



Evaluating the Suitability of Wami River Water for Irrigation in Dakawa, Tanzania: A Seasonal Hydrochemical and Index-Based Analysis

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Abstract

Water is an essential natural resource that supports life and social-economic development, with agricultural irrigation accounting for the largest share of global water consumption. However, increasing anthropogenic activities continue to affect both quality and quantity of water resources. This study evaluated the suitability of water from Wami River for Irrigation purposes. Water samples were collected from eight sampling stations along the river during both the wet and dry season to assess the suitability of the water for irrigation use. Irrigation water quality indices such as SAR, SSC, KR, MAR and PI were computed and compared with local and international guidelines. Results showed that all indices fell within the good to excellent range, indicating that water is generally suitable for irrigation. Despite the overall suitability, MAR values remained consistently high in both season (90.14 ± 4.403 and 89.32 ± 4.323), reflecting elevated magnesium level, which can lead to leaf necrosis and reduce water infiltration capacity to the soil leading to poor growth of grown crops ultimately lower crop yield. The results including survey findings also showed that, high magnesium content in water was possibly due to agricultural runoff containing magnesium-based fertilizers, natural weathering and erosion of magnesium-rich parent rock. Therefore, while water from Wami River is generally suitable for irrigation, the persistent magnesium hazard necessitates management strategies such as controlled fertilizer use and the selection of magnesium-tolerant crops.

Keywords · Anthropogenic activities; Irrigation water; Magnesium hazard; Water quality indices

1. Introduction

Water is the most critical natural resource for sustaining life and enabling socio-economic development, with agricultural irrigation representing its single largest consumptive use globally. Although water covers around 71% of the earth surface, only 2.5% is fresh water found in surface water (Oltulular, 2025). It is estimated that irrigation accounts for

approximately 70% of all freshwater withdrawals from rivers, lakes, and aquifers (United Nations, 2019). This dependency is intensifying due to climate variability, which compels farmers to increasingly rely on irrigation to ensure food security and crop productivity.

According to the United National Report (2019), the water use from rivers have been continual increasing by 1% in each year since 1980, driven by rapid

population growth and social and economic development. This has exacerbated water stress affecting approximately 2 billion people and leading to water scarcity problems for over 4 billion people worldwide, largely due to deteriorating water quality in most of water sources (UN, 2019).

To date, the world is experiencing significant water quality problems particularly water scarcity and increase in water related diseases such as cholera and other chronic toxicity associated with increasing of anthropogenic practices around the water sources. This includes the discharge of effluent into freshwater, and the runoff from agricultural practices, which are intensifying pressure on water resources and ending with negative environmental impacts (Ontumbi *et al*, 2015).

irrigation systems around the rivers which has doubled more than recent decade from 139 ha to 307 million of hector (FAO, 2023).

Emerging and intensive application of inorganic fertilizers as an input to boost crop productivity is rapid growing over countries whose contaminant ended to water sources (Sagasta *et al*, 2018). This practice pollute water bodies which alter the water quality by increasing nutrient loads that leads to eutrophication of water bodies, causing alga blooms (Sharabian *et al*, 2018), lowering dissolved oxygen and ultimately affects aquatic species (UNESCO, 2021). It is estimated that eutrophication has affected almost 54% of lakes and reservoir in Asia, 53% in Europe, 48% in North America, 41% in South America and 28% in Africa, impacting both quality and quantity for human

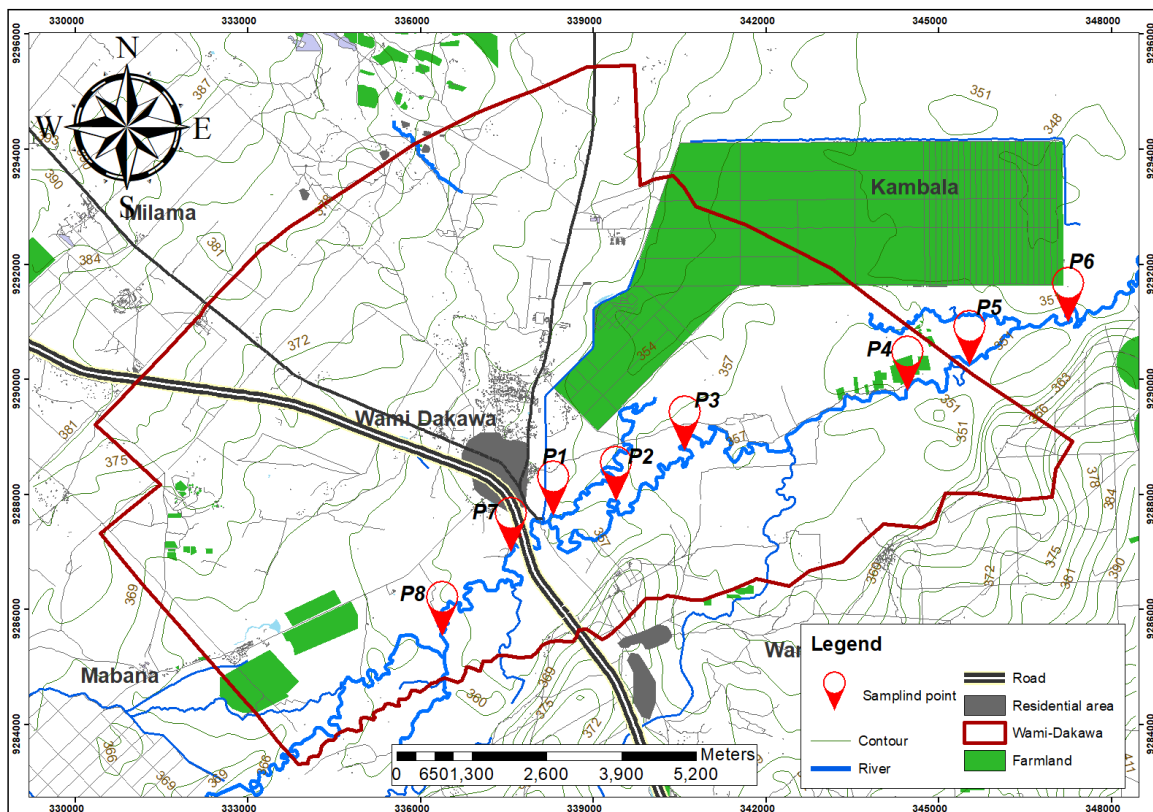


Figure 1: The study area map of water sampling point along Wami River in Dakawa

Agricultural activity has been accounted to contribute to 70% of water sources abstraction globally. This is largely due to rapid expansion of farmland in most of regions to meet the growing food demand, driven by population growth and expansion of

consumption such as drinking and irrigation (Ceres, 2022).

In Sub-Saharan Africa (SSA), agriculture remains the primary livelihood for a majority of the population, driving extensive dependence on surface water

resources. This reliance, coupled with rapid population growth and the expansion of irrigated agriculture, has placed immense pressure on river systems (Adeyemi *et al.*, 2019). The intensification of farming practices, including the widespread application of chemical fertilizers and pesticides, introduces non-point source pollutants into water bodies via runoff. Concurrently, point-source pollution from domestic and industrial wastewater further degrades river water quality, threatening its suitability for irrigation, a sector vital for regional food security and economic stability.

