pipes, appliances, and equipment or result in high soap consumption through scum formation. Naturally soft water with a total hardness < 100 mg/L may conversely have a low buffering capacity, and therefore is more corrosive to water pipes [51].

The highest mean TH values (110.00 $\pm$ 0.76 and 111.00 $\pm$ 0.65 mg/L) were recorded in SPR2 in the dry and wet seasons, respectively. The lowest mean TH values (49.61 $\pm$ 0.53 mg/L and 13.20 $\pm$ 0.49 mg/L) were recorded in SPR4 during the wet and dry seasons, respectively (Table 2). The same trends were observed for Ca hardness, where the highest values (60.10 $\pm$ 0.22 mg/L and 61.80 $\pm$ 0.52 mg/L) were recorded in SPR2 in the dry and wet seasons, whereas the lowest mean values (32.20 $\pm$ 0.32 mg/L and 30.00 $\pm$ 0.48 mg/L) were recorded in SPR4 during the wet and dry seasons, respectively. There was a significant difference in the average of calcium hardness values in all water sources as well as between pairs of water sources in both the dry and wet seasons ($p < 0.05$). These were also reflected in the values of the Mg hardness values recorded. For example, the highest magnesium harness values were 50.00 $\pm$ 0.68 mg/L and 52.10 $\pm$ 0.62 mg/L, and these were from SPR2 for the dry and wet season samples, respectively. The lowest mean values of magnesium hardness were 20.10 $\pm$ 0.01 mg/L and 18.00 $\pm$ 0.20 mg/L for the samples from SPR4 obtained during the wet and dry seasons, respectively (Table 2). There were significant differences in the average of the total, calcium, and magnesium hardness values recorded among the springs, but these differences were not significant when the seasons were considered for a particular spring ($p > 0.05$).

In the Chuho springlets of Uganda, the TH varied from 68.00 to 71.20 mg/L [14] while Nzanzu et al. [37] found Ca and Mg hardnesses of 4.81–20.05 mg/L and 2.50–4.87 mg/L, respectively, for some springs in Banda. A previous study of spring water quality in the mid-hill of Nepal found that the TH varied from 60 to 370 mg/L, while the Ca hardness was from 22 to 168 mg/L [63]. Another investigation of spring water from Giresun Province, Türkiye recorded total, Ca, and Mg hardnesses of 15–411 mg/L, 6.17–150.18 mg/L, and 1.53–35.19 mg/L, respectively [48]. Taken together, the springs in Kansanga belong to the low-flow freshwater category with average water hardness, similar to some freshwater springs of the Chuvash Republic reported by Nikonorova et al. [64].

3.2.8. Sulphates and Phosphates

The highest average sulphate concentration for both the wet and dry seasons (33.70 $\pm$ 0.90 mg/L and 33.20 $\pm$ 0.21 mg/L, respectively) were registered for samples from SPR2 (Table 2). The corresponding lowest concentrations (13.90 $\pm$ 0.20 mg/L and 13.50 $\pm$ 0.30 mg/L, respectively) were in the SPR1 samples. In contrast, SPR1 had the highest mean phosphate concentration (0.07 $\pm$ 0.01 mg/L and 0.23 $\pm$ 0.00 mg/L) in the wet and dry seasons, respectively. The lowest mean total phosphorus content (0.02 $\pm$ 0.01 mg/L) was found in the SPR2 and SPR3 samples, respectively. The sulphate and total phosphorus concentrations exhibited significant differences in both seasons ($p < 0.05$). It should be noted that there are no set regulatory guidelines for both sulphates and total phosphorous in drinking water according to the revised 2022 WHO guidelines for drinking water [51].

In some springs around Kyambogo University (Uganda), the sulphate content of spring water is 2.44–5.31 mg/L, which is lower than that recorded in the present investigation. Sulphates occur naturally in spring water, but it is concerning at high levels in drinking water because it can have laxative effects (diarrhoea) in unaccustomed consumers, induce intestinal irritation, and consequently, dehydration. In addition, high sulphate contents confer a bitter and/or metallic taste to drinking water [65]. Nkurunziza et al. [14] quantified the phosphate content of Chuho springlets in Kisoro (Uganda) and reported an average of 0.75–0.89 mg/L, which was lower than that observed in the Kansanga springs. Phosphates (estimated herein as total phosphorus) have unnoticeable effects at low levels, but digestive troubles can be experienced by individuals that consume water with very high phosphate levels [66].

