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Research Article

Assessment of physicochemical properties and irrigation suitability of surface water along rural and transition zones of Bengaluru

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ABSTRACT

The surface water resources are the major source of irrigation in the rural and transition zones of Bengaluru. These water resources are deteriorating due to unpredictable changes in rural areas and transitions in Bengaluru city caused by rapid urbanization and human activities. So, the present study was conducted in rural and transitional zones of the southern and northern transects of Bengaluru, one of the fastest-growing cities in India. Surface water samples collected from various agroecosystems at the end of October (representing the post-monsoon season) were analyzed for physicochemical properties such as pH, electrical conductivity, total dissolved solids, turbidity, total hardness, major anions, cations, and heavy metals, which are considered critical in water quality assessment for irrigation purposes. The different physicochemical properties of surface water in the rural zone were less polluted than in transition, and all the water samples collected from transects were within the permissible limits of BIS except phosphates. The heavy metal concentration was found to be lower in rural and transition zones, but the iron concentration was slightly higher than the BIS standards. The water quality was assessed for irrigation suitability and parameters like SAR, RSC, SSP, and percent sodium were calculated. Most of the water samples were suitable for irrigation purposes based on SAR values and RSC values were in good and marginal water classes. The percent sodium and soluble sodium percentage were in the excellent to permissible water class. The present study found that the surface water is less contaminated and well-suited for irrigation purposes.

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INTRODUCTION

Water is the most precious and limited resource available on earth [1] [2]. A small fraction of surface water (2.5%) is freshwater, which is utilized for different purposes including agriculture, household activities, industrial maneuver, and aquatic biochemical processes for human beings and other living organisms [3] [4]. Deteriorating water and soil quality reduces water availability and affects water quality for agriculture and human and animal consumption. This is not only a threat to food security but also critically impacts human and animal health. Agriculture is one of the major anthropogenic activities responsible for polluting water and soil because inorganic fertilizers and plant protection chemicals and their residues are found to enter the water bodies as well as remain in the soil and pollute them. Irrigation using polluted water, especially saline water, has limited agricultural production worldwide. Since agriculture consumes about 70% of the available water, deteriorated water can significantly impact productivity.

Increasing urbanization has made noticeable changes like crops cultivated across the rural-urban transitions of Bengaluru. More commercial crops with intensive cultivation practices are grown in urban areas compared to less intensive, resource-driven staple food crops in rural areas [5]. Studies have also revealed that these changes in cropping systems have intensified the use of more chemical fertilizers and plant protection chemicals in crop cultivation, which has resulted in increased concentrations of chemical residues and heavy metals in the soil and water bodies and caused pollution. Inorganic fertilizers are a potential source of heavy metals in the soil and water bodies, especially phosphate fertilizers produced from rock phosphate that contain various metals [6]. As a result, water bodies in and around Bengaluru are being contaminated considerably and are a major hindrance in fulfilling the water requirements of the rapidly growing city [7]. Rapid industrialization and urban development result in the inclusion of a variety of pollutants into water bodies, including heavy metals of geological origin and enter surface water bodies through weathering and erosion and anthropogenic activities like mining, and the discharge of industrial and domestic effluent. Some heavy metals are significant for human metabolism, but they lead to various adverse health effects at high concentrations. It is also a fact that mercury, cadmium, lead, and arsenic are the most toxic metals that are deficient in any crucial substances. Absorption of these heavy metals over some time can lead to debilitating illness and therefore, the progress of any specific, selected, and sensible techniques currently receiving considerable attention. The pollution of the aquatic environment with heavy metals has become a worldwide problem in recent years because they are indestructible and most of them have toxic effects on organisms even in low concentrations in the water. Heavy metals are of particular concern among different environmental pollutants due to their potential toxic effects and ability to bioaccumulate in aquatic ecosystems.

The environmental risk of heavy metal pollution is of great concern. Heavy metals are non-degradable, toxic, persistent and will have widespread and serious ecological ramifications [8]. Heavy metal pollution caused by the agriculture sector has been a serious concern over the past few decades [9]. The heavy metals would accumulate in the crops as they are absorbed from the soil and water and can be biomagnified in the biological systems. The heavy metal-contaminated water will not only lead to various adverse health effects on humans and animals [10] but eventually lead to a shortage of water. According to UN estimates, wastewater production is six times greater than the water present in all rivers of the world [11], suggesting that global water scarcity, in general, is largely due to the deterioration of water quality rather than physical scarcity. Increasing urbanization and related changes in agriculture must be influencing the quality of water bodies in and around Bengaluru significantly. The surface water quality depends on different physicochemical parameters of water. It is difficult to describe a simple, straightforward reason for the water quality deterioration in the rural and transition zones of Bengaluru.