In Tanzania, the Wami river is a crucial water source for Dakawa ward in Morogoro Region, supporting a large-scale rice irrigation scheme covering over 2,000 hectares. The productivity of this scheme and of numerous smallholder farms is intrinsically linked to the river’s water quality. However, expanding anthropogenic activities within the catchment, including agriculture, settlements, and associated runoff, raise significant concerns about potential water quality deterioration. The Wami river in Dakawa is surrounded by agricultural farms and irrigation schemes for rice production which involves high

keeping, industrial and commercial operations, also contribute to the deterioration of the river (USAID, 2015). Currently, the lack of detailed, season-specific water quality data for irrigation purposes limits informed decision-making for farmers and water resource managers in Dakawa.

Assessing irrigation water suitability requires more than evaluating individual parameters; it necessitates integrated tools like water quality indices such as Sodium Adsorption Ratio (SAR), and Magnesium Adsorption Ratio (MAR) that synthesize multiple chemical interactions to predict impacts on soil structure and crop health (Abadi *et al.*, 2024). Therefore, this study aims to evaluate the seasonal suitability of water from the Wami River for irrigation in Dakawa. It does so by analyzing key physicochemical parameters during both wet and dry seasons and interpreting them through established irrigation water quality indices, thereby providing a scientific basis for sustainable agricultural water use in the region

Table 1: Sampling point, location and reason for sampling location selection

Sampling point No	Coordinates	Reason for sampling location selection
P1	-6.4439963, 37.5372406	Irrigation pump
P2	-6.4411761, 37.5464506	Agricultural activities with application of farmyard manure
P3	-6.4326248, 37.5578721	Agricultural surface runoff
P4	-6.4206624, 37.5996479	Agricultural activities with application of agrochemicals
P5	-6.4195739, 37.6031250	Agricultural activities with application of agrochemicals
P6	-6.4119695, 37.6163020	Down stream
P7	-6.4483307, 37.5316337	Livestock keeping
P8	-6.4610670, 37.5209032	Fishing activities

utilization of chemical fertilizers such as diammonium phosphate, calcium ammonium nitrate and magnesium phosphate. Other activities including livestock

2. Materials and Methods

2.1 Description of the Study Area

The study was conducted along the Wami river in Dakawa ward at Mvomero district, Morogoro Region, Tanzania. The river is perennial flowing throughout the year; however, the flow discharge differs between wet and dry season. The river is predicted to experience strong season flow during rainy season (March to May, November to December) and reduced flow during dry season (June to September). Wami river has a length of 490 km a catchment area of Wami basin. Only 9.6 km were covered during this study. The river is flanked by the rice farms and surface irrigation project spanning over 2000 ha. It is located at a latitude $6^{\circ}26'0''\text{S}$ and $37^{\circ}32'0''\text{E}$ (Figure 1), with mean elevation of 361 above mean sea level (a.msl). The area experience bimodal rainfall pattern characterized with short rains in October to January and long rains between March to May. The long rains typically receive rainfall ranging from 74 mm to 410 mm and is generally more reliable for crop cultivation. The area has total population of 34810 (National Bureau of Statistics Tanzania, 2022). It is estimated that approximately 97% of the population relies on agriculture as primary source of income, while the remaining 3% of population engage in other activities such as commerce, fishing, livestock keeping and small-scale industries.

2.2 Sample Collection

Water samples were collected during wet and dry season in March and June of 2024. A total of eight water samples as shown in Figure 1 along Wami River, were collected using water sampler and stored in 1000 ml High-Density Polyethylene (HDPE) sampling container. Prior sampling, sampling containers were rinsed subsequently with distilled water to prevent contamination of water sample collected. To ensure sample preservation, the bottles containing sample were stored into cool box containing ice cubes, then transported to Ardhi University, in the School of Engineering and Environmental Studies for analysis. Upon arrival in the laboratory, all samples were stored in the refrigerator below 4°C until analysis was done. Grab water sampling method was applied thoroughly all water sampling point and only water samples from

river were collected during water sampling, which is the main water source used for irrigation. In selecting water sampling point, main anthropogenic activities conducted along the sampling point of Wami River in Dakawa, Wami river catchment size and distance in Dakawa ward (upstream and downstream) and accessibility were major factors considered in water sampling selection as shown in Table 1

2.3 Water Sample Analysis.

The in-situ measurements were conducted to pH, temperature and electrical conductivity (EC). pH and temperature in water were analyzed using the pH meter series (pH/ORP) mode by electrometric method while the EC was analyzed by using EC meter with similar method as pH. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) anion were determined from alkalinity measurement through titration method. The major cations (Calcium- Ca^{2+} , Magnesium- Mg^{2+} , Sodium- Na^{+} , Potassium- K^{+}) were analyzed using the Atomic Absorption Spectroscopy (AAS). The concentrations of several parameters analyzed were used to calculate the irrigation water quality indices (Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Kelly's Ratio (KR), Soluble Sodium Carbonate (SSC), Residual Sodium Carbonate (RSC) and Permeability Index (PI)).

2.4 Data Analysis.

The data collected were analyzed by using descriptive statistics analysis tools to determine maximum and minimum value of each parameter, the mean and standard deviations. In making comparison of similar parameter across each sampling stations and determining the variables that showed statistically significant differences from others, were achieved using one way ANOVA. A probability value of sampling data less than 5% ($P < 0.05$) was considered to indicate a statistically significance difference. Pearson correlations were conducted to establish the association among analyzed parameters

2.5 Irrigation Water Quality indices

2.5.1 The Sodium Content

High sodium content in water causes the soil to lose their structure leading to increased soil compactions and reduced water infiltration (Tas *et al*, 2022). The sodium content also defines the suitability of water for irrigation purpose by determining Sodium Absorptions Ratio index as shown in Equation 1 (Susaippan *et al*, 2021)

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \quad (1)$$

Water with SAR greater than 9 meq/l affects the soil permeability and structure while less than 8 is good for soil hence no restriction on water use.

2.5.2 The carbonate and Bicarbonate Content of Water

The carbonate and bicarbonate are both important in influencing the soil properties. The ions react with either Ca^{2+} or Mg^{2+} ions in water to precipitate and form calcium carbonate or magnesium carbonate (Bortolini *et al*, 2018). These two products reduce the amount of free calcium and magnesium ions in the soil, therefore enabling sodium ions to complete and occupy the negatively charged exchange site on clay particles which impair soil structure and water infiltration (Hakami *et al*, 2024). This leads to the occurrence of sodium permeability hazards estimated by Residual Sodium Carbonate index as shown in Equation 2 (Tejashvini *et al*, 2024).

$$RSC(Meq/l) = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

2.5.3 Other Irrigation Parameter Index

Other irrigation water quality indices include Soluble Sodium Carbonate, Residual Sodium Carbonate, Magnesium Adsorption Ratio and Permeability Index as shown in Table 2 (Paepae *et al*, 2021)

3. Results and Discussion

3.1 Irrigation Water Quality

The physicochemical characteristics of water samples from the Wami River in Dakawa are summarized in Table 3. All analyzed parameters in both seasons except Mg^{2+} , K^+ , and turbidity, were within the permissible limits set by FAO guidelines for irrigation water (FAO, 2022). The pH values across all sampling points were within the recommended standard range (6.0 – 8.5). During the wet season, pH ranged from 6.83 ± 0.01 to 7.36 ± 0.01 , with a mean of 7.15 ± 0.20 . In dry season, pH was slightly lower, ranging from 6.59 ± 0.01 to 7.21 ± 0.01 , with a mean of 6.88 ± 0.21 (Figure 2). One-way ANOVA revealed a statistically significant seasonal difference in pH ($p = 0.032 < 0.05$), with higher values recorded during the wet season. The elevated pH observed during the wet season may be attributed to the influx of agricultural runoff and other non-point source pollutants, which can introduce alkaline substances into the river. Such increases in pH can negatively affect crop productivity by altering soil chemistry and promoting nutrient leaching (Ling *et al.*, 2017).