3.2.9. Sodium and Potassium Contents

The highest mean Na contents (48.2 ± 0.03 mg/L and 49.1 ± 0.35 mg/L) were recorded in SPR2 in the dry and wet seasons, respectively. The lowest mean values (17.51 ± 0.05 mg/L and 17.20 ± 0.04 mg/L) were recorded in SPR4 during the wet and dry seasons, respectively (Table 2). There was a significant difference in the average sodium concentration values in all water sources as well as between pairs of water sources in both the dry and wet seasons ($p < 0.05$). The average values were all below the acceptable WHO guideline value of 200 mg/L [51]. Similarly, the highest mean potassium contents (22.00 ± 0.02 mg/L and 22.80 ± 0.04 mg/L) were recorded in SPR2 in the dry and wet seasons, respectively. The lowest mean values (4.30 ± 0.06 mg/L and 4.20 ± 0.03 mg/L) were recorded in SPR4 during the wet and dry seasons, respectively. These variations were significant among all of the samples in both seasons ($p < 0.05$). Interestingly, the average potassium contents did not surpass the WHO guideline limit of 50 mg/L [51].

Kiwanuka et al. [33] recently quantified the Na content of some springs in Bwaise, Uganda (61.93–133.7 mg/L), which were higher than what we found in the Kansanga springs. Lower Na (16.11–34.45 mg/L) and K (4.05–11.85 mg/L) contents for some springs in Banda were reported by Nzanzu and his co-authors [37]. Temporal studies in plateaus in Giresun Province, Türkiye reported that the average Na and K contents of spring water were 4.49–38.15 mg/L and 0.58–3.94 mg/L, which were well below the Na content observed in the Kansanga springs. Thus, the results of the Na, K, and Ca hardness contents affirms a recent communication by Macheyeki and Kafumu [67] that Ugandan underground water is most likely to be the Na-Ca-HCO_3 type, as opposed to that of Kenya and Tanzania, which are largely of the Ca-Mg-SO_4 and Na-Cl-HCO_3 types.

3.2.10. Fluorides and Chlorides

The highest mean fluoride content (0.39 ± 0.01 mg/L) was the same and recorded in SPR4 for both seasons. The least mean fluoride content (0.15 ± 0.02 mg/L and 0.16 ± 0.03 mg/L) was for samples from SPR3 in the wet and dry seasons, respectively (Table 2). These concentrations fell below the acceptable value of 1.5 mg/L and showed significant differences in both seasons. For chlorides, SPR2 had the highest mean concentration 62.80 ± 0.45 mg/L in the wet season and 61.20 ± 0.48 mg/L during the dry season. Its lowest mean concentrations (20.10 ± 0.35 mg/L and 18.00 ± 0.45 mg/L) were witnessed in SPR4 in the wet and dry seasons, respectively. There was a significant difference in the mean chloride concentrations irrespective of the sampled spring and season ($p < 0.05$), and all of the means did not surpass the prescribed guideline value (250 mg/L) for chlorides in drinking water.

A few studies in the literature have assessed the fluoride content of spring water. In the Chuho springs, the fluoride content of water was between 2.15 mg/L and 2.45 mg/L, and the high values were attributed to fluoride-containing compounds in the Kisoro volcanic area [14]. It should be noted that water containing high fluoride levels can induce skeletal and dental fluorosis [68], which are generally undesirable.

Similarly, our previous research efforts demonstrated that chloride levels in springs around Kyambogo University (6.63–10.91 mg/L) [23] and in Chuho springs (20.35–22.64 mg/L) [14] were within the acceptable levels for drinking water. However, higher chloride contents of 6.0–79.0 mg/L for the Kisenyi and Katwe springs [21], 2.62–73.50 mg/L for the Katoogo, Katalina, and Bukuuku springs, and 13.49–148.80 mg/L for the Nabukalu, Bishop Mukwaya, Kiggundu, and Jace School springs of Kampala and Bwaise have been previously documented [32]. Elsewhere, chlorides have been found to occur at levels of 48–212.7 mg/L in the springs of Natuv Catchment, Palestine [53].

