Open Journal of Applied Sciences, 2026, 16(3), 975-992
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Assessment of Physico-Chemical Parameters of Selected Sites along the Wanjei River, Pujehun District, Sierra Leone

Prince Tongor Mabey[1], Mustapha Sly Bayon[1], Yahaya Kudush Kawa[2], Samuella Faulkner[3]

[1]Institute of Environmental Management and Quality Control, School of Environmental Sciences, Njala University, Courier Delivery, Freetown, Sierra Leone
[2]Department of Chemistry, School of Basic Sciences, Njala University, Courier Delivery, Freetown, Sierra Leone
[3]Integrated Geo-Information and Environmental Management Services (INTEGEMS), Freetown, Sierra Leone
Email: pmabey@njala.edu.sl

How to cite this paper: Mabey, P.T., Bayon, M.S., Kawa, Y.K. and Faulkner, S. (2026) Assessment of Physico-Chemical Parameters of Selected Sites along the Wanjei River, Pujehun District, Sierra Leone. *Open Journal of Applied Sciences*, **16**, 975-992.
https://doi.org/10.4236/ojapps.2026.163057

Received: January 8, 2026
Accepted: March 23, 2026
Published: March 26, 2026

Abstract

This study examined the physico-chemical parameters of river water samples collected at selected sites along the Wanjei River. The study involved laboratory analysis of water samples collected at four sites including entrance (site 1); upper (site 2); middle (site 3); and lower (site 4) of river Wanjei. Water samples and sampling regimes for the physical parameters (pH, temperature, total dissolved solid (TDS) and electrical conductivity (EC)) were assessed at four different sites in the raining and dry seasons. The results indicate that the highest pH of 8.57 was found at Upper stream during February 2022, while the lowest mean value of 6.70 at same location was exhibited during October 2021. Temperatures across sites and sampling regimes ranged from 26.5˚C (ST-2 during February 2022) to 32.3˚C (ST-1 during December 2021). The TDS ranged from 28.06 (ST-4 during October 2021) to 52.74 (ST-3 and ST-2 during December 2021 and April 2022) sampling regimes. The ECs across sites and sampling regimes ranged from 124.00 µs/cm (ST-4 during July 2022) to 145.20 µs/cm (ST-3 during December 2021) sampling regimes were within the standard level of EC for river (EC = 50 - 1000 µs/cm). Significant ($p < 0.05$) variations were also detected for chemical contents of water sampled across sites and various sampling regimes. The DO values across sites and sampling regimes ranged from 6.54 mg/L (ST-3 during June 2022) to 8.72 mg/L (ST-4 during October 2021) sampling regime that was above the standard level of oxygen demand (DO) for rivers and drinking water. Biochemical oxygen demand (BOD) reported from water samples from Wanjei River ranged between 1.21 mg/L to 2.18 mg/L, whereas calcium ranged from 47.86 mg/L (ST-3 during June 2022) to 63.78 mg/L (ST-1 during February 2022). The values of sodium (Na^{+}), Magnesium (Mg^{2+}), calcium carbonate ($CaCO_3^+$), sulphate (SO_4^{2+}), chloride (Cl^-) and fluoride (Fl^-) across sites and sampling regimes are within the standard levels for aquatic organisms, agriculture and drinking. It is recommended that mitigation measures should be implemented to prevent surface water pollution and the implementation of National Water Resources Management and Development Plan for the management of rivers in Sierra Leone.

Keywords

Physico-Chemical, Site, Wanjei River, Regimes, Contaminant Level, Ions, Minerals

1. Introduction

Water is the most abundant physical material on the planet and it is a clear liquid. It is always the vital commodity for humans, used for drinking, cooking, agriculture, transport and recreation, among other purposes [1]-[3]. Water is a necessary component for the normal functioning of every cell and organ system in the human body [4]. There are two main natural sources of water: surface water, which includes fresh water from lakes, rivers, streams, etc., and ground water, which includes well and borehole water [5] [6]. Water has a high value of dielectric constant and also has an exceptionally high heat of vaporization. Water can dissolve most gases like Oxygen (O_2), carbon dioxide (CO_2), Nitrogen (N_2), Hydrogen (H_2), Sulphur Dioxide (SO_2), and ammonia. Rivers are essential and delicate freshwater systems that supply the majority of the water needed for agricultural, industrial, and residential uses [7] [8]. These are open, dynamic ecosystems whose biological, chemical, and physical properties can be significantly impacted by human activity occurring in their drainage basins [9]. Large volumes of organic and synthetic trash are dumped into rivers by humans with little to no treatment [10] [11].

However, human societies have an increasingly worrying impact on rivers and the structure and function of their ecosystems due to population growth and industrialization [12] [13]. The five characteristics of watersheds and streams—water quality, habitat structure, stream flow patterns, sources of energy and nutrients, and biotic interaction—are often impacted by human activity in rivers and their environment [14] [15]. Soil erosion, domestic waste from both urban and rural regions, agricultural practices, industrial wastes, insufficient treatment, and overuse of scarce water resources could be the main causes of this contamination [16] [17]. Polluted water contains biological contaminants such as pathogenic bacteria, protozoa, viruses, parasites, worms, and fungi, as well as suspended solids, dissolved inorganic compounds, nitrogen and phosphorus compounds, animal wastes, poisonous chemicals, insecticides, pesticides, medical waste, and toxic heavy metals [18] [19].

In water quality evaluation projects, physico-chemical parameters are typically screened, heavy metals are examined, and the biotic and abiotic conditions of ecosystems are assessed [20]. River Wanjei is one of the major rivers in Sierra Leone.