In contrast, a study by Mohamed *et al.* (2022) on the Rwizi River in Uganda reported a different seasonal pH pattern. The study observed significantly higher pH values during the wet season at the Kyani, Kakiika, and Nyakayoko sites (average 6.43 ± 0.06) compared to the dry season (6.19 ± 0.06). However, at the Ndiaga station, pH was higher in the dry season (6.31) than in the wet season (5.65). The authors attributed elevated pH levels in both seasons to geological factors

specifically, erosion of parent rocks and sediments as well as anthropogenic inputs such as basic detergents from domestic and industrial wastewater discharged directly into the river.

The EC, an indicator of the total dissolved ion concentration in water, was measured across all sampling sites. EC values in both seasons fell well within the FAO (2022) irrigation guideline of 3000 $\mu\text{S}/\text{cm}$. Seasonal variation was evident: EC ranged from 181 ± 1.41 to 295 ± 0.98 $\mu\text{S}/\text{cm}$ with mean of 242

dry season (Table 3). This pattern may be attributed to the evaporative concentration of ions and continued mineral dissolution during the dry period, whereas wet-season dilution by increased river flow lowers overall ion concentration (Ngabirano *et al.*, 2016). Comparable seasonal trends, though at lower absolute

Table 2: The classification of the irrigation water quality Index

Parameter	Formula	Range	Water class
Sodium Adsorption Ratio (SAR)	$\frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$	<10	Excellent
		10-18	Good/safe
		18-26	Doubtful/moderate
		>26	Unsuitable
Soluble Sodium Carbonate (SSC)%	$\frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100$	<20	Excellent
		20-40	Good
		40-60	Permissible
		60-80	Doubtful
		>80	Unsuitable
Residual Sodium Carbonate (RSC)	$(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$	< 1.25	Good
		1.25-2.5	Doubtful
		>2.5	Unsuitable
Kelly's Ratio (KR)	$\frac{Na^+}{(Ca^{2+} + Mg^{2+})}$	< 1	Good
		>1	Un suitable
Magnesium Adsorption Ratio (MAR)	$\frac{Mg^{2+}}{(Mg^{2+} + Ca^{2+})} \times 100$	< 25%	Suitable
		25-50%	Permissible
		50-75%	Doubtful
		>75%	Unsuitable
Permeability Index (PI)	$\frac{(Na^+ + K^+) + \sqrt{HCO_3^-}}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100$	>75%	Good-class 1
		25-75%	Good-class II
		<25%	Unsuitable -III

$\mu\text{S}/\text{cm}$ during the wet season, and from 325 ± 1.41 to 445 ± 1.41 $\mu\text{S}/\text{cm}$ with mean of 381 ± 38.94 $\mu\text{S}/\text{cm}$ during the dry season. The highest EC was recorded at site P7 in both seasons, while the lowest was at P8 (wet) and P2 (dry). A one-way ANOVA confirmed a statistically significant seasonal difference ($F = 52.66$, $P = 0.00000418$), with consistently higher EC in the

values, were reported for the Rwizi River in Uganda (Mohamed *et al.*, 2022).

TDS exhibited a similar seasonal pattern to EC, increasing from 90.5 ± 0.14 to 147.5 ± 0.01 mg/L (wet)

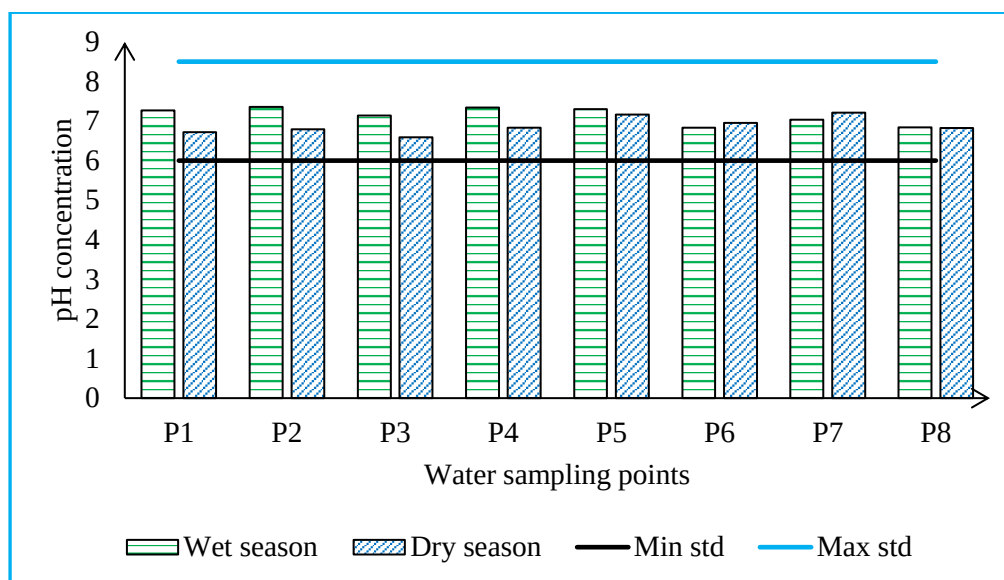


Figure 2: Variation of pH during wet and dry season in Wami river Dakawa

to 162.5 ± 0.01 to 225.5 ± 0.14 mg/L (dry). All recorded value were within the FAO limit of 2000 mg/L (Table 2). In contrast to EC, no significant spatial variation in TDS was observed among the sampling points ($F = 3.49$, $p = 0.082$). A strong positive correlation ($R^2 = 1$) was observed between TDS and EC in both seasons (Table 3). Also, during the wet season, Mg^{2+} showed a strong correlation with both EC and TDS ($R > 0.8$), suggesting that magnesium salts are a primary contributor to salinity in the Wami River during this period.

In the wet season, water temperature averaged 23.9 °C, while in during dry season significant increase to an average of 27.5 °C was recorded, reflecting expected seasonal climatic variation. Turbidity was markedly higher during the wet season, with values ranging from 13 to 1732 Formazin Attenuation Units (FAU) and a mean of 910 FAU which exceed FAO guideline of 5 FAU. The elevated turbidity during wet season can be attributed to increased surface runoff transporting suspended sediments into the river. In the dry season, turbidity decreased substantially to a mean of 296 FAU, though it remained above the recommended limit.

Regarding major cations, Na^+ and Ca^{2+} concentrations were within safe limits in both seasons. K^+ levels exceeded the FAO guideline (2 mg/L) at all

sampling points, with particularly high concentrations in the wet season with mean of 100 mg/L. This is likely linked to leaching from potassium-rich fertilizers applied in the surrounding agricultural catchment (Ara & Kundu, 2019). The most notable cation anomaly was magnesium (Mg^{2+}). Its concentration was consistently high, ranging from 119.92 to 174.87 mg/L and significantly exceeding the FAO limit of 60 mg/L in all samples. Concentrations were slightly higher and less variable in the dry season. Potential sources include weathering of magnesium-rich parent rocks in the catchment and runoff from agricultural inputs (Potasznik & Szymczyk, 2015).