MATERIALS AND METHODS

Study area

This study was conducted in Bengaluru, a rapidly growing metropolis located in southern India. To better understand the area, the city, and its surrounding regions were divided into rural and transition (RUT) zones using a stratification index. This index was determined by considering the percentage of the built-up area within a defined perimeter around a village, as well as the distance between the village centers and the city center [12]. Two transects were then established from the city center, extending into the outer rural areas in the north and south directions. The Northern transect (N-transect) covered an area of approximately 250 km^2 (50 km in length and 5 km in width), while the Southern transect (S-transect) covered an area of 300 km^2 (Fig. 1). Each transect from the city center towards the rural areas is further bifurcated into urban, transition and rural zones.

Collection and analysis of water samples

A total of 30 surface water samples were assessed that represented water bodies from the rural and transition zones of Bengaluru in the northern and southern directions. In each direction, fifteen samples were collected to study the water quality of the surface water bodies at the end of October (representing the post-monsoon and end of the Kharif season). Water bodies present within a radius of approximately one kilometre from agricultural fields were selected in the rural and transition zones of Bengaluru. Further, it was also ensured that these water bodies were not contaminated by other sources of contamination, such as domestic waste and industrial discharge. The intention was to compare the water bodies along the rural and transition zones.

Water samples were collected in plastic bottles (1000 mL). Before the collection of samples, the bottles were thoroughly rinsed with surface water to be collected from agroecosystems. The collected samples were carried to the laboratory and stored at 4°C temperature. Half the samples were acidified as per the standard protocol described by [13] for heavy metal analysis, while the other half was used for physicochemical and chemical water quality analysis. The physicochemical and chemical parameters were analyzed as per the standard procedures (Table 1).

Irrigation water quality parameter (IWQP)

Irrigation water quality assessment primarily denotes various mineral compositions of water and was primarily meant for the assessment of water quality for irrigation purposes because the chemical composition of irrigation water affects directly or indirectly nutrient availability and crop yields [14]. Irrigation water quality is mainly assessed by sodium absorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP) and sodium percent (Na%).

Sodium adsorption ratio (SAR)

SAR was calculated by taking a concentration of Ca, Mg, and Na in irrigation water samples [15] mentioned below.

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

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 [15] mentioned below.

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

Soluble sodium percentage

The sodium percentage and specific conductance in the surface water in evaluating its suitability for irrigation [16]. Sodium percentage determines the sodium concentration ratio to the concentration of the total cations (sodium, potassium, calcium, and magnesium).

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

Sodium percent water

Percent Sodium concentration is a factor to assess its suitability for irrigation purposes [16].

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

Statistical Analysis

The results obtained were subjected to descriptive statistics to calculate the pooled data's mean, minimum, maximum, and standard error mean, regardless of sample sites and sampling period.

RESULTS AND DISCUSSION

General parameters

The physicochemical characteristics of surface water samples were statistically evaluated using distractive statistics given in

Tables 6 and 7. The mean pH values of surface water along the rural and transition zones vary from 7.31 to 7.90, respectively (Tables 2 and 3). The pH of 6.0 to 8.5 shows the productive nature of the water body [7]. The pH of surface water bodies in the rural and transition zones was slightly alkaline and all the water samples were within desirable and permissible limits [17].

The electrical conductivity is a function of total dissolved salts and is used as an indicator to represent the concentration of soluble salts in water [18] [19]. The height of electrical conductivity was recorded in the transition zone (317.64 µS/cm) whereas the rural zone was recorded with a mean value of 303.71 µS/cm (Tables 2 and 3). A similar study also says that the conductivity in water is mainly due to the presence of inorganic dissolved compounds like sulfate, nitrate, phosphate, chloride, calcium, magnesium, sodium, iron, and aluminum ions [20]. The irrigation suitability based on electrical conductivity indicates the water samples from rural and transition belong to the medium (C2) salinity class (Table 4).