3.2.11. Dissolved Oxygen

SPR4 had the highest mean value of dissolved oxygen (6.00 ± 0.31 mg/L), while SPR3 registered the lowest mean dissolved oxygen of 5.900 ± 0.35 mg/L during the wet season (Table 2). The same trend was observed during the dry season, and the means varied significantly between seasons and springs ($p < 0.05$). All of the mean values at all sites were lower than the recommended levels of 6.5–8 mg/L for dissolved oxygen in freshwater. Moulodi and Thorsell [32] and Nkurunziza et al. [14] had previously quantified much lower dissolved oxygen contents (0.33–1.36 mg/L and 3.06–4.87 mg/L) in some springs of peri urban Kampala and Kisoro, Uganda. Higher mean dissolved oxygen values (1.90–15.60 mg/L and 0.4–9.2 mg/L) than those reported for the Kansanga springs had previously been recorded in some springs in western Uganda [31] and Kashmir Himalaya [69]. In the environmental chemistry context, dissolved oxygen refers to the level of free and non-compound oxygen present in water, which can be largely influenced by temperature. High levels of dissolved oxygen can lead to a better taste of water, but low levels in freshwater is suggestive of probable water contamination [69].

Taken together, the hydrochemistry of spring water is largely influenced by rock–water interactions, geochemical processes operating as water reacts with the geologic materials where it flows as well as influences from anthropogenic activities [14,23,48,70]. In this context, we did not compare the compositional ranges of spring water in the current study with previous reports from the Rwenzori, Kitagata, Kibenge, Katanga, Nyakirango, and Ihimbo hot springs of Uganda, where high values of physicochemical parameters such as temperature (up to 94 °C), pH (7.1–9.77), EC (>21,000 µS/cm), turbidity (5.68–120.75 NTU), and Na (up to 5991 mg/kg) have previously been reported [25,27,28]. In the current study, the variations observed among samples obtained during the wet season could be attributed to torrential rains (floods) that mobilise and transport waste into the ground water [36]. Moreover, residents of this area are known to empty their latrines into tertiary drains and dump wastes to be carried away by stormwater, which may end up in the spring areas [71].

3.3. Water Quality Index of the Springs

The spatial and temporal WQI computed based on the 17 physicochemical parameters of the springs were 56, 57, 52, and 50 and 57, 58, 55, and 52 for SPR1, SPR2, SPR3, and SPR4 in the dry and wet seasons, respectively (Figure 3). Based on the predefined WQI categorisation criteria in Section 2.6 [33], the spring water had good water quality. It should be mentioned that the water quality tended to decrease during the wet season, corroborating the observations in their limnochemical characteristics. In the Chuho springs of Kisoro (Western Uganda), we previously found that the spring water could be ranked as fair or marginal, based on the Canadian Council of Ministers of the Environment Water Quality Index [14]. Kiwanuka et al. [33] recently reported that the WQI of four springs in Bwaise (Uganda) were of excellent quality during the dry season (WQI = 40–49), but this quality deteriorated to good in the wet season (WQI = 54–74). Together, our WQI profiling of the springs suggests that freshwater from them is fit for domestic use.

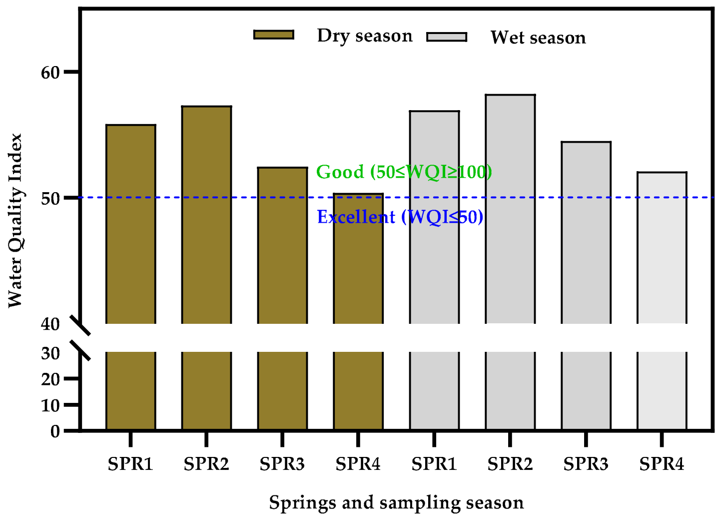

Figure 3. Water quality indices of the springs in Kansanga, Kampala, Uganda. The springs are denoted as SPR1 to SPR4.