The river as it hosts most of the country's fish biodiversity is found in the southern province. The environment damage caused by water pollution from agriculture (especially large-scale palm oil plantations and cassava farming for value chains) and mining (diamonds, gold, and other minerals) are yet to be examined. These uses contribute to localized disturbance and nutrient inputs, particularly during periods of low flow when dilution is reduced, and riverine processes are more sensitive to anthropogenic influence. Seasonal connectivity between riparian wetlands and the main river channel enhances nutrient cycling and supports fisheries productivity [21] [22], which are vital for both ecological integrity and human well-being in communities such as Gbondapi. Thus, this study assesses the physico-chemical parameters of selected sites along the Wanjei River in Pujehun District, Sierra Leone.

2. Research Methodology

2.1. Description of Study Area

The study was carried out in the Gbondapi community, which is in the Southern Province of Sierra Leone, Pujehun District. Pujehun District is bordered by the Atlantic Ocean to the southwest and the Republic of Liberia to the southeast. Gbondapi is in Kpanga-kabonde Chiefdom, and it is situated 19.3 km away from the district headquarter town Pujehun. The study area is on the Wanjei River, which is an important local center for fish landing, informal trade, and river transport in the area. The climate in Pujehun District is tropical and humid. There is a clear rainy season from May to October and a dry season from November to April which is typical of Sierra Leone's southern coastal zone [23] [24]. Along the River Wange area in Pujehun, Sierra Leone, the key economic activities involve agriculture (especially large-scale palm oil plantations and cassava farming for value chains) and mining (diamonds, gold, construction minerals), alongside local fishing, with increasing focus on developing the agricultural value chain to boost local economies. Pujehun is one of Sierra Leone's poorest districts, relying heavily on these natural resources, with international investment in plantations and mining being major employers of the indigenes. The Wanjei River is one of the many lowland rivers that flow from the southern Sierra Leone coastal plains. These rivers have a lot of seasonal changes. During the rainy season, the flow is higher and the surface is more connected. During the dry season, the flow is lower. This is attributed to tidal exchange and freshwater coming in from upland catchments (based on field observations and river discharge characteristics).

2.2. Sample Collection and Preservation

The samples for analysis were collected in sterilized bottles carefully taken so that no bubbling was observed during sampling to avoid influencing the dissolved oxygen result. The water temperature, Dissolved Oxygen, and pH were recorded in situ using 3-in-1 HANNAH portable water quality parameter analyzer. The pH of water samples of the water would be measured with the help of a pH Meter with a glass electrode. All other parameters were collected and analyzed by adopting the procedures that were followed by Sharma and Walia [25]. Water samples collected from the stations or selected sample sites using PETS bottles were corked, stored in the cool box with ice cubes, and transported to the laboratory immediately and stored at a temperature of below 4˚C American Public Health Association [26] to prevent vaporization and biodegradation of the analytes that are awaiting the Physico-chemical analysis [27].

2.3. Experimental Method

The following items Motorized boat, water Quality Parameter testing kits, Global Positioning System (GPS) Device, Digital Camera, Plastic bucket/cool man, PET bottles, Masking tapes, and Markers were some of the field equipment used to conduct the experiment. Data collection design was employed and accompanied by laboratory tests to determine the levels of Physico-chemical parameters of River Wanjei and assess the effects of seasonal variation on the levels of the Physico-chemical parameters of the water body.

Sampling sites or locations within the study area were mapped out on transect (with a specified distance) and located using GPS. All coordinates and elevation were recorded (**Table 1**). Four sites (entrance, upper, middle, and lower) parts of river Wanjei were sampled. The sites were designated as Entrance (Site 1); Upper (Site 2); Middle (Site 3); and Lower (Site 4). During each sampling occasion, samples were taken twice a day (A for morning and B for evening) which corresponds to the highest and lowest water level. To determine the possible sources of pollution, a thorough one-day preliminary survey of sampling stations was conducted, and the proportional sources of pollution to the river were taken into consideration when choosing these sampling sites. Sampling was done in both rainy and dry seasons (October 2021-July 2022) to cover the varying activity periods and to determine the effects of seasonal variation on the levels of Physico-chemical parameters of the river under study. The sampling frequency was two days in a month. During each sampling occasion, samples were taken twice a day corresponding to the highest and lowest water level. Selected parameters of both physical (temperature, electrical conductivity, turbidity, and TDS), and chemical (pH, as well as concentrations of PO_4^{3-}, NH_4^+, DO, BOD5, COD, chloride, total alkalinity, total hardness, biological properties.

Table 1. Sampling location and coordinates.

Site/location	Latitude	Longitude
ST-1A	N 07˚18'22.6"	W 011˚51'11.0"
ST-1B	N 07˚19'14.9"	W 011˚51'18.5"
ST-2A	N 07˚19'21.9"	W 011˚51'58.4"
ST-2B	N 07˚20'30.6"	W 011˚52'45.4"
ST-3A	N 07˚21'06.4"	W 011˚53'28.8"
ST-3B	N 07˚22'01.2"	W 011˚53'19.5"
ST-4A	N 07˚22'34.8"	W 011˚52'59.8"

Continued

ST-4B	N 07˚22'51.7"	W 011˚52'45.1"
Mid-Point-1	N 07˚21'58.5"	W 011˚53'20.7"
Mid-Point-2	N 07˚21'24.7"	W 011˚53'30.1"
Mid-Point-3	N 07˚20'41.2"	W 011˚53'08.7"
Mid-Point-4	N 07˚19'32.6"	W 011˚52'19.3"
Warf Gbondapi	N 07˚19'10.9"	W 011˚51'13.1"

2.4. Data Analysis

Water Samples for the analysis of water parameters temperature, pH, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), chloride, total alkalinity, total hardness, carbon dioxide, total dissolved solids, lead, copper, iron, chromium, cadmium, nickel, and manganese will be preserved and transported to a reputable research laboratory. For the preservation and the analysis of water samples of the water understudy, the standard methods of Trivedy & Goel [28]; and then APHA, 2005 will be followed. Also, the results obtained will be analyzed, compared with the WHO (World Health Organization) (**Table 2**) and other international standards, and discussed in brief, which has to play a conclusive role in deciding the status of water quality of the river under study. These are the *health-based targets* for safe drinking water quality, which are often applied when assessing surface water used for human consumption:

Table 2. WHO (World Health Organization)—Drinking Water Guidelines.

