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Water quality of coffee plantations during pre-monsoon and post-monsoon seasons in the western ghats, Ponnampet, Kodagu district, Karnataka, India

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Abstract
Surface water resources, crucial for irrigation in the coffee-growing areas of Ponampet Taluk, Kodagu District, are deteriorating due to changes in the Western Ghats caused by agricultural and human activities. This study assessed water quality by collecting 50 surface water samples from various coffee-growing areas during the pre-monsoon and post-monsoon seasons. The samples were analyzed for physicochemical properties essential for irrigation. Both seasons' samples showed slightly alkaline characteristics, with all anionic and cationic indicators within BIS (2012) guidelines. Water suitability for irrigation was evaluated using parameters such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), magnesium hardness (MH), Kelley's index, permeability index (PI), and percent sodium. Most samples were deemed suitable based on SAR and RSC values, with percent sodium and SSP ranging from excellent to permissible. Overall study indicates the post-monsoon water samples were less contaminated and better suited for irrigation compared to pre-monsoon samples.

Keywords: Water quality, pre-monsoon, post-monsoon, anions, cations and water quality indices

Introduction

Water quality is a crucial factor influencing agricultural activities and significantly impacts crop cultivation. Research in ecology and agriculture highlights the importance of water due to its essential role in sustaining human health and ecosystem integrity. Without access to high-quality water, achieving sustainable agriculture and maintaining overall life viability becomes unattainable (Thierfelder and Wall., 2009) [46]. To meet the rising food demands of a growing global population, the use of high-yield crop varieties has become prevalent. These varieties often rely on pesticides and fertilizers, which exacerbate pollution in the surrounding environment. In advanced agricultural practices, the risk of water contamination due to agricultural activities cannot be excluded (Tully and Lawrence., 2011) [47]. Water quality is a critical resource for both agricultural and industrial activities and is fundamental to ecological sustainability; progress in these areas depends on its ample availability and high quality. Although water is a fundamental necessity for agriculture, contamination frequently occurs due to the excessive use and mismanagement of agrochemicals (Lu *et al*., 2015) [25]. Excess runoff of fertilizers and pesticides, commonly used in crop cultivation, is a primary contributor to water contamination. Although this type of contamination is classified as non-point source pollution, its remediation and mitigation are challenging. Consequently, effective prevention and sustainable management practices are essential (Novotny., 1999) [28].

This study investigates the impact of modern agricultural practices on water quality in coffee plantations situated within the ecologically sensitive Western Ghats region. The Western Ghats, designated as one of the world's biodiversity hotspots, supports a diverse array of endemic plant and animal species (Raghavendra and Venkatesha., 2020) [32]. Coffee cultivation is integral to preserving the region's unique biodiversity and is crucial for the socio-economic development of the remote hill areas in Karnataka, India. The expansion of coffee plantations, often at the expense of dense forest cover, is closely tied to rising global coffee market demand, which increased by 10% between 1991 and 2002 (Ambinakudige and Choi., 2009) [4]. Therefore, the primary aim of this study was to assess the water quality in perennial coffee plantations within the ecologically sensitive Western Ghats of Karnataka, India.

Materials and Methods

Study area: This study was conducted in Ponnampet taluk, Kodagu district, Karnataka, India, at coordinates 12°12'0" N latitude and 75°54'0" E longitude. Located in southern India, the region experiences a tropical climate that transitions to montane sub-tropical conditions at higher elevations. The area is noted for its red lateritic soils. Summer temperatures typically range from 25.5°C to 28.6°C, while winter temperatures fall between 12°C and 15°C. The region receives annual precipitation ranging from 1126 mm to 2500 mm. This overview highlights the key geographical and climatic features of the study area in Ponnampet taluk, Kodagu district.

Collection and analysis of water samples

A total of 50 water samples were assessed, representing water bodies from coffee plantations in Ponnampet taluk, Kodagu district. The samples were collected in 1000 mL plastic bottles, which were thoroughly rinsed with surface water before collection to ensure cleanliness. After collection, the samples were transported to the laboratory and stored at 4 °C. Half of the samples were acidified according to the standard protocol described by APHA (2005) [5] for heavy metal analysis, while the other half was used for chemical water quality analysis. The chemical parameters were analyzed following standard procedures (Table 1).