4. Conclusions

This study was the first of its kind to investigate the sanitary risks and temporal variations in the limnochemical characteristics and quality of water from springs in Kansanga, a flood-prone area of Kampala, Uganda. Overall, the sanitary risk assessment scores indicated that the springs had medium to high risks of microbial contamination, but most of the investigated water parameters fell within the WHO guidelines for drinking water. Rain (and hence flooding) had a statistically significant contribution to changes observed in the limnochemistry of the freshwater springs studied. However, the variations suggest that there is no significant source of pollution. In this context, initiatives should be launched to mitigate floods and improve the sanitation in Kansanga to protect the health of the local population that depend on spring water. Further studies investigating the occurrence of microbial contaminants could shed more light on the extent of the potential risks from consumption and the use of freshwater from these springs.

Author Contributions: Conceptualisation, R.T. and E.N.; Methodology, R.T., T.O. and E.N.; Software, R.T., G.K. and T.O.; Validation, T.O., C.A. and E.N.; Formal analysis, R.T.; Investigation, R.T.; Resources, R.T., T.O., G.K., C.A. and E.N.; Data curation, R.T., T.O., G.K. and C.A.; Writing—original draft preparation, T.O.; Writing—review and editing, R.T., G.K., C.A. and E.N.; Visualisation, T.O.; Supervision, E.N. All authors have read and agreed to the published version of the manuscript.

Funding: The article processing charge for this article was in part supported by Cranfield University through its Institutional Open Access Program (No. 3171190).

Data Availability Statement: Data supporting the conclusions of this study are available on request from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United Nations. Ensuring Safe Water and Sanitation for All: A Solution through Science, Technology and Innovation. Available online: https://unctad.org/system/files/official-document/ecn162023d3_en.pdf (accessed on 2 August 2024).
2. UN Water. Blueprint for Acceleration: Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 2023. Available online: https://www.unwater.org/sites/default/files/2023-08/UN-Water_SDG6_SynthesisReport_2023.pdf (accessed on 2 August 2024).
3. Musie, W.; Gonfa, G. Fresh water resource, scarcity, water salinity challenges and possible remedies: A review. *Heliyon* **2023**, *9*, e18685. [CrossRef] [PubMed]
4. Evaristo, J.; Jameel, Y.; Tortajada, C.; Wang, R.Y.; Horne, J.; Neukrug, H.; David, C.P.; Fasnacht, A.M.; Ziegler, A.D.; Biswas, A. Water woes: The institutional challenges in achieving SDG 6. *Sustain. Earth Rev.* **2023**, *6*, 13. [CrossRef]
5. Wang, M.; Janssen, A.B.G.; Bazin, J.; Strokal, M.; Ma, L.; Kroeze, C. Accounting for interactions between Sustainable Development Goals is essential for water pollution control in China. *Nat. Commun.* **2022**, *13*, 730. [CrossRef]
6. UNICEF. Triple Threat. How Disease, Climate Risks, and Unsafe Water, Sanitation and Hygiene Create a Deadly Combination for Children. New York: United Nations Children's Fund (UNICEF). Available online: https://www.unicef.org/media/137206/file/triple-threat-wash-EN.pdf (accessed on 24 February 2024).
7. Onen, P.; Akemkwene, R.; Nakiguli, C.K.; Nimusiima, D.; Ruma, D.H.; Khanakwa, A.V.; Angiro, C.; Bamanya, G.; Opio, B.; Gonzaga, A.; et al. Health Risks from Intake and Contact with Toxic Metal-Contaminated Water from Pager River, Uganda. *J. Xenobiot.* **2023**, *13*, 544–559. [CrossRef] [PubMed]
8. Boretti, A.; Rosa, L. Reassessing the projections of the World Water Development Report. *Npj Clean Water* **2019**, *2*, 15. [CrossRef]
9. The World Bank. Assessment of Groundwater Challenges & Opportunities in Support of Sustainable Development in Sub-Saharan Africa. Available online: https://documents1.worldbank.org/curated/en/420291533931251279/pdf/Assessment-of-groundwater-challenges-and-opportunities-in-Sub-Saharan-Africa.pdf (accessed on 24 February 2024).
10. Bonacci, O.; Roje-Bonacci, T. Water temperature and electrical conductivity as an indicator of karst aquifer: The case of Jadro Spring (Croatia). *Carbonates Evaporites* **2023**, *38*, 55. [CrossRef]
11. Dijkstra, A.F.; Husman, A.M.R. Bottled and Drinking Water. In *Food Safety Management*, 2nd ed.; A Practical Guide for the Food Industry; Academic Press: Cambridge, MA, USA, 2023; pp. 339–362.
12. Cousteau, J. The Value of Water. Available online: https://opac.geologie.ac.at/wwwopacx/wwwopac.ashx?command=getcontent&server=images&value=EGU_Eonder%20Water.pdf (accessed on 24 February 2024).
13. Cantonati, M.; Lichtenwöhrer, K.; Leonhardt, G.; Seifert, L.; Mustoni, A.; Hotzy, R.; Schubert, E.; Blattner, L.; Bilous, O.; Lotz, A.; et al. Using Springs as Sentinels of Climate Change in Nature Parks North and South of the Alps: A Critical Evaluation of Methodological Aspects and Recommendations for Long-Term Monitoring. *Water* **2022**, *14*, 2843. [CrossRef]