Parameter	WHO Guideline/Permissible Limit (Drinking Water)
pH	6.5 - 8.5 *typical desirable range* (surface waters assessed similarly)
Total Dissolved Solids (TDS)	≤500 mg/L desirable; extended up to ~1500 mg/L maximum acceptable in some guidelines
Conductivity	No strict WHO numeric limit for surface water itself, but often interpreted as ≤750 µS/cm for potable waters based on related standards
Dissolved Oxygen (DO)	≥6 mg/L is generally favorable for aquatic life (not a strict WHO guideline but widely used)
Nitrate (NO_3^-)	≤10 mg/L (as nitrate-N or 50 mg/L as NO_3^-) for drinking safety
Phosphate (PO_4^{3-})	WHO does not set a strict limit for phosphate, but ≤2 mg/L is often referenced for potable surface waters
Fluoride (F^-)	≤1.5 mg/L to protect dental/health outcomes
Parameter	FAO Guideline/Acceptable Range (Irrigation)
pH	6.0 - 8.5 suitable for most crops
TDS	0 - 2000 mg/L acceptable for general irrigation
Electrical Conductivity (EC)	0 - 3 dS/m (0 - 3000 µS/cm) generally suitable; lower is better to avoid salinity stress

Continued

Nitrate-N (NO_3-N)	0 - 10 mg/L typical desirable range for irrigation water
Ammonium-N (NH_4-N)	0 - 5 mg/L generally acceptable
Phosphate-P (PO_4-P)	0 - 2 mg/L acceptable for most irrigated crops
Potassium (K^+)	0 - 2 mg/L typical guideline
Parameter	**FAO Guideline/Acceptable Range (Irrigation)**
pH	6.0 - 8.5 suitable for most crops
TDS	0 - 2000 mg/L acceptable for general irrigation
Electrical Conductivity (EC)	0 - 3 dS/m (0 - 3000 μS/cm) generally suitable; lower is better to avoid salinity stress
Nitrate-N (NO_3-N)	0 - 10 mg/L typical desirable range for irrigation water
Ammonium-N (NH_4-N)	0 - 5 mg/L generally acceptable
Phosphate-P (PO_4-P)	0 - 2 mg/L acceptable for most irrigated crops
Potassium (K^+)	0 - 2 mg/L typical guideline

3. Results and Discussion

3.1. Physical Parameters of Wanjei River Water Collected from Selected Sites

Significant variations ($p < 0.05$) exist among water samples and sampling regimes for the physical parameters (pH, temperature, TDS and electrical conductivity) assessed at four different sites (Table 3). The highest mean value (pH = 8.57) of pH was found at Upper stream during February 2022 sampling, while the lowest mean value of 6.70 at same location was exhibited during October 2021 sampling regime. The pH values of the four locations and the sampling regimes were within the standard level of pH for rivers (pH = 6.5 - 8.5), except for the pH value of 8.57 obtained at the upper stream for sampling in February 2022. These values are within the permissible limit of WHO and FAO set for drinking and irrigation purposes, respectively. These findings are similar to those of Shamsur *et al.* [29], who noted the highest mean pH value of 6.68 in Tatholia Union and lowest mean pH value of 6.52 in Gaglajur Union, Bangladesh. Jesmin [30], also found pH values of groundwater in Gaibandha aquifers ranging from 6.73 - 8.66 indicating slightly acidic to alkaline water. Temperatures across sites and sampling regimes ranged from 26.5˚C (ST-2 during February 2022) to 32.3˚C (ST-1 during December 2021) sampling regime and were found within the permissible limit of WHO standards (WHO, 2021). This result falls below the limit of other studies, that was reported to be within the range of 19.0 to 23.9˚C [31]. Thus, the average temperature of the river is favorable for aquatic ecosystem. Since it influences both the physical and chemical properties of the water as well as the organisms, temperature is a crucial component for the aquatic ecosystem. Total Dissolved Solid (TDS) values across sites and sampling regimes ranged from 28.06 (ST-4 during October 2021) to 52.74 (ST-3 and ST-2 during December 2021 and April 2022) sampling regimes. These values are far below the WHO and FAO standards level of TDS for rivers (500 and 2000 mg/L) respectively. These findings are also below the figures 120.190 mg/L reported by Alam [32]. Total dissolved solids indicate the salinity behavior of water [33]. Water containing more than 500 mg/L of TDS is not considered as desirable for drinking water supplies and water with high TDS may taste bitter, salty, or metallic and may have unpleasant odors which are undesirable or harmful to human and aquatic life [31].

Electrical conductivity (EC) values across sites and sampling regimes ranged from 124.00 µs/cm (ST-4 during July 2022) to 145.20 µs/cm (ST-3 during December 2021) sampling regime that was within the standard level of EC for river (EC = 50 - 1000 µs/cm). The ability of water to transmit electric current is referred to electrical conductivity and it is a method for determining the purity of water (Sakthivadivel *et al.* [34]. The presence of ions, their overall concentration, mobility, valence, relative concentrations, and measuring temperature are all known to be affected by this ability. Findings of this study indicate low mineralization. The definitions of mineralization levels vary from country to country [35]. For this study, low mineralization indicates less than 200 µS/cm, moderate mineralization indicates between 200 to 700 µS/cm, high mineralization indicates between 700 to 2500 µS/cm and super high mineralization (medicinal water) indicates more than 2500 µS/cm. The EC values of the present study exhibited low salinity compared to the EC values (255 to 497 µS/cm) found by Halim [36] that signified medium salinity of their water sampled across seasons.

Table 3. Physical parameters for water samples collected from selected sites.