The mean concentration of TDS for surface water in rural and the transition was in the range 44.20-418.50 and 52.15-814.50 mg/L respectively (Tables 2 and 3). The concentration of TDS was within the permissible limits as per BSI standards (2000 mg/L). The total dissolved solids (TDS) mainly consist of inorganic salts such as carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates of calcium, magnesium, sodium, potassium etc, and a small amount of organic matter. The runoff from surrounding agriculture fields can add some of these compounds as residues to water bodies and result in the deposition of salts in the water bodies [21].

The total hardness of the water in the rural zone was 66.98 and 71.70 mg/L in the transition zone. The values were within the standard limits of Indian standards. The ions concentration like Ca and Mg has an impact on the overall hardness of the water. The dissolved calcium imparts the total hardness of water and magnesium to a lesser extent [22]. The classification of the hardness of the study area has been represented in Table 5. Soft water class levels were found in 60 and 40% of the samples, 26 and 34% were found to be moderately hard, and 14 and 26% were hard in the rural and transition zones.

The turbidity values of surface water in the rural and transition zones were 8.03 and 9.37 NTU respectively. The highest turbidity of water was observed in the surface water of rural areas along with the rural and transition zones, which can be attributed to runoff from agricultural lands. Turbidity doesn't affect human health directly but provides a congenial atmosphere for microbial growth which in turn causes diseases in humans and animals upon consumption [23].

Major cations

The trend of predominant cation was in the order of Na^{+} > Ca^{2+} > Mg^{2+} > K^{+} in the rural and Ca^{2+} > Na^{+} > K^{+} > Mg^{2+} in the transition zone. The mean concentration of cations in the rural area was 26.27, 16.05, 6.55, and 5.61 mg/L for sodium, calcium, magnesium, and potassium and 17.93, 17.87, 6.69 and 6.55 mg/L in the transition for calcium, sodium, potassium, and magnesium (Tables 2 and 3). The dominant cation in rural was sodium and calcium in transition. However, these two cation concentrations were within the permissible standard limits [17].

Major anions

The trend of predominant anions content was in the order of chlorides > bicarbonates > sulfates > nitrates > carbonates > phosphate with the mean value of 158.58, 124.13, 40.45, 36.71, 6.98, and 0.47 mg/L for the rural zone. In the transition zone, anions concentrations were in the order of bicarbonates > chlorides > sulfates > nitrates > carbonates > phosphate with the mean value of 140.20, 128.78, 44.42, 24.04, 7.77, and 0.36 mg/L (Tables 2 and 3). The anion concentrations were within the standard limits except for phosphate which was slightly more than desirable and a permissible limit of 0.3 mg/L. The anthropogenic source of phosphorous is sewage, detergents, effluents of agricultural and fertilizers [24]. The concentration of nitrates in surface water is generally low, but elevated concentrations may increase contamination from agricultural runoff, fertilizers, and domestic human and animal wastes [7].

Heavy metal concentration

The iron concentration in rural was found more than desirable and permissible with a concentration of 1.23 mg/L and other heavy metals like arsenic, cobalt, chromium, manganese, nickel, lead, and zinc was recorded with mean values of 0.01, 0.03, 0.016, 0.026, 0.003, 0.04 mg/L respectively and the cadmium and copper concentration were not detected in the rural zone (Table 6). The concentration of heavy metals in the transition zone was 0.017, 0.001, 0.027, 0.015, 0.048, 0.034, 0.004, and 0.061 mg/L for arsenic, cadmium, cobalt, chromium, manganese, nickel, lead, and zinc respectively (Table 7). The iron concentration in transition (1.45 mg/L) was more compared to the rural zone and also more than the standard limits but iron is a micronutrient, and it is more essential for plant growth. Other heavy metals were within the safe limits except arsenic in transition [17] [25].

Irrigation water quality parameters (IWQP)

Assessing the water quality using the water quality index provides a comprehensive idea of the quality of water considering different physical, chemical, and biological traits [26]. To assess the quality of surface water for its suitability for agriculture purposes, parameters such as soluble sodium percentage (SSP), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), sodium content, Kelly's ratio and permeability index (PI) are shown to be pertinent [27].