14. Nkurunziza, G.; Omara, T.; Nakiguli, C.K.; Mukasa, P.; Byamugisha, D.; Ntambi, E. Physicochemical Quality of Water from Chuho Springs, Kisoro District, Uganda. *Fr. Ukr. J. Chem.* **2021**, *9*, 12–26. [CrossRef]
15. June, A.; Mika, S. Metals in kitagata hot springs and water quality effect from Balneotherapy and Hydrotherapy. *Res. J. Chem. Environ.* **2012**, *16*, 182–188.
16. Ndiba, J. Facts About African Great Lakes—Summary from the AGLI Website. Available online: https://www.africangreatlakesinform.org/article/facts-about-african-great-lakes-summary-agli-website (accessed on 24 February 2024).
17. U.S. Department of State. About the Great Lakes Region. Available online: https://2009-2017.state.gov/s/greatlakes_drc/191417.htm (accessed on 24 February 2024).
18. Karp, T.; Scholz, C.A.; McGlue, M.M. Structure and stratigraphy of the Lake Albert rift, East Africa: Observations from seismic reflection and gravity data. In *Lacustrine Sandstone Reservoirs and Hydrocarbon Systems: AAPG Memoir 95*; Baganz, O.W., Bartov, Y., Bohacs, K., Nummedal, D., Eds.; American Association of Petroleum Geologists: Tulsa, OK, USA, 2012; pp. 299–318.
19. Penny Africa Safaris. Hot Springs in East Africa. Available online: https://pennyafricasafaris.travel/hot-springs-in-east-africa/ (accessed on 4 April 2024).
20. Butturini, A.; Amalfitano, S.; Herzsprung, P.; Lechtenfeld, O.J.; Venturi, S.; Olaka, L.A.; Pacini, N.; Harper, D.M.; Tassi, F.; Fazi, S. Dissolved Organic Matter in Continental Hydro-Geothermal Systems: Insights from Two Hot Springs of the East African Rift Valley. *Water* **2020**, *12*, 3512. [CrossRef]
21. Haruna, R.; Ejobi, F.; Kabagambe, E.K. The Quality of Water from Protected Springs in Katwe and Kisenyi Parishes, Kampala City, Uganda. *Afr. Health Sci.* **2005**, *5*, 14–20. [PubMed]
22. Uche, C.K.A.; Amgbara, T.O.; Birungi, M.; Taremwa, D. Quality Analysis of Water from Kitagata Hot Springs in Sheema District, Western Region, Uganda. *Int. J. Eng. Inform. Syst.* **2021**, *5*, 18–24.
23. Omara, T.; Nassazi, W.; Adokorach, M.; Kagoya, S. Physicochemical and Microbiological Quality of Springs in Kyambogo University Propinquity. *OALibJ* **2019**, *6*, e5100. [CrossRef]
24. Bakyayita, G.K.; Norrström, A.C.; Kulabako, R.N. Assessment of Levels, Speciation, and Toxicity of Trace Metal Contaminants in Selected Shallow Groundwater Sources, Surface Runoff, Wastewater, and Surface Water from Designated Streams in Lake Victoria Basin, Uganda. *J. Environ. Public Health* **2019**, *2019*, 6734017. [CrossRef]
25. Nabagyea, A.; Yatuha, J. Physico-chemical Parameters and Species' Distribution Patterns of Extremophilic Bacteria in Kitagata and Ihimbo Hot Springs in South Western Uganda. *Am. Acad. Sci. Res. J. Eng. Technol. Sci.* **2022**, *86*, 157–173.
26. Onohuean, H.; Okoh, A.I.; Nwodo, U.U. Epidemiologic potentials and correlational analysis of Vibrio species and virulence toxins from water sources in greater Bushenyi districts, Uganda. *Sci. Rep.* **2021**, *11*, 22429. [CrossRef]
27. Kato, V.; Kraml, M. Geochemistry of Rwenzori hot spring waters. In Proceedings of the 3rd East African Rift Geothermal Conference, Djibouti, Djibouti, 22–25 November 2010; p. 12.
28. Bwire, G.; Sack, D.A.; Kagirita, A.; Obala, T.; Debes, A.K.; Ram, M.; Komakech, H.; George, C.M.; Orach, C.G. The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera prone communities of Uganda: An analysis of vital physicochemical parameters. *BMC Public Health* **2020**, *20*, 1128. [CrossRef]
29. Apecu, R.O.; Ampaire, L.; Mulogo, E.M.; Bagenda, F.N.; Traore, A.; Potgieter, N. Quality of water sources in Southwestern Uganda using the compartment bag test (CBT): A cross-sectional descriptive study. *J. Water Sanit. Hyg. Dev.* **2019**, *9*, 683–693. [CrossRef]
30. Lukubye, B.; Andama, M. Bacterial Analysis of Selected Drinking Water Sources in Mbarara Municipality, Uganda. *J. Water Resour. Protect.* **2017**, *9*, 999–1013. [CrossRef]
31. Lukubye, B.; Andama, M. Physico-Chemical Quality of Selected Drinking Water Sources in Mbarara Municipality, Uganda. *J. Water Resour. Protect.* **2017**, *9*, 707–722. [CrossRef]
32. Moulodi, S.; Thorsell, J. Evaluation of the Levels of Selected Trace Metal Pollutants in Groundwater and Soil from Protected Springs in Peri-Urban Kampala, Uganda. Master's Thesis, TRITA-LWR Degree Project 13: 17. Royal Institute of Technology (KTH), Stockholm, Sweden, 2013; 56p.
33. Kiwanuka, M.; Mutanda, H.E.; Niyomukiza, J.B.; Nakasagga, E. Assessment of suitability of drinking water from the springs in Urban slums of Kampala. *Environ. Chall.* **2023**, *10*, 100667. [CrossRef]
34. Okot, J.; Otim, J. The quality of drinking water used by the communities in some regions of Uganda. *Int. J. Biol. Chem. Sci.* **2015**, *9*, 552–562. [CrossRef]
35. Ntuwa, R.; Onen, P.; Baguma, G.; Niringiyimana, E.; Byaruhanga, I.; Otema, T.; Ampaire, W.; Ogenrwot, D.A.; Ocira, D. Comparative Analysis of Some Trace Metals in Municipal and Spring Water from Makerere University and Selected Springs in Bunga, Uganda. *Asian J. Fish. Aquat. Res.* **2022**, *18*, 42–47. [CrossRef]
36. Nsubuga, F.B.; Kansiime, F.; Okot-Okumu, J. Pollution of protected springs in relation to high and low density settlements in Kampala—Uganda. *Phys. Chem. Earth* **2004**, *29*, 1153–1159. [CrossRef]
37. Nzanzu, T.; Barasa, J.; Nanyonga, S.K.; Binenwa, J. Water Quality in Selected Water Springs in Banda, Kampala-Uganda. *SJHR-Africa* **2022**, *3*, 11.
38. Kampala City Guide. Kansanga. Available online: https://www.kampalacityguide.com/kampala-city/makindye/kansanga.html (accessed on 24 February 2024).
39. The Independent. The Ghost Flood Villages of Kansanga. Available online: https://www.independent.co.ug/the-ghost-flood-villages-of-kansanga/ (accessed on 24 February 2024).