	Sampling regime					
	Oct.-2021	Dec.-2021	Feb.-2022	Apr.-2022	Jun.-2022	Jul.-2022
Site	pH					
ST-1	6.70	7.47	8.57	7.08	7.50	6.77
ST-2	7.17	7.07	7.96	7.45	7.58	6.83
ST-3	7.23	7.13	7.67	7.13	7.67	7.57
ST-4	7.43	8.10	7.24	6.95	7.07	8.33
Mean	7.13	7.44	7.86	7.16	7.45	7.38
LSDsite	0.35					
LSDsreg	0.43*					
LSDs*sreg	0.85*					
CV (%)	7.0					
MCL	6.5 - 8.5					
Site	Temperature (˚C)					

Continued

ST-1	31.3	32.3	28.1	28.5	29.8	30.3
ST-2	31.5	31.2	26.5	26.8	31.5	31.5
ST-3	29.0	30.4	28.2	28.8	29.0	29.0
ST-4	30.3	30.6	27.0	30.0	29.3	29.3
Mean	30.5	31.1	27.4	28.5	29.9	30.0
LSDsite	0.5*					
LSDsreg	0.6*					
LSDs*sreg	1.2*					
CV (%)	2.5					
MCL	-					
Site	TDS (mg/L)					
ST-1	33.02	49.43	51.91	52.51	47.91	31.69
ST-2	32.38	50.71	51.08	52.74	47.74	33.29
ST-3	28.07	52.74	51.42	51.95	44.92	36.59
ST-4	28.06	45.06	50.87	52.34	44.33	34.96
Mean	30.38	49.48	51.32	52.39	46.23	34.13
LSDsite	2.28					
LSDsreg	2.79*					
LSDs*sreg	5.57ns					
CV (%)	7.7					
MCL	1000					
Electrical conductivity Site	EC (μS/cm)					
ST-1	130.13	136.27	129.17	132.63	129.83	128.80
ST-2	128.77	135.67	140.33	132.33	128.20	128.20
ST-3	127.87	145.20	140.87	135.20	129.87	128.87
ST-4	126.87	142.00	140.33	136.03	132.67	124.00
Mean	128.41	139.78	137.68	134.05	130.14	127.47
LSDsite	1.31*					
LSDsreg	1.61*					
LSDs*sreg	3.21*					
CV (%)	1.5					
MCL	2500					

MCL = maximum contaminant level accepted, LSD = least significant difference, s = site, sreg = sampling regime.

3.2. Chemical Parameters for Wanjei River Collected from Selected Sites

3.2.1. Major Ions and Minerals Assessed

Sodium (Na^+) values across sites and sampling regimes ranged between 26.16 mg/L (ST-3 during June 2022) and 31.14 mg/L (ST-1 during December 2021) sampling regimes (Table 4). These values are within the standard level of sodium for both general use of water and for drinking purposes (Na^+ = 200 mg/L). Potassium (K^+) values across sites and sampling regimes ranged between 28.60 mg/L (ST-1 during June 2022) and 31.83 mg/L (ST-3 during October 2021) sampling regimes (Table 4). These values are above the standard level of potassium for drinking (K^+ =< 6.0 mg/L). Magnesium (Mg^{2+}) values across sites and sampling regimes ranged between 15.58 mg/L (ST-4 during December 2021) and 22.45 mg/L (ST-4 during April 2022) sampling regimes (Table 4). These values are within the standard level of magnesium for drinking (Mg^{2+} = 80 mg/L). Calcium (Ca^{2+}) values across sites and sampling regimes ranged from 47.86 mg/L (ST-3 during June 2022) to 63.78 mg/L (ST-1 during February 2022) sampling regimes (Table 4). These values are within the FAO and WHO permissible level (800 mg/L and 100 mg/L respectively) for drinking water and irrigation purposes. The highest amount of calcium recorded in water samples during dry season was 63.78 mg/L in February at site-1 could possibly be as a result of the close proximity of the site to the Wharf or jetty, hence addition of waste water and introduction of sewage water along with rain could be responsible for the increase in amount of calcium [37]. The lowest amount of calcium in water was recorded during raining season, possibly due to calcium absorbed by many organisms for shell construction, bone building and flora precipitation of lime [38].

Table 4. Chemical ions and minerals in water samples collected from selected sites.

	Sampling regime					
	Oct.-2021	Dec.-2021	Feb.-2022	Apr.-2022	Jun.-2022	Jul.-2022
Site	Sodium (mg/L)					
ST-1	28.06	28.49	26.38	27.14	26.16	27.16
ST-2	28.13	28.89	28.54	28.82	28.41	27.90
ST-3	29.45	29.68	29.82	29.49	29.08	29.68
ST-4	29.94	31.14	26.99	30.33	27.94	30.17
Mean	28.9	29.55	27.93	28.95	27.90	28.73
LSDsite	1.06*					
LSDsreg	1.29					
LSDs*sreg	2.59ns					
CV (%)	5.5					
MCL	200					
Site	Potassium (mg/L)					
ST-1	29.20	29.13	28.77	29.50	28.60	28.93