The SAR values in the study area were less than 10 for water samples indicating the water is excellent for irrigation. The SAR values of the water bodies in the rural and transition zones were found to be excellent for irrigation. The RSC values from the study site concluded that 60% of water samples from the rural zone, and 33% from the transition indicated excellent water class, whereas 40% and 67% of the samples were under marginal water class. The SSP values in the rural zone fall under the excellent (47%), good (33%), and permissible (20%) water classes whereas in the transition zone 33% of samples in the excellent water class, 27% in good and 40% in permissible water class. It has been generally suggested that to avoid adverse impacts on soil, the sodium content of the water used for irrigation should not exceed 50–60% and the percent sodium is more than the 80% which indicates water is unsuitable for irrigation. The percent sodium in rural zone is only 20% of samples were excellent water class, 53 and 27% of samples in good and permissible limits respectively. In the transition zone, the water samples were in good and permissible water categories with 47 and 53% respectively (Table 8).

CONCLUSIONS

The variations in the physicochemical properties of surface water in rural and transitional areas are high and are caused by the runoff of surface water from surrounding ecosystems. The higher concentrations were recorded in transition areas and the lowest in rural areas. The higher concentration is due to rapid urbanization and intensive agricultural activities in the transition zone. Based on SAR values, surface water is suitable for irrigating all crops and soil except for crops sensitive to sodium. Other irrigation water quality parameters like SSP and percent sodium also concluded that surface water belongs to the excellent to permissible water class and shows the suitability of water for irrigation purposes.

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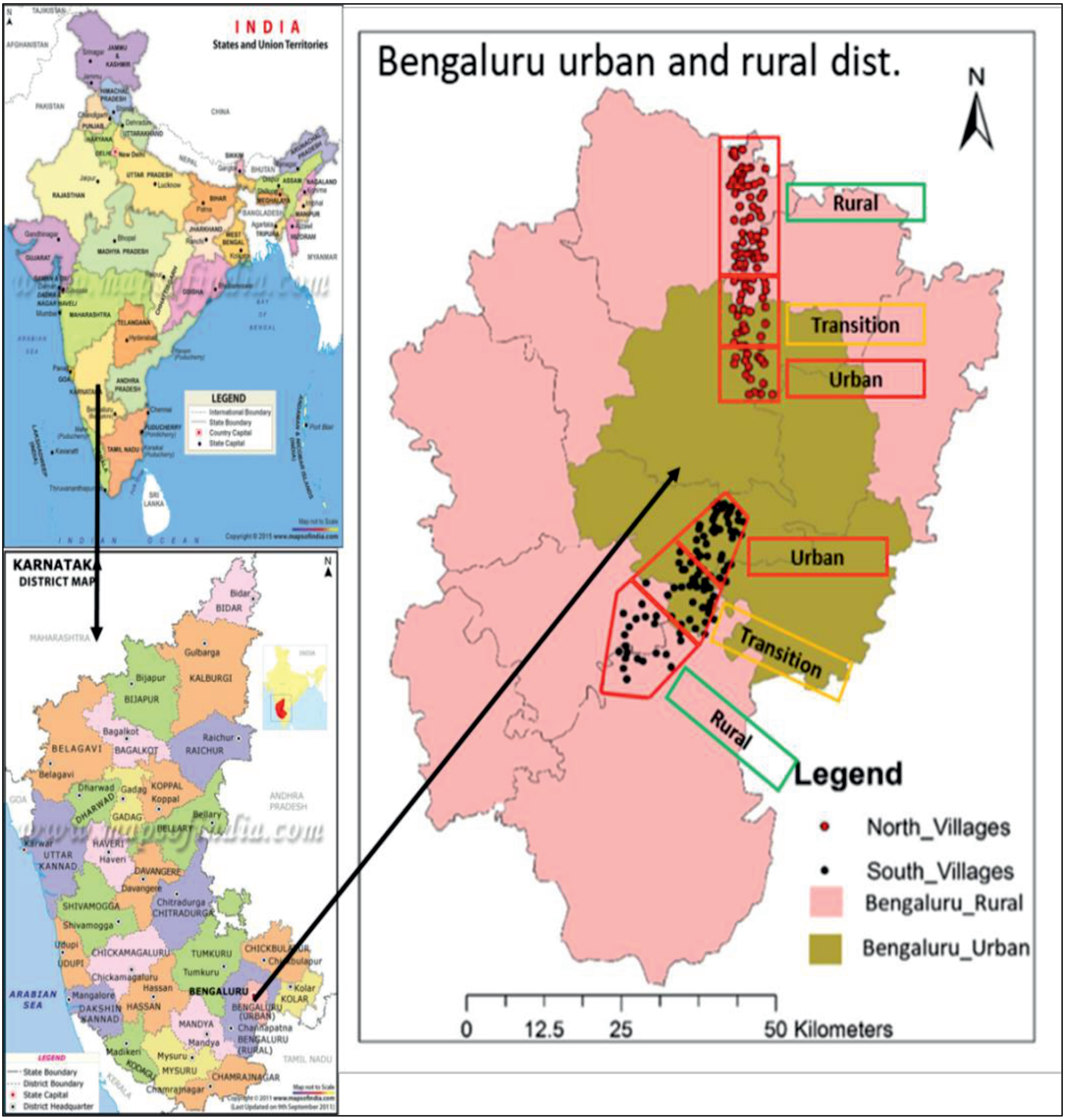