Table 1: Analysis of chemical properties in the surface water bodies

Paraneters	Analytical method / instrument used	Unit
General Parameters		
pH	Combined water analyzer (Systronics, Model-371, india).	-
Electrical Conductivity		$\mu S\ L^{-1}$
Total Dissolved solids		$mg\ L^{-1}$
Total Hardness	$4.1\ (Mg^{2+}) + 2.5\ (Ca^{2+})$	$mg\ L^{-1}$
Major Anions		
Bicarbonate and Carbonate	Volumetric Method	$mg\ L^{-1}$
Chloride	Titrimetric Method	$mg\ L^{-1}$
Nitrates	Chronotropic acid method	$mg\ L^{-1}$
Sulphate	Turbiometric Method	$mg\ L^{-1}$
Phosphates	Olsen's extractant	$mg\ L^{-1}$
Major Cations		
Calcium, Magnesium, Pottasium, Sodium	Inductively coupled plasma optical Emission spectrometry (ICP-OES, Ametek-Spectrogenesis, Germany)	$mg\ L^{-1}$

Irrigation Water Quality Parameters (IWQP)

Irrigation water quality assessment primarily denotes various mineral compositions of water. It is primarily meant for the assessment of water quality for irrigation purposes because the chemical composition of irrigation water directly or indirectly affects nutrient availability and crop yields (Khalid, 2019) [20]. Irrigation water quality is mainly assessed by sodium absorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), sodium percent (Na%), permeability index, magnesium absorption ratio (MAR) and Kelley's index (KI) or Kelley's ratio.

Sodium Adsorption Ratio (SAR)

SAR was calculated by taking a concentration of Ca, Mg and Na in irrigation water samples (Richards, 1954) [39] mentioned below.

$$\mathbf{SAR} = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

Residual Sodium Carbonate (RSC)

RSC was calculated by taking a concentration of (CO_3^{2-} + HCO^3) and (Ca^{2+} + Mg^{2+}) in irrigation water samples (Richards, 1954) [39] mentioned below.

$$RSC = (HCo_3^- + Co_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Soluble Sodium Percentage (SSP)

Wilcox (1955) [49] used the sodium percentage and specific conductance in the groundwater in evaluating its suitability for irrigation. Sodium percentage determines the ratio of sodium concentration to the concentration of the total cations (sodium, potassium, calcium and magnesium).

$$SSP = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)}$$

Sodium percent water

Percent Sodium concentration is a factor to assess its suitability for irrigation purposes (Wilcox, 1955) [49].

$$\%\ Sodium = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100$$

Permeability Index

The Permeability Index (PI) is an indicator to study the suitability of water for irrigation purposes. Water movement capability in soil (permeability) is influenced by the long-term use of irrigation water (with a high concentration of salt) as it is affected by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- ions of the soil. PI formula has been developed by Doneen (1964) [12], to assess water movement capability in the soil as the suitability of any kind of source of water for irrigation, and it is formulated as an equation.

$$\text{Permeability Index} = \frac{Na^+ + \sqrt{HCO_{3-}}}{Ca^{2+} + Mg^{2+} + Na^+}$$

Magnesium Hazard (MH) or Magnesium adsorption ratio (MAR)

MH is another indicator to know the water quality for irrigation. Szabolcs and Darab (1964) [45] have proposed a relation to find the magnesium hazard. The concentrations are in milliequivalents / litre.

$$\text{Mg Hazard} = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Kelley's Index (KI) or Kelley's Ratio

Kelley's ratio is used to assess the quality and classification of water for irrigation purposes based on the concentration of Na^+ against Ca^{2+} and Mg^{2+} (Kelley, 1963) [19]. It can be calculated using equation,

$$\text{Kellys Ratio} = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

Statistical Analysis

The results were subjected to a paired t-test to assess the significance of the differences in the chemical properties of water between the two consecutive seasons (Shah, 2024) [43].

Results and Discussion

Chemical water quality indicators

pH

In the post-monsoon season, pH values varied between 6.01 and 7.32, with an average of 6.80. During the pre-monsoon season, pH levels ranged from 5.08 to 7.22, with a mean of 6.05 (Table 2). According to the BIS guideline (2012) [7], pH levels should ideally fall within the range of 6.5 to 8.5 for compliance (Table 1) and all samples collected during both the post-monsoon and pre-monsoon seasons adhered to this limit. The higher mean pH observed in the post-monsoon season can be attributed to the dilution of electrolytes in surface water, leading to an increase in pH levels (Samantray *et al.*, 2009) [42]. Surface water samples showed a slightly alkaline pH throughout both the post-monsoon and pre-monsoon seasons. Similarly, earlier studies (Manzoor *et al.*, 2017) [27] have reported neutral to slightly alkaline pH levels in surface water.