For major anions, SO_4^{2-} and HCO_3^- concentrations were within acceptable limits. NO_3^- levels were within the safe limit (10 mg/L) during the wet season but exceeded it at several points (P2, P3, P5, P8) during the dry season, with a maximum of 24.5 mg/L. This pattern suggests a dilution effect in the wet season and a potential point source or concentrated leaching of nitrogenous fertilizers during the dry period. Ammonium (NH_4^+) levels remained low and within the permissible limit across both seasons.

Meanwhile, major cations, Na^+ ranged from 20.37 ± 0.01 to 68.12 ± 0.04 mg/L in wet season while during dry season, it varied between 46.90 ± 0.35 and 185.0 ± 0.14 mg/L with average mean concentration of $81.78 \pm$

Table 3: Physicochemical characteristics of water quality in samples collected during the wet and dry season

S/N		pH	Temp (°C)	EC ($\mu S/cm$)	TDS (mg/L)	Turbidity (FAU)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	NH ₄ ⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	HCO ₃ ⁻ (mg/L)
P1	Wet	7.27±0.01	23.8±0.14	229±1.41	114.5±0.71	1252±0.71	19.2±0.14	0.90±0.01	1.25±0.03	68.12±0.04	92.08±0.02	39.89±0.02	147.66±0.59	61.99±0.01
	Dry	6.72± 0.03	27.0±1.41	394±2.83	197.0±1.06	350±1.41	22.0±2.82	0.50±0.01	0.85±0.01	46.90±0.35	42.44±0.02	21.90±0.04	174.21±0.57	70.15±0.01
P2	Wet	7.36± 0.01	23.8±0.02	254±1.27	127.0±0.21	1732±0.56	23.8±0.07	0.01±0.01	0.56±0.01	65.36±0.02	87.16±0.04	48.08±0.01	160.46±0.02	137.25±0.01
	Dry	6.79±0.01	27.0±0.14	325±1.41	162.5±0.01	290±0.14	27.0±1.41	24.5±0.35	0.63±0.01	79.39±0.01	43.96±0.01	30.17±0.01	174.32±0.02	82.35±0.01
P3	Wet	7.14±0.02	23.6±0.14	254±2.82	127.0±1.41	1709±2.12	15.5±0.14	0.70±0.14	0.66±0.01	49.19±0.08	107.93±0.01	15.08±0.01	154.78±0.03	57.01±0.04
	Dry	6.59±0.01	27.0±1.76	402±1.41	201.0±0.64	374±1.41	23.0±1.97	11.7±0.14	0.57±0.01	62.53±0.01	49.78±0.03	28.41±0.01	174.87±0.02	58.32±0.01
P4	Wet	7.34±0.01	24.4±0.02	257±0.18	128.5±0.06	571±0.07	16.7±0.04	1.60±0.01	0.12±0.01	45.36±0.01	108.05±0.02	21.96±0.01	150.40±0.01	53.02±0.05
	Dry	6.83±0.01	27.0±0.14	375±0.14	187.5±0.01	356±0.14	30.6±0.02	0.40±0.01	0.68±0.01	60.12±0.01	43.39±0.01	27.54±0.01	174.34±0.03	31.72±0.01
P5	Wet	7.30±0.02	23.9±0.04	295±0.98	147.5±0.01	181±0.10	14.3±0.03	0.70±0.01	0.53±0.01	44.27±0.01	83.41±0.01	21.14±0.01	165.87±0.01	61.02±0.01
	Dry	7.16±0.02	27.1±0.21	385±1.41	192.5±0.14	121±0.42	28.0±1.41	12.5±0.14	0.46±0.02	185.43±0.02	62.62±0.01	75.70±0.14	171.40±0.14	50.33±0.01
P6	Wet	6.83±0.01	23.9±0.14	249±1.41	124.5±0.28	1522±1.41	27.9±0.14	2.10±0.10	0.77±0.01	59.66±0.02	57.83±0.01	11.49±0.01	166.87±0.01	52.01±0.01
	Dry	6.95±0.01	28.3±0.14	330±2.83	165.0±1.41	273±1.41	40.2±0.14	1.40±0.14	0.64±0.01	77.54±0.01	43.79±0.01	36.47±0.01	174.11±0.01	37.82±0.01
P7	Wet	7.03±0.01	23.6±0.14	274±1.41	137.0±1.41	300±1.41	36.8±0.14	0.90±0.14	0.06±0.02	48.42±0.01	116.17±0.02	11.49±0.01	157.01±0.01	75.02±0.01
	Dry	7.21±0.01	27.9±0.14	445±1.41	222.5±0.14	320±2.12	18.7±0.14	7.60±0.14	0.78±0.01	75.36±0.02	49.14±0.01	29.31±0.01	174.28±0.01	183.2±0.14
P8	Wet	6.84±0.01	23.4±0.14	181±1.41	90.5±0.14	13±1.41	21.8±0.14	0.60±0.13	0.72±0.01	20.37±0.01	146.83±0.01	35.10±0.14	119.92±0.01	97.02±0.02
	Dry	6.82±0.01	29.4±0.14	392±1.41	196.0±1.41	286±1.41	25.0±0.98	15.60±0.14	0.67±0.1	66.96±0.01	42.74±0.01	31.27±0.01	168.5±0.14	56.43±0.01
FAO, 2022-Guideline		6.0-8.5	NS	3000	2000	5	960	10	5	920	2	400	60	610

43.23 Which is within the recommended FAO guideline of 920 mg/L. Also, K^+ varied from 57.83 ± 0.01 to 146.83 ± 0.01 mg/L in wet season, and $42.44 \pm$

observed during dry season, likely due to increase of evaporation in the river, which concentrate dissolved solid in river. In contrast, the elevated Mg^{2+}

Table 4: Pearson's correlation of water physico-chemical parameter during wet and dry season
a) Wet season

	pH	Temp	EC	TDS	Turbidity	SO_4^{2-}	NO_3^-	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-
pH	1												
Temp	0.547	1.000											
EC	0.493	0.438	1.000										
TDS	0.493	0.438	1.000	1.000									
Turbidity	0.171	0.071	0.064	0.064	1.000								
SO_4^{2-}	-0.496	-0.316	0.011	0.011	-0.066	1.000							
NO_3^-	-0.379	0.509	0.075	0.075	0.006	0.138	1.000						
NH_4^+	-0.106	-0.293	-0.470	-0.470	0.409	-0.313	-0.074	1.000					
Na^+	0.435	0.316	0.391	0.391	0.755	0.114	0.071	0.319	1.000				
K^+	-0.191	-0.448	-0.540	-0.540	-0.566	0.010	-0.387	-0.246	-0.758	1.000			
Ca^{2+}	0.402	-0.101	-0.449	-0.449	0.156	-0.236	-0.633	0.442	0.178	0.145	1.000		
Mg^{2+}	0.338	0.424	0.876	0.876	0.438	0.101	0.227	-0.180	0.674	-0.850	-0.374	1.000	
HCO_3^-	0.132	-0.361	-0.265	-0.265	0.109	0.226	-0.745	-0.024	0.014	0.224	0.729	-0.217	1.000

0.01 to 62.62 ± 0.01 mg/L in dry season which exceed the permissible FAO standard of 2 mg/L. The K^+ at all sampling point exceeded the FAO recommended guideline during wet season, likely resulting from agricultural runoff, erosion of sediments and geological rocks rich in potassium ions (Ara *et al*, 2019). Ca^{2+} during wet season ranged from 11.49 ± 0.01 to 48.08 ± 0.01 mg/L, while during the dry season, Ca^{2+} ranged from 21.90 ± 0.04 to 75.70 ± 0.14 mg/L, remaining within the recommended FAO guideline. Also, Mg^{2+} ion also varied seasonally, increasing from 119.92 ± 0.01 to 168.87 ± 0.01 mg/L during wet season and ranging from 168.50 ± 0.14 to 174.87 ± 0.02 mg/L during the dry season.

