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Chemical and Hydro-chemical Studies of Ground Water Quality for Irrigation near the Treated Sewage Water Tanks in Eastern Dry Zone of Karnataka

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundwater is a main source Eastern Dry Zone of Karnataka where it is used for domestic, irrigation and industrial purposes. The recharge of ground water last five years by treated sewage water which is discharge form Bangalore metropolitan city and this water is mainly used for irrigation. The main objective of this study was to assess the chemical and hydro-chemical properties of groundwater and to determine its suitability for irrigation in this zone. Using GPS tool 50 groundwater samples were collected. These samples analysed for various parameters like pH, EC, Sodium Adsorption ratio (SAR), Residual sodium carbonate (RSC), Total dissolved salts (TDS) and Total hardness (TH), cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, CO_3^-, SO_4^-, Cl^-, NO_3^-, F^-, PO_4^{2-}). Results indictes that groundwater is neutral to slightly alkaline with pH values between 7.1 and 8.2. Total soluble salts (electrical conductivity) 587 µmhos cm^{-1}, Sodium Adsorption Ratio 0.54, Residual sodium carbonate -5.37 meq L^{-1}, TDS (382.69 mg L^{-1}) was found to be normal and total hardness (596.16 mg L^{-1}) is more. From the piper trilinear diagram, water quality belongs to calcium-magnesium- chloride-sulphate type. All cations and anions are in suitable range for irrigation purpose except chloride (11.06 meq L^{-1}) and fluoride (3.06 mg L^{-1}). According to the US salinity classification, the majority of samples were acceptable for irrigation.

Keywords: Groundwater quality; irrigation water; hydro-chemical process; piper trilinear diagram; TSW tank.

1. INTRODUCTION

Groundwater irrigation is an important part of productive agriculture, especially in regions where the uneven distribution of rainfall is the limiting factor in providing sufficient water for crop growth. It has played a crucial role in the development of the agricultural sector and has significantly increased crop production and productivity in arid and semi-arid regions. Approximately 16 percent of the world's agricultural land is irrigated and 40 percent of crop yields are achieved through irrigation. This means that irrigated land is 3.6 times more productive than rain-fed agriculture. In India, almost 48.8% of the 140 million hectares of agricultural land is irrigated, while the remaining 51.2 is *rainfed* (Jat et al. 2023).

The average rainfall in India is 1194 mm/year. Due to erratic and uncertain distribution of monsoon (rainfall in the southwest and northeast) and faulty water management, the country faces water scarcity and irrigation plays an important role in water management for productive agriculture. The sources of irrigation in India include a network of major and minor canals from Indian rivers, groundwater well systems, tanks and other rainwater harvesting projects for agricultural activities. The groundwater system is the largest source of irrigation. The annual net availability of groundwater is 398 billion cubic meters, of which India withdraws 245 billion cubic meters (62%) annually (Anon., 2009). More than 60 percent of irrigated agriculture and 85 percent of drinking water supplies depend on groundwater. However, groundwater is becoming increasingly scarce in both rural and urban areas because pollution and overuse of groundwater is leading to a decline in aquifers. The availability of fresh water that can be used for irrigation in India is decreasing. In the context of scientific development and the growing water crisis, wastewater reuse is worth considering as it helps to reduce water consumption and water pollution.

Consequently, the use of treated wastewater for irrigation of agricultural land is increasing, especially in India's major cities. On the other hand, there is growing concern about the accumulation of heavy metals in the food chain all over the world, including India, due to the constant use of wastewater. In addition, heavy metals accumulate in plants grown on soil contaminated with metals in such high quantities that they endanger human and animal health (Tiller, 1986). Plant species accumulate metals differently in their tissues (Datta et al*.,* 2000), and the efficiency of different plants in absorbing metals is assessed either by the uptake of metals by the plants or by the transfer factor of metals from soil to plants. The potential health risks and environmental impacts arising from the use of wastewater for irrigation are well documented (Angelakis et al*.,* 2003). Although there is information on agricultural land irrigated with wastewater for a long time in various parts of India, information on the use of treated wastewater in agriculture in India, particularly in Karnataka, is very scanty. Treated wastewater has alternative sources of water and can be used to recharge groundwater that is generated in major cities. Removal of sediments and solids in primary treatment, chlorination and oxidation in secondary treatment of domestic wastewater can be used for gardening and filling of drained tanks. In this context, water samples were taken to examine the groundwater quality for chemical and hydro-chemical properties for irrigation purposes.

2. MATERIALS AND METHODS

2.1 Sampling and Analysis

Fifty irrigation water samples were collected in clean polypropylene bottles from bore wells in farmers' fields in different villages of Kolar and Chickballapur districts in the Eastern Dry Zone of Karnataka, India (Fig. 1). The water samples collected were from tanks filled with treated wastewater, which is the source of groundwater recharge in this region, to assess its quality for irrigation and drinking purposes. The Global Positioning System (GPS) was used to record the coordinates of the sampling points.

The treated water is piped to 126 tanks in Kolar district. Currently, about 25 tmc of water flows from the valley to Tamil Nadu. In the first phase, about 4.4 tmcft of water will be treated and sent to tanks in Kolar district. Later, more treated water will be diverted to fill tanks in Chickballapur district. The total length of the pipeline will be 85 km. The tanks in Kolar and Chickballapur districts have been identified for rejuvenation.