Electrical conductivity (µS cm^{-1})

The electrical conductivity values ranged from 63.41 to 355.06 µS cm^{-1} in the pre-monsoon season and from 94.85 to 400.86 µS cm^{-1} during the post-monsoon season (Table 2). The significantly higher electrical conductivity observed in the post-monsoon season is influenced by factors such as temperature, ion concentration, and the types of ions present in surface water (Adimalla and Venkatayogi, 2018) [1]. Findings from a similar study indicated that physicochemical parameters, such as electrical conductivity, increased during the post-monsoon period (Pavan and Benarjee, 2015) and showed temporal variation, with higher values recorded during the post-monsoon compared to the pre-monsoon season. This increase could be attributed to the continuous flushing of effluents during the rainy season (Fatema *et al.*, 2014).

Table 2: The major water quality indicating traits of surface water samples (N=50)

Parameters	Monsoon Season	Min.	Max.	Mean	SD	t calculated	Sig. (t test)	BIS (2012) [7]	
General parameters (EC: µS/cm)								Desirable limits	Permissible limit
pH	Post	6.01	7.32	6.80	0.30	-27.99	<0.01	6.5-8.5	6.5-8.5
	Pre	5.08	7.22	6.05	0.49				
EC (mg L^{-1})	Post	63.41	355.06	129.64	58.28	-41.41	<0.01	2000	3000
	Pre	94.85	400.86	169.91	59.33				
TDS (mg L^{-1})	Post	34.28	199.38	69.74	30.87	-41.40	<0.01	1000	2000
	Pre	65.77	245.25	110.09	32.36				
TH (mg L^{-1})	Post	15.01	65.14	32.49	12.67	-1179.11	<0.01	300	600
	Pre	35.42	85.99	53.09	12.79				
Major cations (mg/L)									
Ca^{2+}	Post	4.01	16.03	8.18	2.78	-601.24	<0.01	75	200
	Pre	8.16	20.40	12.40	2.83				
Mg^{2+}	Post	1.22	7.35	2.95	1.58	-117.97	<0.01	30	100
	Pre	3.17	9.55	5.00	1.67				
K^+	Post	0.53	5.65	1.61	1.14	-37.16	<0.01	10	200
	Pre	2.16	7.95	3.48	1.24				
Na^+	Post	2.43	10.70	4.40	2.13	-136.51	<0.01	100	200
	Pre	8.99	17.60	11.27	2.15				
Major anions (mg/L)									
HCO_3^-	Post	12.20	48.82	31.12	9.24	-37.75	<0.01	200	-
	Pre	15.87	53.70	34.93	9.12				
Cl^-	Post	202.07	354.50	286.58	50.46	-42.30	<0.01	250	1000
	Pre	225.25	383.86	311.98	51.06				
PO_4^{3-}	Post	0.23	5.15	0.88	1.10	-37.16	<0.01	0.3	0.3
	Pre	1.49	6.35	2.75	1.09				
SO_4^{2-}	Post	0.63	31.46	4.77	5.83	-23.42	<0.01	200	400
	Pre	1.83	32.76	5.83	5.86				
NO_3^-	Post	5.76	28.70	13.20	5.47	-38.09	<0.01	45	45
	Pre	8.07	30.51	15.10	5.45				

Note: EC- Electrical Conductivity, TDS- Total Dissolved Soilds, TH- Total Hardness, Ca^{2+}- Calcium Mg^{2+}- Magnesium, K^+-Pottasium, Na^+-Sodium, HCO_3^- - Bicarbonate, Cl^- - Chloride, PO_4^{3-} - Phosphates, SO_4^{2-}- Sulphates, NO_3^- - Nitrates, Post- Post monsoon, Pre- Pre monsoon; $p< 0.05$ indicates significance

Total dissolved solids (mg L^{-1})

The elevated concentrations of dissolved solids increase water density and influence the osmoregulation of freshwater organisms (Raj *et al.*, 2018) [34]. Total dissolved solids (TDS) values during the post-monsoon season ranged from 34.28 to 199.38 mg L^{-1}, while they varied from 65.77 to 245.25 mg L^{-1}

during the pre-monsoon period (Table 2). In the present study, it was observed that TDS levels were higher in the pre-monsoon season compared to the post-monsoon season, consistent with findings by Gadhia *et al*. (2012) [16]. Lower TDS values imply that runoff water dilution predominates during the rainy season and post-monsoon (Izonfuo and Bariweni, 2001). The acceptable TDS limit in surface water is 1000 mg L^{-1} according to BIS 2012 [7] standards and all surface water samples remained within the permissible limit during both the post-monsoon and pre-monsoon seasons.