Notably Mg^{2+} concentration exceeded the permissible FAO limit of 60 mg/L at all sampling point in both seasons. Higher magnesium concentration was

concentration during wet season were primarily attributed with weathering of magnesium-rich rocks, sediments and runoff from agricultural land and other anthropogenic contaminants (Potasznik *et al*, 2015). The Findings reported by Adeyemi *et al* (2019) indicated higher concentration of Mg^{2+} in wet season compared to dry season. In wet season, Mg^{2+} ranged from 17 to 18 mg/L with mean concentration of 17.67mg/L, while in dry season, the Mg^{2+} ranged from 8 and 9 mg/L with mean value of 8.33mg/L underlying with the permissible standard resulting water suitable for irrigation.

Ammonium (NH_4^+) ranged from 0.12 ± 0.01 to 1.25 ± 0.03 mg/L with mean concentration of 0.584 ± 0.38 mg/L during wet season, while in dry season, NH_4^+ level ranged from 0.46 ± 0.02 to 0.85 ± 0.01 mg/L with mean concentration of 0.66 ± 0.12 mg/L. NH_4^+

concentration in both seasons were within the permissible FAO guideline 2022 of 5 mg/L. Maximum NH_4^+ concentration was observed in wet season compared to the dry season at most sampling point except at P2, P6 and P7. These were likely to be

while in dry season, NO_3^- ranged from 0.4 to 24.5 mg/L. During wet season, NO_3^- at sampling point were within acceptable standard of 10 mg/L. However, in n dry season, NO_3^- at P2, P3, P5 and P8 exceeded the recommended FAO guideline of 10mg/l while other

Table 4(b): Pearson's correlation during dry season

	pH	Temp	EC	TDS	Turbidity	SO_4^{2-}	NO_3^-	NH_4^+	Na^+	K^+	Ca_2^+	l
pH	1.000											
Temp	0.193	1.000										
EC	0.262	0.075	1.000									
TDS	0.262	0.075	1.000	1.000								
Turbidity	-0.640	-0.103	0.194	0.194	1.000							
SO_4^{2-}	0.038	0.144	-0.778	-0.778	-0.279	1.000						
NO_3^-	-0.064	0.071	-0.209	-0.209	-0.293	-0.248	1.000					
NH_4^+	-0.118	0.116	0.311	0.311	0.641	-0.363	-0.440	1.000				
Na^+	0.621	-0.136	-0.046	-0.046	-0.942	0.153	0.271	-0.740	1.000			
K^+	0.539	-0.283	0.272	0.272	-0.732	-0.118	0.190	-0.688	0.905	1.000		
Ca_2^+	0.583	-0.081	-0.067	-0.067	-0.944	0.232	0.196	-0.762	0.990	0.887	1.000	
Mg_2^+	-0.186	-0.702	-0.096	-0.096	0.501	0.031	-0.324	0.248	-0.335	-0.155	-0.381	1
HCO_3^-	0.483	0.065	0.607	0.607	0.140	-0.655	0.144	0.446	-0.097	0.070	-0.201	(

influenced by agricultural runoff containing nitrogenous from organic fertilizers leaching to the river (Alavaisha *et al*, 2019). High NH_4^+ -N concentration at P2, P6 and P7 was maximum in dry season than wet season. This might be due to lower dilution effect of ammonium input and deposition of organic waste such as dead plants, sewage and animal waste (Zhou *et al*, 2022). Additionally, ANOVA revealed that no statistically significance difference of Ammonium concentration between the sampling point in both seasons ($P = 0.594$) > 5%.

During wet season, SO_4^{2-} ranged from 14.3 to 36.8 mg/L while in dry season ranged between 18.7 to 40.2 mg/L. The Findings in both seasons respectively were within the recommended FAO guideline of 960 mg/L. NO_3^- in wet season varied between 0.01 to 2.10 mg/L

sampling point remained within acceptable standard (10 mg/L). Maximum value of NO_3^- were observed during dry season than wet season due to dilution effect that lowers the concentration of contaminant from agrochemicals, nutrients and other wastewater containing nitrate and sulphate during the wet season (Nalumenya *et al*, 2024). Bicarbonate (HCO_3^-) ranged from 52.01 ± 0.01 to 137.25 ± 0.01 with mean of 74.29 ± 29.41 in wet season, while in dry season, HCO_3^- varied from 37.82 ± 0.01 to 183.20 ± 0.14 mg/L reflecting seasonal variability in river chemistry.

3.2 Results from Pearson Correlations

Pearson's correlation analysis was performed to identify relationships between physicochemical parameters in the Wami River during the wet and dry

seasons (Table 3). Strong and moderate correlations revealed important connections between ions and potential common sources of water quality variation. A strong positive correlation ($R^2 = 1$) was observed

moderately with turbidity ($R = 0.755$), suggesting that Na^+ transport is associated with sediment load and surface runoff during the wet season. The correlation between (HCO_3^-) and (Ca^{2+}) ($R = 0.729$) points to the