Continued

ST-2	31.03	30.40	30.97	30.63	30.30	30.97
ST-3	31.83	31.20	30.93	31.20	30.80	31.03
ST-4	30.43	29.23	30.27	30.46	29.10	30.43
Mean	30.62	29.99	30.23	30.45	29.70	30.34
LSDsite	0.91*					
LSDsreg	1.12ns					
LSDs*sreg	2.24ns					
CV (%)	4.5					
MCL	<6.0					
Site	Magnesium (mg/L)					
ST-1	18.80	18.06	19.63	19.26	17.60	18.10
ST-2	18.73	18.13	18.90	20.73	18.07	18.73
ST-3	18.09	17.27	17.47	21.80	17.14	17.59
ST-4	18.49	15.58	18.45	22.45	15.78	16.92
Mean	18.53	17.26	18.61	21.06	17.15	17.84
LSDsite	0.39*					
LSDsreg	0.48*					
LSDs*sreg	0.95*					
CV (%)	3.1					
MCL	80					
Site	*Calcium* (mg/L)					
ST-1	59.48	57.42	63.78	59.55	57.42	58.75
ST-2	60.77	48.43	59.30	58.60	48.27	58.61
ST-3	61.60	48.23	58.20	58.20	47.86	59.53
ST-4	61.83	48.90	59.94	58.80	48.60	58.33
Mean	60.92	50.74	60.30	58.79	50.54	58.80
LSDsite	0.99*					
LSDsreg	1.21*					
LSDs sreg*	2.42*					
CV (%)	2.6					
MCL	180					
Site	$CaCO_3$ (mg/L)					
ST-1	33.47	32.00	30.10	33.52	30.33	30.67
ST-2	30.03	30.09	29.35	32.98	29.36	29.33
ST-3	28.92	28.62	29.18	32.75	28.42	28.75
ST-4	28.21	29.84	30.77	33.11	29.77	28.77
Mean	30.15	30.14	29.85	33.09	29.47	29.38

Continued

LSDsite	0.69*					
LSDsreg	0.85*					
LSDs*sreg	1.69*					
CV (%)	3.4					
MCL	≤300					
Site	Sulphate (mg/L)					
ST-1	6.75	6.85	7.88	7.55	6.55	6.93
ST-2	7.62	7.45	7.46	7.48	7.30	7.62
ST-3	7.41	7.15	7.48	6.85	7.48	7.47
ST-4	7.68	7.12	8.85	7.41	7.51	7.88
Mean	7.37	7.14	7.92	7.32	7.21	7.48
LSDsite	0.21*					
LSDsreg	0.26*					
LSDs*sreg	0.52*					
CV (%)	4.2					
MCL	250					
Site	Chloride (mg/L)					
ST-1	5.57	4.58	4.80	7.53	4.80	5.17
ST-2	4.83	4.52	5.40	6.73	4.40	4.83
ST-3	5.37	4.77	5.00	6.27	4.67	5.10
ST-4	5.70	4.82	5.60	5.60	4.60	4.70
Mean	5.37	4.67	5.20	6.53	4.62	4.95
LSDsite	0.28ns					
LSDsreg	0.34*					
LSDs*sreg	0.68*					
CV (%)	7.9					
MCL	<250					
Site	Fluoride (mg/L)					
ST-1	1.73	1.43	1.25	1.18	1.26	1.66
ST-2	1.45	1.47	2.01	1.18	1.15	1.38
ST-3	1.54	1.82	1.86	1.89	1.09	1.21
ST-4	1.76	1.69	1.83	1.93	1.73	1.86
Mean	1.62	1.60	1.74	1.55	1.31	1.53
LSDsite	0.10*					
LSDsreg	0.12*					
LSDs*sreg	0.25*					
CV (%)	9.6					
MCL	<1.5					

MCL = maximum contaminant level accepted, LSD = least significant difference, s = site, sreg = sampling regime.

Calcium carbonate ($CaCO_3^+$) values across sites and sampling regimes ranged between 28.21 mg/L (ST-4 during October 2021) and 33.52 mg/L (ST-1 during April 2022) sampling regimes (Table 3). These values are within the standard level of calcium carbonate for drinking ($CaCO_3^+ \le 300$ mg/L).

Sulphate (SO_4^{2+}) values across sites and sampling regimes ranged between 6.55 mg/L (ST-1 during June 2022) and 8.85 mg/L (ST-4 during February 2022) sampling regimes (Table 3). These values are within the standard level of sulphate for drinking ($SO_4^{2+} = 250$ mg/L).

Chloride (Cl^-) values across sites and sampling regimes ranged between 4.40 mg/L (ST-2 during June 2022) and 7.53 mg/L (ST-1 during April 2022) sampling regimes (Table 3). These values are within the standard level of chloride for drinking ($Cl^- = <250$ mg/L). These findings are similar to those range reported by Jindal and Sharma (2011). Fluoride (Fl^-) values across sites and sampling regimes ranged between 1.09 mg/L (ST-4 during June 2022) and 2.01 mg/L (ST-3 during February 2022) sampling regimes (Table 3). At site ST-1, sampling regimes in December 2021 (1.43 mg/l), February 2022 (1.25 mg/l), April 2022 (1.18 mg/l), and June 2022 (1.43 mg/l) are within the standard level of fluoride for drinking ($Fl^- < 1.5$ mg/L). Similarly, at ST-2, sampling regimes Oct.-2021 (1.45 mg/l), Dec.-2021 (1.47 mg/l), Apr.-2022 (1.18 mg/l), Jun.-2022 (1.15 mg/l), and Jul.-2022 (1.38 mg/l); and at ST-3, Jun.-2022 (1.09 mg/l) and Jul.-2022 (1.21 mg/l) are within the standard level of fluoride for drinking and irrigation purposes.

3.2.2. Chemical Nutrients Assessed

Phosphate (PO_4^{3-}) values across sites and sampling regimes ranged between 0.40 mg/L (ST-1 during June 2022) and 4.43 mg/L (ST-1 during February 2022) sampling regimes (Table 5). These values are above the standard level of phosphate for drinking ($PO_4^{3-} = 2$ mg/L), which may be considered to indicate pollution or increased risk of eutrophication. Site ST-2 had consistently phosphate values within the standard level of phosphate for drinking ($PO_4^{3-} = 2$ mg/L). Sampling at Feb.-2022 for sites ST-1 (4.43 mg/l), ST-3 (2.53 mg/l) and ST-4 (2.57 mg/l) exhibited higher values above the accepted standard level of phosphate for drinking.