Total hardness (mg L^{-1})
The hardness of water can be attributed to the presence of multivalent metallic cations (Hem, 1985) [17]. Water hardness significantly affects pH and plays a crucial role in pH stability control. Hardness values during the post-monsoon season ranged from 15.01 to 65.14 mg L^{-1} and from 35.42 to 85.99 mg L^{-1} during the pre-monsoon season (Table 2). According to the BIS (2012) [7] guidelines, the maximum permissible limit is 600 mg L^{-1} and all samples remained within this limit during both monsoon seasons. A notable increase in mean total hardness values was observed during the pre-monsoon season compared to the post-monsoon season. The differences in total hardness observed in surface water bodies are largely attributed to higher concentrations of calcium and magnesium cations. Furthermore, elevated hardness levels may stem from the natural weathering of calcium-bearing minerals or from excessive lime usage in agricultural practices.

Cationic water quality indicators
Calcium and magnesium
The concentrations of calcium and magnesium in the surface water of the study area vary from 4.01 to 16.03 mg L^{-1} and 0.22 to 7.35 mg L^{-1}, respectively, during the post-monsoon season, whereas during the pre-monsoon season, concentrations were recorded as 8.16 to 20.40 mg L^{-1} for calcium and 3.17 to 9.55 mg L^{-1} for magnesium (Table 2). The presence of a large amount of carbon dioxide may increase the solubility of calcium up to 200-300 mg L^{-1} in the presence of bicarbonate (Hem, 1985) [17]. The concentrations of calcium and magnesium ions were within the desirable and permissible limits prescribed by the BIS for surface water for irrigation (Table 2) and did not exceed the maximum permissible limits.

Sodium and potassium: The concentration of sodium during the post-monsoon seasons was found to be in the range of 2.43 to 10.70 mg L^{-1}, while potassium ranged from 0.53 to 5.65 mg L^{-1}. Conversely, during the pre-monsoon season, sodium concentrations ranged from 8.99 to 17.60 mg L^{-1}, and potassium ranged from 2.16 to 7.95 mg L^{-1}, as shown in table 2. According to the BIS (2012) [7] guidelines (Table 2), all the samples were within the allowable limits during both monsoon seasons. Aman (2020) [3] documented elevated cation concentrations during the pre-monsoon season, consistent with the findings of this study. This phenomenon is attributed to reduced hydrological flow, leading to an accumulation of ionic species in the water. Conversely, lower cation concentrations observed during the post-monsoon season are likely due to the influence of monsoon rains and subsequent runoff from agricultural areas, resulting in increased surface water flow and volume (Akhionbare, 1997; Dubey and Ujjania, 2016) [2, 13].

Anionic water quality indicators
Carbonates and bicarbonates: Carbonates in the surface water of the study area were not found in both seasons. Bicarbonates vary from 12.20 to 48.82 mg L^{-1} in the post-monsoon, whereas it varies from 15.87 to 53.70 mg L^{-1} during pre-monsoon (Table 2). All the bicarbonate values were in the permissible range (Table 1) during both the monsoon season. The elevated concentrations of bicarbonate and chloride in the region can be attributed to geogenic processes occurring in the area (Bhardwaj and Singh 2011) [6].

Chlorides
The chlorides values during the post-monsoon season ranged from 202.07 to 354.50 mg L^{-1}. The desirable limit of chloride in potable water is 250 mg L^{-1} (BIS 2012) [7], and only 32% of surface water samples were within this allowable limit during the post-monsoon season. In the pre-monsoon season, chloride levels varied from 225.25 to 383.86 mg L^{-1} with 86% of the samples exceeding the desirable concentration (Table 2). The leaching of upper soil layers and dry climate may be responsible for this trend. A significantly higher chloride concentration was observed in the pre-monsoon season attributed to a decrease in the flow of water from agricultural fields. Comparatively lower chlorine content was observed in the post-monsoon period (Dubey and Ujjania, 2016) [13] due to surface runoff of water from farmlands resulting in water dilution. Our results align with those of Aman (2020) [3].