40. James, M.K. Effects of Poor Sanitation Management on the Urban Population in Uganda: The Case of Kansanga Parish, Makindye Division, Kampala, Central Uganda. Bachelor's Thesis, Kampala International University, Kampala, Uganda, 2009.
41. Akugizibwe, I. KIU General News: Water Crisis Hits Kansanga. Available online: https://kiu.ac.ug/news-page.php?i=kiu-general-news-water-crisis-hits-kansanga (accessed on 1 February 2024).
42. WHO. Sanitary Inspection Package (Drinking-Water): Spring. Available online: https://cdn.who.int/media/docs/default-source/wash-documents/water-safety-and-quality/water-safety-planning/sanitary-inspection-packages/3.-spring_web.pdf?sfvrsn=378469bb_5 (accessed on 1 February 2024).
43. American Public Health Association (APHA); American Water Works Association (AWWA); Water Environment Federation (WEF). *Standard Methods for the Examination of Water and Wastewater*, 22nd ed.; Rice, E.W., Baird, R.B., Eaton, A.D., Clesceri, L.S., Eds.; American Public Health Association: Washington, DC, USA, 2012.
44. Omara, T.; Nteziyaremye, P.; Akaganyira, S.; Opio, D.W.; Karanja, L.N.; Nyangena, D.M.; Kiptui, B.J.; Ogwang, R.; Epiaka, S.M.; Jepchirchir, A.; et al. Physicochemical quality of water and health risks associated with consumption of African lung fish (*Protopterus annectens*) from Nyabarongo and Nyabugogo rivers, Rwanda. *BMC Res. Notes* **2020**, *13*, 66. [CrossRef]
45. Nimusiima, D.; Byamugisha, D.; Omara, T.; Ntambi, E. Physicochemical and Microbial Quality of Water from the Ugandan Stretch of the Kagera Transboundary River. *Limnol. Rev.* **2023**, *23*, 157–176. [CrossRef]
46. Kanadhia, K.C.; Ramavataram, D.V.; Nilakhe, S.P.; Patel, S. A study of water hardness and the prevalence of hypomagnesaemia and hypocalcaemia in healthy subjects of Surat district (Gujarat). *Magnes. Res.* **2014**, *27*, 165–174. [CrossRef]
47. Thangiah, A.S. Spectrophotometric determination of sulphate and nitrate in drinking water at Asia-Pacific International University Campus, Muak Lek, Thailand. *Rasayan J. Chem.* **2019**, *12*, 1503–1508. [CrossRef]
48. Karadeniz, S.; Ustaoğlu, F.; Aydın, H. Toxicological risk assessment using spring water quality indices in plateaus of Giresun Province/Türkiye: A holistic hydrogeochemical data analysis. *Environ. Geochem. Health* **2024**, *46*, 285. [CrossRef]
49. WHO. *Guidelines for Drinking-Water Quality*, 4th ed.; World Health Organization: Geneva, Switzerland, 2024; Volume 38, pp. 1–564. [CrossRef]
50. Mukisa, W.; Yatuha, J.; Andama, M.; Aventino, K. Heavy metal pollution in the main rivers of Rwenzori region, Kasese district South-western Uganda. *Octa J. Environ. Res.* **2020**, *8*, 78–90.
51. WHO. *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First and Second Addenda*; World Health Organization: Geneva, Switzerland, 2022. Available online: https://iris.who.int/bitstream/handle/10665/352532/9789240045064-eng.pdf?sequence=1 (accessed on 7 August 2024).
52. Elambo, G.N.; Kinyuy, B.L.; Martel, J.; Aghaindum, A.G. An appraisal of some water ressources in the city of Yaoundé (Cameroon): Water adduction potentialities, physico-chemistry and consequent eco-sanitary repercussions. *CJBBS* **2020**, *28*, 67–85.