Nitrate (NO_3^-) values across sites and sampling regimes ranged between 21.90 mg/L (ST-1 during June 2022) and 27.93 mg/L (ST-4 during December 2021) sampling regimes (Table 5). These values are above the standard level of nitrate for drinking ($NO_3^- = <10$ mg/L). Ammonia (NH_3^{2+}) values across sites and sampling regimes ranged from 0.13 mg/L (ST-3 during June 2022) to 2.63 mg/L (ST-4 during December 2021) sampling regimes (Table 5). In this present study, the measured value of ammonia is similar to that done by Mezgebe *et al.* [39] who obtained a range of 0.16 ± 0.01 to 0.43 ± 0.19 mg/L. The statistical analysis showed least significance differences among the studied sites. Thus, our experimental findings showed that the amount of ammonia was within the permissible limit of FAO (5 mg/L) for drinking and irrigation purposes.

Table 5. Chemical Nutrients in water samples collected from selected sites.

	Sampling regime					
	Oct.-2021	Dec.-2021	Feb.-2022	Apr.-2022	Jun.-2022	Jul.-2022
Site	Phosphate (mg/L)					
ST-1	0.93	1.67	4.43	1.97	0.40	0.70
ST-2	1.57	1.43	1.73	1.60	0.77	1.53
ST-3	1.70	1.40	2.53	0.87	0.67	1.27
ST-4	1.67	1.60	2.57	2.00	0.77	1.60
Mean	1.47	1.52	2.82	1.61	0.65	1.27
LSDsite	0.79					
LSDsreg	0.97*					
LSDs*sreg	1.94ns					
CV (%)	75.8					
MCL	2					
Site	Nitrate (mg/l)					
ST-1	25.30	25.96	25.48	25.23	21.90	23.23
ST-2	26.26	26.49	25.08	27.49	25.36	26.59
ST-3	25.83	27.50	25.99	29.36	25.37	25.37
ST-4	24.93	27.93	26.27	29.59	22.77	24.50
Mean	25.58	26.97	25.71	27.92	23.85	24.92
LSDsite	0.63*					
LSDsreg	0.77*					
LSDs*sreg	1.55*					
CV (%)	3.6					
MCL	<10					
Site	Ammonia (mg/L)					
ST-1	2.10	2.20	1.20	0.71	0.19	1.60
ST-2	1.32	2.50	0.87	1.18	0.16	0.83
ST-3	1.81	2.15	1.23	1.38	0.13	1.45
ST-4	2.30	2.63	0.95	0.95	0.19	2.12
Mean	1.88	2.37	1.06	1.05	0.17	1.50
LSDsite	0.30					
LSDsreg	0.36*					
LSDs*sreg	0.73ns					
CV (%)	33.1					
MCL	-					

MCL = maximum contaminant level accepted, LSD = least significant difference, s = site, sreg = sampling regime.

3.2.3. Dissolved Gases Assessed

Important variations exist in the chemical content of water sampled across sites and various sampling regimes. Dissolved oxygen (DO) and biological oxygen demand (BOD) significantly ($p < 0.05$) differed among water samples assessed across sites and sampling regimes. The DO values across sites and sampling regimes ranged from 6.54 mg/L (ST-3 during June 2022) to 8.72 mg/L (ST-4 during October 2021) sampling regime that was above the standard level of DO for rivers and drinking water (WHO, 2008) (**Table 6**). The maximum value recorded in ST-4 may be due to the self-purification of the water along the course of the river. This is similar to study done by Mezgebe *et al.* [39] who recorded 10.2 mg/L in Tsaeda Agam River in Mekelle City, Tigray, Ethiopia

The oxygen necessary for the microorganism to undertake the biological breakdown of dissolved solids or organic materials in the wastewater under aerobic circumstances is known as the biochemical oxygen demand [40] [41]. The biochemical oxygen demand reported from water samples from Wanjei River ranged between 1.21 mg/L to 2.18 mg/L. The highest demand for oxygen in the water was recorded during the dry season (at ST-3 in February 2022) due to the possible addition of high amount of waste from the surrounding and the addition of organic waste in river by certain human activities including are not limited to farming and pepper garden which also be responsible for the increase in BOD [42].

Table 6. Dissolved gases in water samples collected from selected sites.

	Sampling regime					
	Oct.-2021	Dec.-2021	Feb.-2022	Apr.-2022	Jun.-2022	Jul.-2022
Site	DO (mg/L)					
ST-1	6.93	8.53	7.23	7.87	6.87	6.83
ST-2	7.39	8.24	8.45	7.45	7.24	7.24
ST-3	7.75	6.93	7.34	7.67	6.54	7.54
ST-4	8.72	7.62	6.96	7.39	7.30	8.39
Mean	7.70	7.83	7.49	7.59	6.99	7.50
LSDsite	0.35*					
LSDsreg	0.43*					
LSDs*sreg	0.85*					
CV (%)	6.9					
MCL	4-6					
Site	BOD (mg/L)					
ST-1	1.73	1.83	2.09	1.79	1.69	1.57
ST-2	1.68	1.70	2.00	1.76	1.24	1.47
ST-3	1.58	1.61	2.18	1.81	1.21	1.41
ST-4	1.58	1.60	1.87	1.87	1.47	1.58
Mean	1.64	1.69	2.03	1.81	1.40	1.51

Continued

LSDsite	0.14ns
LSDsreg	0.17*
LSDs*sreg	0.33ns
CV (%)	12.1
MCL	<2.0

MCL = maximum contaminant level accepted, LSD = least significant difference, s = site, sreg = sampling regime.