Nitrates, Phosphates and sulphates
Nitrates concentrations exhibited a range of 5.76 to 28.70 mg L^{-1} during the post-monsoon period and 8.07 to 30.51 mg L^{-1} during the pre-monsoon season (Table 2). Remarkably, all samples remained below the permissible limit (<45 mg L^{-1}), indicating suitability for potable water usage. Elevated nitrate levels, typically resulting from factors such as inadequate well structures, excessive application of chemical fertilizers, or improper disposal of organic waste, pose carcinogenic risks in groundwater (Dissanayake *et al*., 1987) [11]. The pronounced increase in nitrate levels in surface water bodies during both pre and post-monsoon seasons can be primarily attributed to the excessive use of agrochemicals. Rainfall-induced dilution during the post-monsoon period resulted in comparatively lower nitrate concentrations. Processes such as surface runoff and percolation contribute to the influx of nitrates into aquatic ecosystems, thereby heightening contamination concerns (Sneha and Sagar, 2016) [44].
A phosphate varies from 0.23 to 5.15 mg L^{-1} in the post-monsoon, whereas it varies from 1.49 to 6.35 mg L^{-1} during pre-monsoon (Table 2). All the phosphate values were not in the permissible range (BIS 2012) [7] during both the monsoon season.
Sulphate is derived from the reduction of sulphate compounds, dissolved under low-oxygen conditions when anaerobic bacteria are present (Lehr *et al*. 1980) [23]. The sulphate values of post-monsoon seasons were found in the range from 0.63 to 31.46 mg L^{-1}, whereas, during the pre-monsoon season, it varied from 1.83 to 32.76 mg L^{-1} (Table 2). According to the BIS standard (2012) [7], the permissible limit of sulphate in potable water is 200 mg L^{-1}, and all the samples of the study area were within permissible limits during both the monsoon seasons.

Hydro-chemical facies (type of water) of water samples
In hydrogeological studies, the Piper diagram, also referred to as the Trilinear diagram, serves as a valuable tool for assessing how salts influence water quality. This graphical representation is based on the percentage composition of six ion groups:

sulfate, chloride, carbonate and bicarbonate anions, as well as calcium, magnesium, sodium and potassium cations. The core principle of this method is that cations and anions in natural waters generally exist in a chemically balanced equilibrium (Ravikumar *et al*., 2015) [38].

Piper plots include two triangles, one for plotting cations and another for plotting anions. These diagrams allow hydrogeologists to infer hydrogeochemical facies by pinpointing a single point within a diamond-shaped area formed by the combination of cation and anion fields. Tri-linear diagrams are valuable tools for illustrating chemical correlations between water samples with clarity (Sadashivaiah *et al*., 2008) [40]. The majority of water samples in both the post-monsoon and pre-monsoon seasons exhibited a mixed Ca-Mg-Cl-SO4 type, characterized by permanent hardness. None of the samples fell into the categories of temporary hardness, saline water, or alkali carbonates (Fig. 1).

This analysis provides insights into the relative abundance of common ions in water samples, indicating potential future effects on soil health, bioaccumulation of ions in the food chain (e.g., chlorine bioaccumulation) and both positive and negative impacts on crops. For instance, secondary nutrients such as calcium and magnesium, which are applied to plants and can be leached into water bodies through runoff, have been associated with issues like scouring and diarrhea in livestock. Therefore, assessing ion concentrations using the Piper diagram approach is valuable for understanding how various types of ions influence water quality and their broader environmental impacts.