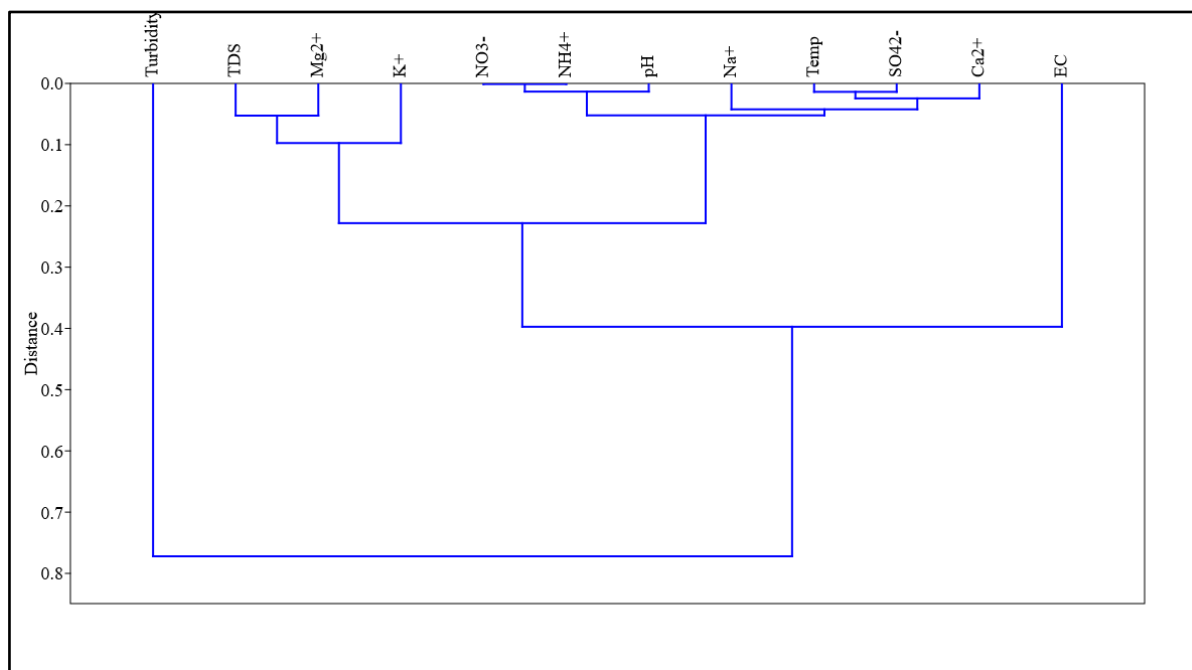


Figure 3: Dendrogram of water quality variables in wet season

between EC and TDS, confirming that TDS is the primary driver of conductivity, as expected. Notably, magnesium (Mg^{2+}) showed a strong positive correlation with both EC ($R = 0.876$) and TDS ($R = 0.876$), indicating that Mg^{2+} salts are a major contributor to the salinity of the river during the rainy period (Table 4a). This is consistent with the significantly elevated Mg^{2+} concentrations measured. A strong negative correlation was found between Mg^{2+} and K^+ ($R = -0.850$), which may suggest competitive ion dynamics or distinct, inversely related source inputs.

Moderate positive correlations provide further insight into parameter linkages. The relationship between pH and temperature ($R = 0.547$) may reflect biological or geochemical activity influenced by warmth. The correlation between NO_3^- and temperature ($R = 0.509$) could indicate microbial mineralization processes. Furthermore, Na^+ correlated

common origin of temporary water hardness, likely from the dissolution of carbonate minerals (e.g.,

In dry season, the strong link between EC and TDS remained ($R^2 = 1$) as presented in Table 4(b), with different dominant relationships emerged. Very strong positive correlations were observed among Na^+ , K^+ , and (Ca^{2+}) (R values between 0.887 and 0.990). This suggests a common geogenic or anthropogenic source for these cations during the dry period, potentially from evaporative concentration of base cations or a specific pollution input. A strong negative correlation was identified between pH and turbidity ($R = -0.640$), which may imply that suspended sediments or associated colloidal matter buffer or lower the pH. In dry season, moderate correlations also shifted. A positive correlation between NH_4^+ and turbidity ($R = 0.641$) may link organic matter or fine sediments with nutrient retention. Bicarbonate (HCO_3^-) showed a moderate positive correlation with EC ($R = 0.607$),

Table 5 (a): Irrigation water quality parameter indices during wet season

	pH	EC ($\mu S/cm$)	Na ⁺ meq/L	K ⁺ meq/L	Ca ²⁺ meq/L	Mg ²⁺ Meq/L	HCO ₃ ⁻ meq/L	SAR	MAR (%)	KI	SSC (%)	PI (%)
P1	7.27	229	2.962	2.361	1.994	12.31	1.016	1.108	86.06	0.207	27.12	32.26
P2	7.36	254	2.842	2.234	2.404	13.37	2.250	1.012	84.76	0.180	24.35	31.54
P3	7.14	254	2.138	2.767	0.754	12.89	0.934	0.819	94.47	0.157	26.44	31.65
P4	7.34	257	1.972	2.770	1.098	12.53	1.000	0.755	91.94	0.145	25.81	31.26
P5	7.30	295	1.924	2.139	1.057	13.82	1.197	0.705	92.89	0.129	21.45	27.23
P6	6.83	249	2.594	1.483	0.575	13.91	0.852	0.964	96.03	0.179	21.96	26.94
P7	7.07	252	2.105	2.979	1.575	13.98	1.229	0.754	89.87	0.135	24.63	30.00
P8	6.96	275	0.886	3.765	1.755	9.993	1.590	0.366	85.06	0.075	28.36	36.05
Mean	7.16	258.13	2.178	2.562	1.402	12.85	1.258	0.810	90.14	0.151	25.02	30.86
Std.dev	0.193	19.45	0.656	0.676	0.635	1.319	0.462	0.229	4.403	0.040	2.417	2.914
Min	6.83	229	0.886	1.483	0.575	9.993	2.852	0.366	84.76	0.075	21.45	26.94
Max	7.34	295	2.962	3.765	2.404	13.98	2.250	1.108	96.03	0.207	28.36	36.05

highlighting its increased role in salinity during the dry season. The positive correlations of pH with Na⁺, K⁺, and Ca²⁺ (R values of 0.583 - 0.621) further support the influence of concentrated base cations on the alkaline character of dry-season water.

The shift in correlation patterns between seasons underscores the changing dominant processes controlling water chemistry. The wet season is characterized by runoff-driven inputs, where Mg²⁺ and sediment-associated ions (Na⁺) are prominent. In contrast, the dry season reflects an evaporative-concentration regime where a suite of base cations

(Na^+ , K^+ , Ca^{2+}) become co-dominant and more strongly influence pH and salinity. These correlation structures support the seasonal variations observed in individual parameter concentrations and highlight the complex

specifically (NH_4^+ , Mg^{2+}) vs Turbidity, (K^+ + Na^+) vs pH, HCO_3^- vs EC revealed moderate positive correlation more than 0.5 as shown in Table 4b. Any variations or changes in major cations and other water

Table 5(b): The Irrigation water quality parameter indices during dry season in Dakawa Wami river

	pH	EC ($\mu\text{S}/\text{cm}$)	Na^+ (meq/L)	K^+ (Meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	HCO_3^- meq/L	SAR	MAR (%)	KI	SSC (%)	PI (%)
P1	6.72	394	2.038	1.088	1.095	14.53	1.150	0.729	92.99	0.130	16.67	28.23
P2	6.79	325	3.452	1.12	1.509	14.53	1.350	1.219	90.59	0.215	22.18	27.82
P3	6.59	402	2.718	1.276	1.42	14.57	0.956	0.961	91.12	0.169	19.99	24.88
P4	6.83	375	2.620	1.112	1.377	14.53	0.520	0.929	91.34	0.165	19.00	22.68
P5	7.16	385	8.062	0.16	3.785	14.28	0.825	2.682	9.05	0.446	31.28	34.73
P6	6.95	330	3.372	1.122	1.824	14.51	0.620	1.180	88.83	0.206	21.58	25.36
P7	7.21	445	3.277	1.260	1.466	14.52	3.00	1.159	90.83	0.205	22.11	30.55
P8	6.82	392	2.912	1.096	1.564	14.04	0.925	1.043	89.98	0.187	20.44	25.34
Mean	6.884	381	3.556	1.029	1.755	14.44	1.168	1.238	89.32	0.215	21.66	27.45
Std.dev	0.212	38.943	1.879	0.359	0.845	0.184	0.787	0.605	4.323	0.097	4.297	3.808
Min	6.59	325	2.038	0.16	1.095	14.28	0.520	0.729	88.83	0.130	16.67	22.68
Max	7.21	445	8.062	1.276	3.785	14.57	3.00	2.682	92.99	0.446	31.28	34.73

interplay between natural weathering and anthropogenic influences in the catchment (Mallick

In dry season, TDS vs EC, (K^+ + Ca^{2+}) vs Na^+ and Mg^{2+} vs K^+ cations indicated the strong positive correlation of more than 0.8, while other ions

parameters showing a positive correlation may impact water quality parameter indices thereby affecting River's suitability for Irrigation purpose (Mallick *et al*, 2022).