4. Conclusion and Recommendation

The study evaluated the physicochemical quality of Wanjei River across four sites and multiple seasons. Most physical parameters (pH, temperature, TDS, and electrical conductivity) were within WHO and FAO permissible limits, indicating generally good water quality with low mineralization and salinity. Major ions such as sodium, calcium, magnesium, chloride, sulphate, and calcium carbonate were also within acceptable standards; however, potassium levels consistently exceeded drinking water limits, and fluoride occasionally approached or exceeded recommended values. Nutrient analysis revealed concerns, with phosphate exceeding permissible limits at some sites during the dry season and nitrate levels consistently above WHO standards across all sites, posing potential health risks. Despite this, high dissolved oxygen and low BOD values indicate good aeration, low organic pollution, and strong self-purification capacity of the river. Hence, while the river remains largely suitable for use, increasing nutrient and potassium levels reflect growing anthropogenic pressures that could threaten water quality if unmanaged. Key recommendations include regular water quality monitoring, control of agricultural runoff, improved wastewater treatment, public awareness on safe water use, strengthened regulatory enforcement, and further research incorporating microbiological and heavy metal assessments.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Bhagwat, V.R. (2019) Safety of Water Used in Food Production. In: Singh, R.L. and Mondal, S., Eds., *Food Safety and Human Health*, Elsevier, 219-247. https://doi.org/10.1016/b978-0-12-816333-7.00009-6

[2] David, L.O., Aigbavboa, C., Nwulu, N. and Adepoju, O.O. (2024) General Description of Water, Energy, and Food Resources. In: David, L.O., Aigbavboa, C., *et al.*, Eds., *Green Energy and Technology*, Springer, 21-61. https://doi.org/10.1007/978-3-031-72833-4_2

[3] Kılıç, Z. (2020) The Importance of Water and Conscious Use of Water. *International Journal of Hydrology*, **4**, 239-241. https://doi.org/10.15406/ijh.2020.04.00250

[4] Yadav, A.K. (2016) Physicochemical Studies on Assessment of Ground Water Quality

of Kota District. Doctoral Dissertation, University of Kota.

[5] Ezugwu, C.N. and Apeh, S. (2017) Ground Water and Surface Water as One Resource: Connectivity and Interaction. *IOSR Journal of Mechanical and Civil Engineering*, **14**, 54-59. https://doi.org/10.9790/1684-1403075459

[6] Katsanou, K. and Karapanagioti, H.K. (2017) Surface Water and Groundwater Sources for Drinking Water. In: Gil, A., Galeano, L. and Vicente, M., Eds., *The Handbook of Environmental Chemistry*, Springer International Publishing, 1-19. https://doi.org/10.1007/698_2017_140

[7] Bănăduc, D., Simić, V., Cianfaglione, K., Barinova, S., Afanasyev, S., Öktener, A., *et al.* (2022) Freshwater as a Sustainable Resource and Generator of Secondary Resources in the 21st Century: Stressors, Threats, Risks, Management and Protection Strategies, and Conservation Approaches. *International Journal of Environmental Research and Public Health*, **19**, Article 16570. https://doi.org/10.3390/ijerph192416570

[8] Mishra, R.K. (2023) Fresh Water Availability and Its Global Challenge. *British Journal of Multidisciplinary and Advanced Studies*, **4**, 1-78. https://doi.org/10.37745/bjmas.2022.0208

[9] Cantonati, M., Poikane, S., Pringle, C.M., Stevens, L.E., Turak, E., Heino, J., *et al.* (2020) Characteristics, Main Impacts, and Stewardship of Natural and Artificial Freshwater Environments: Consequences for Biodiversity Conservation. *Water*, **12**, Article 260. https://doi.org/10.3390/w12010260

[10] Noor, T., Javid, A., Hussain, A., Bukhari, S.M., Ali, W., Akmal, M., *et al.* (2020) Types, Sources and Management of Urban Wastes. In: Verma, P., Singh, P., *et al.*, Eds., *Urban Ecology*, Elsevier, 239-263. https://doi.org/10.1016/b978-0-12-820730-7.00014-8

[11] Yohannes, H. and Elias, E. (2017) Contamination of Rivers and Water Reservoirs in and around Addis Ababa City and Actions to Combat It. *Environment Pollution and Climate Change*, **1**, 1-12. https://doi.org/10.4172/2753-458x.1000116

[12] Choudhury, M., Pervez, A., Sharma, A. and Mehta, J. (2022) Human-Induced Stresses on the Rivers Beyond Their Assimilation and Regeneration Capacity. In: Madhav, S., Kanhaiya, S., *et al.*, Eds., *Ecological Significance of River Ecosystems*, Elsevier, 281-298. https://doi.org/10.1016/b978-0-323-85045-2.00019-4

[13] Haidvogl, G. (2018) Historic Milestones of Human River Uses and Ecological Impacts. In: Schmutz, S. and Sendzimir, J., Eds., *Riverine Ecosystem Management*, Springer International Publishing, 19-39. https://doi.org/10.1007/978-3-319-73250-3_2

[14] Hamid, A., Bhat, S.U. and Jehangir, A. (2019) Local Determinants Influencing Stream Water Quality. *Applied Water Science*, **10**, 1-16. https://doi.org/10.1007/s13201-019-1043-4

[15] Liao, H., Sarver, E. and Krometis, L.H. (2018) Interactive Effects of Water Quality, Physical Habitat, and Watershed Anthropogenic Activities on Stream Ecosystem Health. *Water Research*, **130**, 69-78. https://doi.org/10.1016/j.watres.2017.11.065

[16] Singh, S. (2024) Water Pollution in Rural Areas: Primary Sources and Associated Health Issues. In: Madhav, S., Srivastav, A.L. *et al.*, Eds., *Water Resources Management for Rural Development*, Elsevier, 29-44. https://doi.org/10.1016/b978-0-443-18778-0.00011-8

[17] Tariq, A. and Mushtaq, A. (2023) Untreated Wastewater Reasons and Causes: A Review of Most Affected Areas and Cities. *International Journal of Chemical and Biochemical Sciences*, **23**, 121-143.

[18] Aggarwal, R. and Arora, S. (2012) A Study of Water Quality of Kaushalya River in the Submountaneous Shivalik Region. *International Journal of Scientific & Technology*

Research, **1**, 52-68.

[19] Pardeshi, D.S. and Baidya, S. (2015) Physicochemical Assessment of Waldhuni River Ulhasnagar, Thane, India—A Case Study. *International Journal of Current Research & Academic Review*, **3**, 234-248.