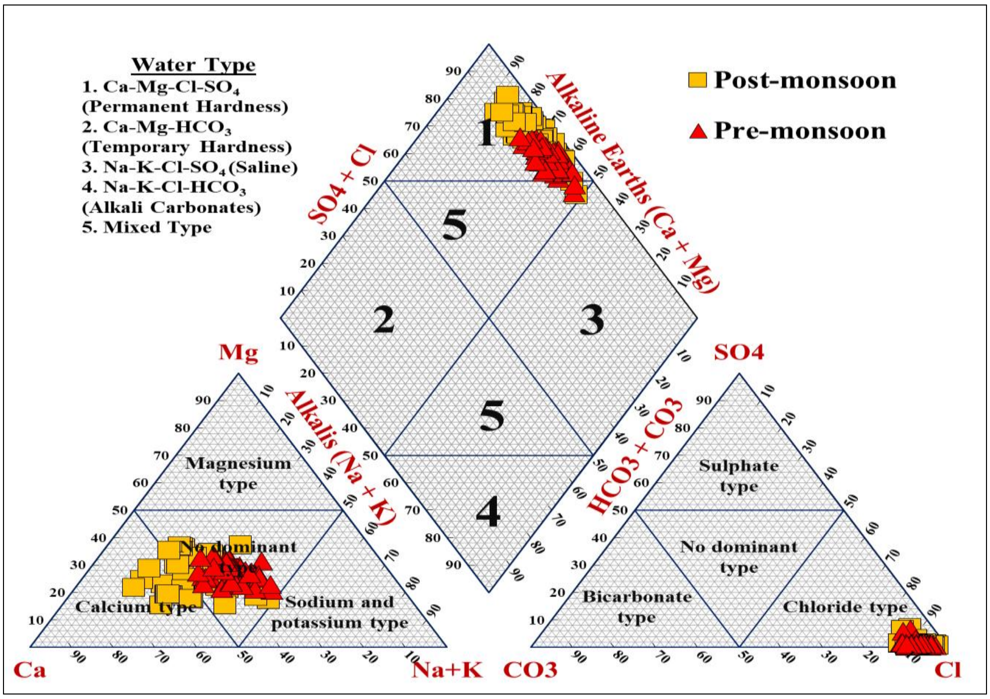

Fig 1: Hydro-chemical facies (type of water) of surface water samples

Irrigation water quality parameters (IWQP)

The water quality index provides a comprehensive evaluation of water quality by integrating various physical, chemical and biological characteristics (Sahu and Sikdar, 2008) [41]. Assessing the suitability of surface water for agricultural purposes involves considering key parameters such as soluble sodium adsorption ratio (SAR), sodium percentage (SSP), magnesium hazard (MH), residual sodium carbonate (RSC), sodium content, Kelly's ratio and permeability index (PI) (Kshitindra *et al*., 2020) [22].

Soluble sodium percentage (SSP)

The percentage of soluble sodium is an important parameter used in defining water in terms of soil permeability, according to Kshitindra *et al*. (2020) [22]. The mean concentration of SSP in the post-monsoon season was 0.22 meq L^{-1} with a maximum of 0.40 meq L^{-1} and minimum of 0.11 meq L^{-1}, whereas during the pre-monsoon season the mean SSP value was 0.31 meq L^{-1} with a maximum of 0.40 meq L^{-1} and minimum of 0.21 meq L^{-1} (Table 4). The highest mean value of soluble sodium percentage was noticed during the pre-monsoon season (0.31 meq L^{-1}) and the lowest mean value of soluble sodium percentage was recorded during the pre-monsoon season (0.22 meq L^{-1}). Soluble sodium percentage (SSP) values less than or equal to 50 are considered as good quality for irrigation purpose. SSP values greater than 50 are unacceptable for irrigation as the permeability is very low in this case. 100% of the surface water samples were in the good quality class of SSP values in both the seasons (Table 4). In comparison to the pre-monsoon season, the post-monsoon season recorded the lowest values. Similar trends were reported by Kishan *et al*. (2018) [21] who attributed such a trend for the good post-monsoon season.

Sodium absorption ratio (SAR)

The sodium hazard is typically expressed as sodium adsorption ratio (SAR) and the values are in meq L^{-1}. This index quantifies the proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg2+) in water. The mean SAR in the post-monsoon season was 0.27 meq L^{-1} and during pre-monsoon, the mean SAR value was 0.97 meq L^{-1} of surface water samples (Table 3). SAR values less than 10 would be suitable for irrigation, whereas greater than 26 would be not comfortable for irrigational purposes (Richards 1954) [39]. 100% of surface water samples of both seasons fall under the excellent class of SAR values (Table 4).

Residual sodium carbonate (RSC)

The sodium risk increases with the increase in the bicarbonate ion concentration. As the sodium concentration increases in the soil, the calcium and magnesium tend to precipitate as carbonates, resulting in an increase in the relative proportion of sodium (Ravikumar *et al*., 2013) [37]. The mean concentration of RSC during the post-monsoon season was -0.14 meq L^{-1} while during the pre-monsoon season, it was -0.48 meq L^{-1} for surface water samples (Table 3) The hazardous effect of carbonate and bicarbonate in water for agricultural purposes can be determined by residual sodium carbonate (RSC) analysis (Eaton 1950) [14]. According to RSC values (Table 4), 100% of surface water samples belong to the safe category during post and pre-monsoon seasons. A negative value of RSC indicates the higher concentrations of Ca and Mg in surface water. The increased RSC seen in the post-monsoon could be due to a decrease in runoff of water and dilution, resulting in higher concentrations of bicarbonate in water. Li *et al*. (2016) found that RSC was less than 1.25 meq L^{-1} in both seasons, which is deemed appropriate for irrigation except in the south transition zone of the post-monsoon season.