Fig. 1: Details of the experimental site showing the rural, urban, and transition zones of Bengaluru and the north and south transects where water samples were collected.

Table 1: Analysis of physicochemical properties and heavy metals in the surface water bodies

Parameters	Analytical Method / Instrument Used	Unit
General Parameters		
pH	Combined water analyzer (Systronics, Model-371, India).	-
Electrical Conductivity		µS/cm
Turbidity		NTU
Total Dissolved Solids		mg/L
Total hardness	4.1 (Mg^{2+}) + 2.5 (Ca^{2+})	mg/L
Major Anions		
Bicarbonate and Carbonate	Volumetric Method	mg/L
Chloride	Titrimetric Method	mg/L
Nitrates	Chronotropic Acid	mg/L
Sulphate	Turbidimetric	mg/L
Phosphates	Olsen's Extractant	mg/L
Major Cations and Heavy Metals		
Calcium, Magnesium, Potassium, Sodium	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, Ametek-Spectrogenesis, Germany).	mg/L
Arsenic, Cadmium, Copper, Manganese, Nickel, Lead and Zinc		mg/L

Table 2: General parameters of surface water in the rural zone of Bengaluru

Parameters	Mean ± SE.m	Range		BIS (2012)	
		Min.	Max.	Desirable Limits	Permissible Limits
pH	7.31 ± 0.304	6.70	8.40	6.5-8.5	6.5-8.5
EC (µS/cm)	303.71 ± 110.75	77.16	730.50	2000	3000
TDS (mg/L)	162.28 ± 62.52	44.20	418.50	1000	2000
Total Hardness (mg/L)	66.98 ± 19.60	32.22	154.75	300	600
Turbidity (NTU)	8.03 ± 0.73	5.66	10.22	5	10
Major Anions (mg/L)					
Bicarbonate	124.13 ± 11.30	98.33	154.66	200	-
Carbonate	6.98 ± 0.06	6.87	7.24	-	-
Phosphate	0.30 ± 0.04	0.13	0.41	0.3	0.3
Sulphate	40.45 ± 5.98	25.10	63.30	200	400
Chlorine	158.58 ± 23.74	98.99	245.31	250	1000
Nitrates	36.71±6.54	14.52	52.34	45	45
Major Cations (mg/L)					
Calcium	16.05 ± 3.76	8.95	32.03	75	200
Magnesium	6.55 ± 2.52	2.30	18.21	30	100
Potassium	5.61 ± 1.49	3.42	12.24	10	200
Sodium	26.27 ± 10.37	3.48	61.16	100	200

Table 3: General parameters of surface water in the transition zone of Bengaluru

Parameters	Mean ± SE.m	Range		BIS (2012)	
		Min.	Max.	Desirable Limit	Permissible Limit
pH	7.90 ± 0.36	6.82	8.77	6.5-8.5	6.5-8.5
EC (µS/cm)	317.64 ± 119.36	52.15	814.50	2000	3000
TDS (mg/L)	181.79 ± 67.76	29.65	461.00	1000	2000
Total Hardness(mg/L)	71.70 ± 22.24	28.96	167.03	300	600
Turbidity (NTU)	9.37 ± 3.76	1.50	22.00	5	10
Major Anions (mg/L)					
Bicarbonate	140.20 ± 7.71	123.00	165.55	200	-
Carbonate	7.77 ± 0.28	6.98	8.88	-	-
Phosphate	0.36 ± 0.03	0.28	0.44	0.3	0.3
Sulphate	44.42 ± 11.07	18.90	85.60	200	400
Chlorine	128.78 ± 13.48	89.34	165.32	250	1000
Nitrates	24.04 ± 5.34	12.30	47.32	45	45
Major Cations (mg/L)					
Calcium	17.93 ± 4.68	8.77	38.02	75	200
Magnesium	6.55 ± 2.61	1.71	17.55	30	100
Potassium	6.69 ± 1.17	3.25	10.37	10	200
Sodium	17.87 ± 5.81	3.48	38.21	100	200

Table 4: Classification of water based on the electrical conductivity.