[20] Hisseien, A., Kamga, R. and Mahamat, T. (2015) Physico-Chemical Analysis of Logone River Water at Moundou City in Southern Chad. *International Journal of Biological and Chemical Sciences*, **9**, 1654-1664. https://doi.org/10.4314/ijbcs.v9i3.44

[21] Gordon, B.A., Dorothy, O. and Lenhart, C.F. (2020) Nutrient Retention in Ecologically Functional Floodplains: A Review. *Water*, **12**, Article 2762. https://doi.org/10.3390/w12102762

[22] Pratt, O.P., Beesley, L.S., Pusey, B.J., Setterfield, S.A. and Douglas, M.M. (2024) The Implications of Brief Floodplain Inundation for Local and Landscape-Scale Ecosystem Function in an Intermittent Australian River. *Marine and Freshwater Research*, **75**, MF24123. https://doi.org/10.1071/mf24123

[23] Mustapha, S., Peters, K. and Tunis, N. (2017) Rural Transport Diagnostic Study in Sierra Leone. Project SLE2108A. Final Report. Africa Community Access Partnership (AfCAP), Cardno Emerging Markets, Thame.

[24] Sierra Leone Meteorological Agency (2022) Climate and Average Weather Year Round in Pujehun Sierra Leone.

[25] Sharma, V. and Walia, Y. (2015) Water Quality Assessment Using Physico-Chemical Parameters and Heavy Metals of Gobind Sagar Lake, Himachal Pradesh (India). *Current World Environment*, **10**, 967-974. https://doi.org/10.12944/cwe.10.3.28

[26] American Public Health Association (APHA) 2005 Standard Methods for the Examination of Water and Wastewater, 20th Edition.

[27] Gichuki, J.G. and Gichumbi, J.M. (2012) Physico-Chemical Analysis of Ground Water from Kihara Division, Kiambu County, Kenya. *Journal of Chemical, Biological and Physical Sciences* (*JCBPS*), **2**, 2193-2200.

[28] Trivedy, R.K. and Goel, P.K. (1984) Chemical and Biological Methods for Water Pollution Studies. Environmental Publications.

[29] Shamsur, R., Muhammad, A.A., Azharul, M.I., Sayema, T.F.K. and Mohammod, L.K. (2017) Assessment of Drinking Water Quality and Hygienic Conditions of the People Living around the Dingaputha Haor Area of Netrokona District, Bangladesh. *Research & Reviews*: *Journal of Ecology and Environmental Sciences*, **5**, 12-23.

[30] Jesmin, M.S. (2000) Pollution Studies on Groundwater for Irrigation, Drinking and Industrial Usage in Gaibandha Aquifers. Doctoral Dissertation, Bangladesh Agricultural University.

[31] Okweye, P.S. (2013) Seasonal Variation in Physico-Chemical Parameters and Heavy Metals Assessment in Surface Water of North Alabama. *Research Journal of Chemistry and Environment*, **17**, 68-115.

[32] Alam, M.S. (2008) Assessment of Surface Water Quality for Agricultural Usage in Chalan Beel Area. Doctoral Dissertation, Bangladesh.

[33] Islam, M.S., Mohanta, S.C., Siddique, M.A.B., Abdullah-Al-Mamun, M., Hossain, N. and Bithi, U.H. (2018) Physico-Chemical Assessment of Water Quality Parameters in Rupsha River of Khulna Region, Bangladesh. *International Journal of Engineering Science*, **7**, 73-78.

[34] Sakthivadivel, M., Nirmala, A., Sakthivadivel, J., Mukhilan, R.R. and Tennyson, S. (2020) Physicochemical and Biological Parameters of Water at Industrial Sites of Metropolitan City of Chennai, Tamil Nadu, India. *Water Conservation and Management*,

4, 90-98. https://doi.org/10.26480/wcm.02.2020.90.98

[35] Howarth, R.W., Boyer, E.W., Pabich, W.J. and Galloway, J.N. (2002) Nitrogen Use in the United States from 1961-2000 and Potential Future Trends. *AMBIO: A Journal of the Human Environment*, **31**, 88-96. https://doi.org/10.1579/0044-7447-31.2.88

[36] Halim, M.A. (2009) Seasonal Variation of Pond Water Quality in Selected FISH farms of Mymensingh Area. Doctoral Dissertation, Bangladesh Agricultural University.

[37] Verma, P.U., Chandawat, D. and Solanki, H.A. (2010) Study of Water Quality of Hamirsar Lake-Bhuj. *International Journal of Bioscience Reporter*, **8**, 145-153.

[38] Solanki, H. (2012) Status of Soils and Water Reservoirs Near Industrial Areas of Baroda: Pollution and Soil; Water Chemistry. Lap Lambert Academic Publishing.

[39] Mezgebe, K., Gebrekidan, A., Hadera, A. and Weldegebriel, Y. (2015) Assessment of Physico-Chemical Parameters of Tsaeda Agam River in Mekelle City, Tigray, Ethiopia. *Bulletin of the Chemical Society of Ethiopia*, **29**, 377-385. https://doi.org/10.4314/bcse.v29i3.5

[40] Singh, S., Singh, J. and Singh, H. (2021) Chemical Oxygen Demand and Biochemical Oxygen Demand. In: Inamuddin, Boddula, R. and Asiri, A.M., Eds., *Green Sustainable Process for Chemical and Environmental Engineering and Science*, Elsevier, 69-83. https://doi.org/10.1016/b978-0-12-821883-9.00007-2

[41] Solanki, P. (2018) Development of Ecofriendly Hybrid Model for Wastewater Treatment. https://krishikosh.egranth.ac.in/server/api/core/bitstreams/1ca1f8ab-f8da-418e-9ce1-6fc6402f91fd/content

[42] Solanki, H.A. (2007) Ecological Studies of Phytoplankton of Mini Mahi River, Gujarat, India. *Vidya*, **2**, 47-57.