3.2.1 Hierarchical Cluster Analysis of Water Quality Parameters

The hierarchical cluster analysis (HCA) dendrogram for the wet season (Figure 3) reveals distinct groupings

a common origin likely linked to agricultural runoff and soil weathering. The other major cluster further subdivides, grouping NO_3^- with NH_4^+ reflecting a unified nitrogen cycle influence and pairing pH with

Table 6: Summary irrigation water quality parameter findings to both wet and dry season

Irrigation parameter	Per-Season	Results	Permissible FAO 2013	Irrigation condition
pH	Wet	7.16 ± 0.193	6.5-8.5	Permissible
	Dry	6.88 ± 0.212		
EC ($\mu\text{S}/\text{cm}$)	Wet	242.087 ± 52.45	<250 Excellent	Good
	Dry	381 ± 38.94	250-750 Good 750-2000 Permissible 2000-3000 Doubtful	
TDS (mg/L)	Wet	121.043 ± 26.23	<1000 non-saline	Non-saline
	Dry	190.5 ± 19.47	1500-3000 Slightly saline 3000-10000 Moderate saline >10000 Very saline	
SAR	Wet	0.810 ± 0.61	<10 Excellent	Excellent
	Dry	1.238 ± 0.61	10-18 Good 19-26 Moderate (Doubtful) >26 Unsuitable	
MAR	Wet	90.14 ± 4.403	<25% Suitable	Unsuitable
	Dry	89.32 ± 4.323	25-50% Permissible 50-75% Doubtful >75% Unsuitable	
KI	Wet	0.151 ± 0.04	<1 Good	Good
	Dry	0.215 ± 0.097	>1 unsuitable	
SSC	Rainy	25.02 ± 2.417	<20 % Excellent	Good
	Dry	21.66 ± 4.297	20-40 % Good 40-60% Permissible 60-80% Doubtful. >80 % Unsuitable	
PI (%)	Wet	30.62 ± 2.93	>75% Good class I	Good Class II
	Dry	27.45 ± 3.808	25-75 Good class II <25 Unsuitable class III	

of water quality parameters, indicating shared sources or controlling processes. Two primary clusters are evident: one associates Na^+ , K^+ , and HCO_3^- , suggesting

temperature, which is often governed by temperature-dependent biogeochemical equilibria. A particularly strong linkage between TDS and Mg^{2+} statistically

confirms that Mg^{2+} salts are a dominant component of salinity. Turbidity remains the most independent variable, connecting last in the dendrogram, which underscores that suspended sediment transport is governed by physical erosion processes distinct from the dissolved ion chemistry.

Overall, the HCA visually organizes the parameters into meaningful functional groups: a salinity group

Indices, Soluble Sodium Carbonate and Permeability Index were evaluated as detailed below:

3.3.1 Sodium Adsorption Ratio (SAR)

SAR ranged from 0.366 to 1.108 with mean concentration 0.810 ± 0.229 during wet season while in dry season varied from 0.729 to 2.682 with average mean concentration of 1.238 ± 0.605 . Sodium Adsorption Ratio along the sampling point were less

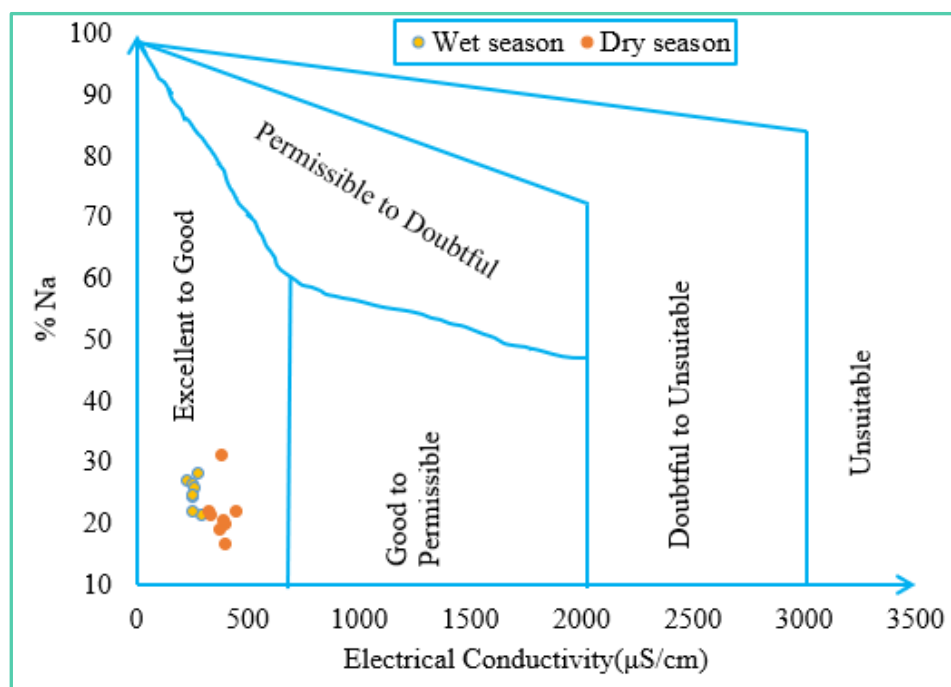


Figure 4: The Wilcox diagram for Perennial River in Dakawa during wet and season

(Mg^{2+} , TDS), a cation-bicarbonate group (Na^+ , K^+ , HCO_3^-), a nitrogen group (NO_3^- , NH_4^+), and a physical-kinetic group (pH, temperature). This structure confirms that spatial water quality variation in the Wami River is systematic and driven by integrated geological weathering, agricultural inputs, and seasonal hydrological processes (Leonard *et al.*, 2023).

3.3 Irrigation Water Quality Parameter Indices

In assessing the suitability of water quality for irrigation, indices parameters such as Sodium Adsorption Ratio, Magnesium Adsorption Ratio, Kelly

than 10 ($SAR < 10$) indicating water is excellent and suitable for irrigation purpose in Dakawa. Findings in both wet and dry season were within the permissible FAO guideline 2013, making the water from river in Dakawa suitable for irrigation purpose. High value of magnesium (Mg^{2+}) and calcium in each season reduces the effect of sodium in water therefore maintaining the soil structure as well as infiltration rate (Paepae *et al.*, 2021).

Similar to study done by Mukiza *et al.* (2021), SAR varied from 0.716 to 2.181 during dry season while in wet season, SAR ranged from 0.559 to 2.428 with average mean of 1.50 and 1.601 in dry and wet season,

in both condition the sodium adsorption value was within the acceptable FAO standard making water considered as excellent for irrigation purpose.

3.3.2 Magnesium Adsorption Ratio (MAR)

SAR is important for determining the MAR as it affects irrigation under high concentration of magnesium in water, causing effect to soil quality and crop yield due to high alkaline in water. MAR ranged

This damage the crops and affect both productivity and soil structure due to high absorption of Mg^{2+} content (Hakami *et al*, 2024).