Water class	Conductivity Ranges	Irrigation Suitability
Low salinity water (C1)	100 and 250 µS/cm	Suitable for all types of crops and all kinds of soil. Permissible under normal irrigation practices except in soils of extremely low permeability
Medium salinity water (C2)	250 and 750 µS/cm	Can be used, if a moderate amount of leaching occurs. Normal salt-tolerant plants can be grown without much salinity control
High salinity water (C3)	750 and 2,250 µS/cm	Unsuitable for soil with restricted drainage. Only high-Salt-tolerant plants can be grown
Very high salinity (C4)	> 2,250 µS/cm	Unsuitable for irrigation

Table 5: Classification of surface water based on the total hardness.

Classification	Hardness range (mg/L)	Percentage of samples	
		Rural	Transition
Soft	0–75	60	40
Medium hard	75–150	26	34
Hard	150–300	14	26
Very hard	Above 300	0	0

Table 6: The heavy metal concentration of surface water in the rural zone of Bengaluru

Heavy metals (mg/L)	Mean ± SE.m	Range		BIS (2012)	
		Min.	Max.	Desirable Limit	Permissible Limit

Arsenic	0.01±0.005	0.002	0.032	0.01	0.05
Cadmium	ND	-	-	0.01	-
Cobalt	0.03±0.001	0.025	0.029	0.05	1.5
Chromium	0.016±0.002	0.013	0.023	0.05	-
Copper	ND	-	-	-	0.05
Iron	1.23±0.85	0.016	4.430	0.3	1.0
Manganese	0.03±0.02	0.000	0.119	0.1	0.3
Nickel	0.026±0.002	0.019	0.032	0.02	0.2
Lead	0.003±0.001	0.000	0.006	0.05	-
Zinc	0.04±0.03	0.007	0.215	1	15

Table 7: The heavy metal concentration of surface water in the transition zone of Bengaluru

Heavy metals (mg/L)	Mean ± SE.m	Range		BIS (2012)	
		Min.	Max.	Desirable Limit	Permissible Limit
Arsenic	0.017±0.004	0.006	0.03	0.01	0.05
Cadmium	0.001±0.001	0.000	0.008	0.01	-
Cobalt	0.027±0.001	0.024	0.033	0.05	1.5
Chromium	0.015±0.002	0.012	0.022	0.05	-
Copper	ND	ND	ND	-	0.05
Iron	1.45±0.68	0.016	4.35	0.3	1.0
Manganese	0.048±0.032	0.011	0.20	0.1	0.3
Nickel	0.034±0.003	0.018	0.048	0.02	0.2
Lead	0.004±0.002	0.000	0.012	0.05	-
Zinc	0.061±0.020	0.003	0.123	1	15

Table 8: Grades of surface water samples for irrigation purposes based on various indices for rural zones during the post-monsoon season.

Parameters	Range	Water class	No. of samples		Samples (%)	
			Rural	Transition	Rural	Transition
SAR	0–10	Excellent	**15**	**15**	**100**	**100**
	10–18	Good	0	0	0	0
	18–26	Fair	0	0	0	0
	>26	Poor	0	0	0	0
RSC	<1.25	Safe/good	**9**	**5**	**60**	**33**
	1.25–2.50	Marginal/doubtful	**6**	**10**	**40**	**67**
	>2.50	Unsuitable	0	0	0	0
SSP	0-20	Excellent	**7**	**5**	**47**	**33**
	20-40	Good	**5**	**4**	**33**	**27**
	40-60	Permissible	**3**	**6**	**20**	**40**
	60-80	Doubtful	0	0	0	0
	>80	Unsafe	0	0	0	0
Sodium (%)	<20	Excellent	**3**	0	**20**	0
	20–40	Good	**8**	**7**	**53**	**47**
	40–60	Permissible	**4**	**8**	**27**	**53**
	60-80	Doubtful	0	0	0	0
	>80	Unsuitable	0	0	0	0

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