53. Ghanem, M.; Jebreen, H.; Sege, J.; Rubin, Y. Investigation of spring water quality in the Natuv catchment, Palestine: A component for the regional environmental management system. *Euro-Mediterr. J. Environ. Integr.* **2019**, *4*, 2. [CrossRef]
54. Weber, G.; Kubiniok, J. Spring waters as an indicator of nitrate and pesticide pollution of rural watercourses from nonpoint sources: Results of repeated monitoring campaigns since the early 2000s in the low mountain landscape of Saarland, Germany. *Environ. Sci. Eur.* **2022**, *34*, 53. [CrossRef]
55. Akhmedenov, K.M.; Idrisova, G.Z. The importance of springs, self-flowing artesian wells, underground cave lakes of Western Kazakhstan in tourism. *Geo. J. Tourism. Geosites* **2021**, *37*, 747–756. [CrossRef]
56. Li, Y.; Gao, Z.; Liu, J. Hydrogeochemical and isotopic characteristics of spring water in the Yarlung Zangbo River Basin, Qinghai-Tibet Plateau, Southwest China. *J. Mt. Sci.* **2021**, *18*, 2061–2078. [CrossRef]
57. Nasir, M.; Tufail, M.; Ayaz, T.; Khan, S.; Khan, A.Z.; Lei, M. Groundwater quality assessment and its vulnerability to pollution: A study of district Nowshera, Khyber Pakhtunkhwa, Pakistan. *Environ. Monit. Assess.* **2022**, *194*, 692. [CrossRef]
58. World Health Organization. *Guidelines for Drinking-Water Quality: Incorporating the First and Second Addenda*; World Health Organization: Geneva, Switzerland, 2008. Available online: https://iris.who.int/rest/bitstreams/907844/retrieve (accessed on 5 August 2024).
59. *EPA 822-F-18-001*; 2018 Edition of the Drinking Water Standards and Health Advisories Tables. United States Environmental Protection Agency: Washington, DC, USA, 2018; pp. 9–19.
60. Ward, M.H.; Jones, R.R.; Brender, J.D.; De Kok, T.M.; Weyer, P.J.; Nolan, B.T.; Villanueva, C.M.; Van Breda, S.G. Drinking Water Nitrate and Human Health: An Updated Review. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1557. [CrossRef]
61. Omer, N.H. Water Quality Parameters. In *Water Quality—Science, Assessments and Policy*; IntechOpen: London, UK, 2019; pp. 1–18.
62. Water Stewardship Information Series. Hardness in Groundwater. Available online: https://www.rdn.bc.ca/cms/wpattachments/wpID2284atID3802.pdf (accessed on 5 August 2024).
63. Pantha, S.; Timilsina, S.; Pantha, S.; Manjan, S.K.; Maharjan, M. Water quality index of springs in mid-hill of Nepal. *Environ. Challenges* **2022**, *9*, 100658. [CrossRef]
64. Nikonorova, I.; Ilyin, V.; Ilyina, A.; Nikitin, A. Increasing the ecological and recreational importance of the springs of the Chuvash Republic. *BIO Web Conf.* **2024**, *116*, 03013. [CrossRef]
65. Backer, L.C. Assessing the acute gastrointestinal effects of ingesting naturally occurring, high levels of sulfate in drinking water. *Crit. Rev. Clin. Lab. Sci.* **2000**, *37*, 389–400. [CrossRef] [PubMed]
66. Water Research Center. Phosphate in Surface Water Streams, Lakes, and Ponds. Available online: https://www.knowyourh2o.com/outdoor-4/phosphate-in-surface-water-streams-lakes-ponds#google_vignette (accessed on 5 August 2024).