3.3.3 Kelly Index (KI)

In wet season, the KI ranged from 0.075 to 0.207 meq/L with mean concentration of 0.151 ± 0.04 while in dry season, KI varied between 0.130 to 0.446 as shown in Table 5(a). KI Findings in both seasons

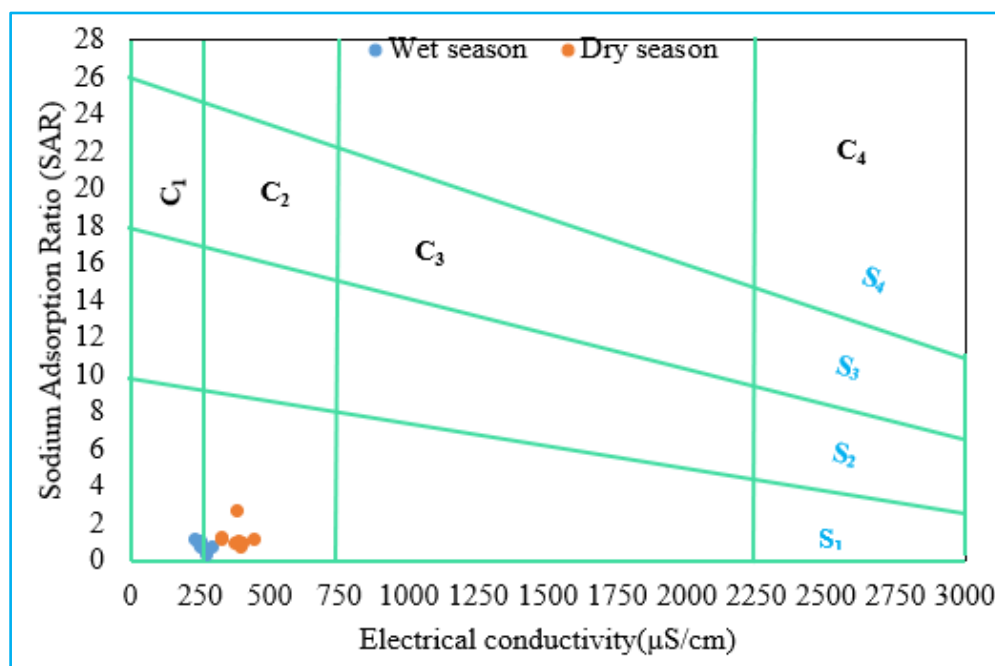


Figure 5: The USSL diagram for highlighting irrigation water quality based on electrical conductivity and sodium adsorption ratio during wet and dry season

from 84.8 to 96.03% in wet season while during dry season, MAR varied between 88.83 to 92.99 with mean concentration of 89.32 ± 4.323 . The computed MAR in both season respectively were compared with FAO guideline 2013 to determine the suitability of water for irrigation. The computed MAR in wet and dry season followed within unsuitable range. High Magnesium concentration in both seasons was predicted to be associated with geological mineral deposit rich in Magnesium and organic fertilizers containing Mg^{2+} which hydrolysed in water and causing detrimental effects to the crops grown by leading to leaf necrosis.

respectively, were less than 1 ($KI < 1$) reflecting water is suitable (good) for irrigation. Similar to the findings collected by Assiel *et al* (2022) who conducted the study on assessment of irrigation water quality and suitability for Irrigation of Rugende dam, recorded low value of Kelly Index (0.2) and found to be within the acceptable standard (< 1). Revealing that, water was safe and suitable for irrigation purpose and free from non-alkali hazard (Adeyemi *et al*, 2019)

3.3.4 Soluble Sodium Carbonate (SSC)

SSC is also the important parameter in assessing the water quality for irrigation. In wet season, SSC concentration ranged from 21.45 to 28.36% with mean concentration of 25.02 ± 2.417 while during dry season as shown in Table 5(b), SSC varied from 16.67 to 31.28% with mean value of 21.66 ± 4.297 . SSC in both seasons ranged within the permissible FAO permissible guideline of 2013 (20 - 40%) categorizing water as good and suitable for irrigation as specified in Table 6.

3.3.5 Permeability Index (PI)

The permeability index (PI) ranged from 26.94 to 36.35 % with mean concentration of 30.86 ± 2.914 in wet season while in dry season ranged between 22.68 and 34.73% which is within a standard range of 25-75% (Good class II) as shown in Table 6, making water suitable for irrigation in agricultural plantation as recommended by FAO guideline 2013. Similar findings were observed by Mohamed *et al*, (2024) who conducted the study along Nile River in Rosetta branch. The permeability index ranged from 68.32 to 85.97% with average mean of $76.25 \pm 6.49\%$ and therefore water was considered good for irrigation in agricultural farms.

3.4 Salinity Hazards

The Wilcox diagram as seen in (Figure 4) described the interaction of electrical conductivity (EC) and SSC depicts for assessing the suitability of water quality for irrigation. The diagram was classified into five (5) components, which include excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable phase. The corresponding irrigation indices findings for all water sample during wet season fell into excellent to good classification zone with medium irrigation condition for Sodium Soluble Carbonate (%Na) and (EC) revealing the water from Wami River in Dakawa was suitable for irrigation.

During the dry season, 37.5% of water samples (3 samples) fell in the line between 10 and 20%

classification range, 50% of water samples (4) lied between 20 to 30% of SSC while the remaining 1 water sample (12.5%) depicted between 30 to 40 % of SSC. All water sample findings developed at the similar EC between 0 to 750 $\mu\text{S}/\text{cm}$ signifying the water is suitable for irrigation. The overall data for all water samples collected fell in the classification zone of excellent to good reflecting the water from Wami river is suitable (Ravi *et al*, 2023)

The USSL diagram presented in Figure 5 was used in assessing the suitability of water for irrigation in the study area by considering the EC and SAR of all water samples collected during wet and dry season. The diagram was classified into four (4) components of low (1), medium (2), high (3) and very high (4) for salinity (S) and sodium hazard (C). The Findings displayed in the USSL diagram as shown in Figure 5, it can be seen that 25% of water sample collected during wet season fell in $\text{C}_1\text{-S}_1$, while the remaining 75% of water sample in similar season depicted in $\text{C}_2\text{-S}_1$ zone indicating low salinity in water with low to medium sodium hazard. All water samples collected during the dry season, fell in $\text{C}_2\text{-S}_1$ classification zone revealing low salinity of water with medium sodium (Boukich *et al*, 2025). Low to medium risk level of sodium hazard was possibly associated with lower concentration of sodium ions across all water sampling point in both season as indicated in Table 3 (Arup *et al*, 2022). The Na^+ concentration were within the permissible value of 950 mg/l.

4. Conclusions

All water samples from the sampling station during wet and dry season varied within the acceptable recommended limit. The irrigation water quality parameter indices except Magnesium Adsorption Ratio (MAR) ranged from good to excellent reflecting, water is suitable for irrigation which was also revealed by Wilcox diagram. High magnesium Adsorption Ratio (90.14 ± 4.403 , 89.32 ± 4.323) was observed in both seasons due to high magnesium content in water which may affect crops by causing leaf necrosis, lowering water infiltration capacity to the soil, causing poor

growth of rice crops and ultimately reduce the crops yield. The study recommends the adoption of precision fertilization practices among farmers, including regular soil testing, the use of organic fertilizers such as farmyard manure and composite manure, and the application of targeted fertilizer rates based on crop and soil requirement. These practices can help minimize excessive nutrient accumulation and reduce the risk of water contamination. Furthermore, the study recommends the establishment of additional vegetative buffer strips along the edge of farm fields and the banks of the Wami River in Dakawa to reduce the transport of excess magnesium into the river through soil erosion and the weathering of magnesium -rich parent rocks. It is also recommended to grow crops tolerant to high magnesium concentration and adoption of efficient irrigation system (drip, sprinklers) to subsequently improve crop productivity. The land use and other development human activities in water catchment areas should incorporate water quality conservation and management into their planning. Since the water quality along Wami -Dakawa River is suitable for Irrigation, it is important to sustain its quality for present and future generations through continual water quality monitoring by mandated Institution.

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