Percent sodium (%Na)

The sodium percentage (Na %) is an important factor in deciding whether or not water is suitable for irrigation. Alkaline soil is formed when sodium ions are coupled with carbonate ions, while saline soil is formed when sodium ions are associated with chloride ions. These types of soil will eventually become unsuitable for irrigation (Pandian and Shankar, 2007) [30]. The mean sodium percent in pre-monsoon and post-monsoon season water samples were 26.71 and 35.96 meq L^{-1} respectively (Table 3). According to the % Na values (Table 4), 22% of samples were grouped into excellent class, 74% were in good, and 4% were in permissible classes of percentage sodium during post-monsoon season. In the pre-monsoon season, 84% of the samples were fallen into good and 16% of the sample falls under permissible classes of % Na values.

Kelly's ratio (KR)

Kelley (1963) [19] developed a method to assess the quality of irrigation water based on the concentrations of different salts in the water. A Kelley's ratio of higher than one indicates that the groundwater is unsuitable for irrigation (Chandrashekhar *et al*., 2019) [9]. If Kelly's ratio is greater than one suggests that the water contains too much sodium and water is unsuitable for irrigation (Chandrashekhar *et al*., 2019; Ramesh *et al*., 2020) [9, 35]. The Kelley's index in the post-monsoon and pre-monsoon was with mean values of 0.32 meq L^{-1} and 0.48 meq L^{-1}. Table 5 represents the suitability classification of water for different seasons in the study area based on Kelly's ratio. 100% of the surface water samples of both the seasons fell into the suitable class of Kelly's ratio values.

Permeability index (PI)

The permeability of the soil is impacted by the concentrations of Na Ca^{2+}, Mg^{2+} and HCO^{3-}, as well as the long-term usage of irrigation water (Ramesh and Elango, 2012) [36]. Soil permeability is affected due to through continuous use of water for irrigation as precipitation of certain elements in soil reduces the void space depending upon the quality, thereby hampering the water dynamics (Doneen 1964) [12]. Doneen proposed permeability index (PI) for characterizing the suitability of irrigational water. It has been categorized into three classes. Class I (> 75%) and Class II (25–75%) represents the waters suitable for irrigation with 75% or more of maximum permeability. In contrast, Class III (< 25%) characterizes the water unsuitable for irrigation with 25% of maximum permeability (Table 4). The WHO (2011) adopts a permeability index (PI) criterion to assess the appropriateness of water for irrigation, where the requisite ion concentrations are expressed in meq/L (Ragunath, 1987) [33].

The mean values of the permeability index were found highest during the post-monsoon season (116.84 meq L^{-1}) and the lowest permeability index was found during the pre-monsoon season (82.46 meq L^{-1}) (Table 3). Accrording table 4 during post-monsoon season, none of the samples enter to the Class III and unfit for irrigation purposes, whereas 10% samples belong to Class II and 90% fall under the Class I, shows suitability for irrigation purposes with maximum permeability. In the pre-monsoon seasons, none of the samples belong to Class III, whereas 32% enter to Class II and 68% of the samples enter to the Class I. According to this assessment, water samples show suitable to good water quality in both the post and pre-monsoon seasons, making it ideal for irrigation. According to the findings of Brindha and Elango (2011) [8], the mean permeability index value changed during the post and pre-monsoon seasons (Kishan *et al*., 2018) [21].

Table 3: Irrigation water quality indices of surface water samples (N=50)

Parameters	Monsoon Season	Min	Max	Mean	SD	t Calculated	sig. (t test)
% Sodium (meq L^{-1})	Post	14.20	48.71	26.71	8.08	-16.44	<0.01
	Pre	24.77	47.88	35.96	5.00		
SAR (meq L^{-1})	Post	0.14	0.66	0.27	0.12	-71.16	<0.01
	Pre	0.70	1.53	0.97	0.17		
RSC (meq L^{-1})	Post	-0.80	0.30	-0.14	0.26	66.24	<0.01
	Pre	-1.14	-0.04	-0.48	0.26		
PI (meq L^{-1})	Post	65.31	204.24	116.84	35.97	10.37	<0.01
	Pre	60.43	109.33	82.46	12.94		
Mg Hazard (meq L^{-1})	Post	20.00	54.55	35.56	8.11	-10.42	<0.01
	Pre	33.33	52.63	41.74	4.28		
Kelly's (meq L^{-1}) ratio	Post	0.13	0.78	0.32	0.15	-19.98	<0.01
	Pre	0.28	0.77	0.48	0.11		
SSP (meq L^{-1})	Post	0.11	0.40	0.22	0.07	-17.24	<0.01
	Pre	0.21	0.40	0.31	0.05		