67. Macheyeki, A.S.; Kafumu, D.P. Hydrogeological (water) resources. In *The East African Rift System. Geodynamics and Natural Resource Potentials*; Elsevier: Amsterdam, The Netherlands, 2024; pp. 241–296.
68. Umer, M.F. A Systematic Review on Water Fluoride Levels Causing Dental Fluorosis. *Sustainability* **2023**, *15*, 12227. [CrossRef]
69. Bhat, S.U.; Nisa, A.U.; Sabha, I.; Mondal, N.C. Spring water quality assessment of Anantnag district of Kashmir Himalaya: Towards understanding the looming threats to spring ecosystem services. *Appl. Water Sci.* **2022**, *12*, 180. [CrossRef]
70. Dikeogu, T.C.; Okeke, O.C.; Ogbekhiulu, L.O.; Ogbenna, P.C. Major ion chemistry and hydrochemical processes of Ngeneagu spring water at Akpugoeze, Oji river, Enugu, southeastern Nigeria. *J. Adv. Acad. Res.* **2018**, *4*, 41–53.
71. Isunju, J.B.; Orach, C.G.; Kemp, J. Hazards and vulnerabilities among informal wetland communities in Kampala, Uganda. *Environ. Urban* **2016**, *28*, 275–293. [CrossRef]