Note: SAR: Sodium Absorption Ratio, RSC: Residual Sodium Carbonate, SSP: Soluble Sodium Percentage, PI: Permeability Index, TH: Total Hardness; $p < 0.05$ indicates significance

Table 4: Grades of surface water samples for irrigation purposes based on various indices during post and pre-monsoon season (N=50)

Parameters	Range	Water class	No. of samples		Samples (%)	
			Post -monsoon	Pre -monsoon	Post -monsoon	Pre –monsoon
SAR (meq L^{-1})	0–10	Excellent	50	50	100	100
	10–18	Good	-	-	-	-
	18–26	Fair	-	-	-	-
	>26	Poor	-	-	-	-
RSC (meq L^{-1})	<1.25	Safe/good	50	50	100	100
	1.25–2.50	Marginal	-	-	-	-
	>2.50	Unsuitable	-	-	-	-
SSP (meq L^{-1})	0-20	Excellent	50	50	100	100
	20-40	Good	-	-	-	-
	40-60	Permissible	-	-	-	-
	60-80	Doubtful	-	-	-	-
	>80	Unsafe	-	-	-	-
Sodium %	<20	Excellent	11	-	22	-
	20–40	Good	37	42	74	84
	40–60	Permissible	2	8	4	16
	60-80	Doubtful	-	-	-	-
	>80	Unsuitable	-	-	-	-
PI (meq L^{-1})	> 75%	Suitable	45	34	90	68
	25–75%	Good	5	16	10	32
	< 25%	Unsuitable	-	-	-	-
Mg Hazard (meq L^{-1})	< 50	Suitable	49	49	98	98
	> 50	Unsuitable	1	1	2	2
Kelly's ratio (meq L^{-1})	< 1	Suitable	50	50	100	100
	>1	Unsuitable	-	-	-	-

Magnesium hazards (MH)

A magnesium ratio of more than 50 meq L^{-1} in groundwater is deemed hazardous and unfitfor irrigation (Szabolcs and Darab, 1964) [45]. Magnesium and calcium usually maintain a state of equilibrium in surface water (Adimalla and Venkatayogi 2018) [1]. The maximum value of magnesium hazard found during pre-monsoon of surface water varied from 33.33 to 52.63 meq L^{-1} with a mean value of 41.74 meq L^{-1} and the lowest magnesium hazard found during pre-monsoon, varied from 20 to 54.55 meq L^{-1} with a mean value of 35.56 meq L^{-1} (Table 3). A higher concentration of magnesium in water can affects the soil quality through changing it into alkaline nature. As soils become more alkaline, will have a negative impact on crop yield. During post-monsoon season, 98% of the samples belong to the suitable class of irrigation according to MH values (Table 4), whereas 2% of the samples were categorized as unsuitable. 98% of the samples were grouped as a suitable class of irrigation, and 2% were belonging to the unsuitable class during pre-monsoon seasons.

Conclusion

In this study, particular emphasis was placed on understanding the influence of agrochemicals on surface water quality in coffee plantations. The quality of water and its potential end uses are derived based on its physical and chemical properties. Surface water samples collected during both the post-monsoon and pre-monsoon seasons exhibited slightly alkaline characteristics, with the post-monsoon period demonstrating the highest mean pH and electrical conductivity (EC). According to the BIS (2012) [7] guidelines, the anionic and cationic water quality indicators of all samples remained within allowable limits throughout both monsoon seasons. Notably, the majority of water bodies during the post-monsoon season were classified as excellent in terms of water quality indices, contrasting with the pre-monsoon season where they were predominantly categorized as good. This shift towards excellent water quality post-monsoon could be attributed to the dilution effect of surface water bodies from agricultural runoff originating from surrounding agro ecosystems.

Future scope

Long-Term Monitoring of Agrochemicals: Future research could track how different agrochemicals affect surface water quality over time and across seasons. This would help us understand their long-term impact.

Improving Water Quality: Studies could focus on finding ways to reduce the negative effects of agricultural runoff on water quality. This might include developing better practices for using agrochemicals and methods to improve water quality, especially before the monsoon season.

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