Water was first drained from the bore well for about 15 minutes to obtain clear water without sediments. Thereafter, the collected water samples were stored in polyethylene bottles of 500 ml capacity. Each bottle was rinsed with the sample water and 2-3 drops of toluene were added to prevent microbial growth before collecting the water sample. The bottles were then sealed airtight and labelled. The water samples were filtered through filter paper to remove dirt and dust particles in the laboratory. All water samples were chemically analyzed for various parameters.

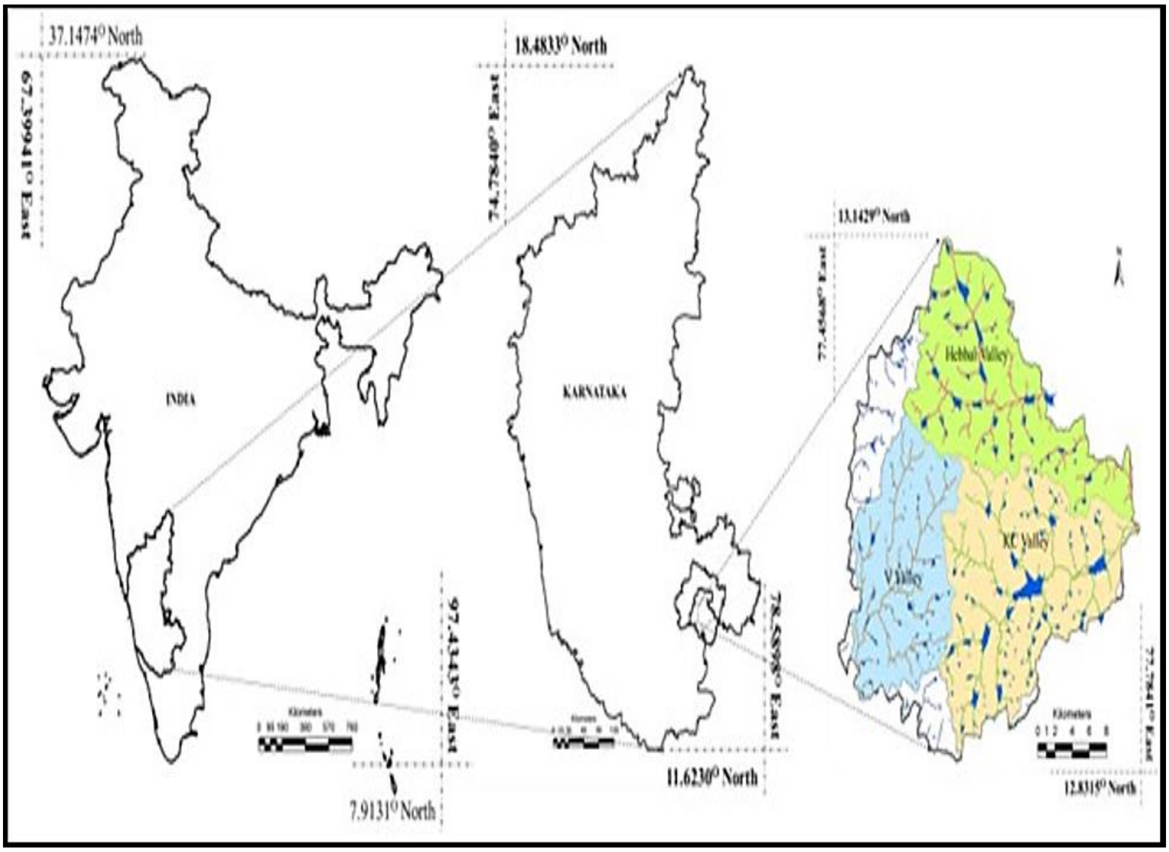

Fig. 1 Location of the study area

2.2 Irrigation Water Physicochemical Parameters

pH, electrical conductivity (EC), dissolved oxygen (DO), salinity and total dissolved solids (TDS) were determined on site using potentiometric and conductometric electrodes (Systronics). Spectrophotometric methods were used to estimate Cl^-, F^-, SO_4^{2-} and PO_4^{3-}-content, and titrimetric methods were used to determine TA, TH and HCO_3^-, Ca^{2+} and Mg^{2+}. Na^+ and K^+ were estimated by flame photometer and irrigation water quality indices such as sodium absorption ratio (SAR), permeability index (PI), Kelly index (KI), magnesium adsorption ratio (MAR) and irrigation water quality index (IWQI) were calculated to evaluate the suitability of water for irrigation.

2.3 Irrigation Water Quality Parameters

2.3.1 Sodium adsorption ratio of irrigation water samples

The sodium adsorption ratio (SAR) is an index generally used to assess the suitability of water for irrigation purposes, as it is an index of the sodium/alkali vulnerability of crops. The SAR value is determined by the ratio of Na^+ to Ca^{2+} + Mg^{2+} and. Magnesium and calcium ions are important as these ions tend to balance the effect of sodium. The potential exposure to sodium increases with a higher SAR value. The SAR was estimated using this formula:

$$\mathrm{SAR}=\frac{Na}{\sqrt{Ca+Mg}} \text{ (Richard, 1954)}$$

2.3.2 Residual Sodium Carbonate of irrigation water samples

The bicarbonate and carbonate content of the irrigation water was also analysed for its suitability for irrigation purposes. The excess sum of carbonate and bicarbonate over the sum of calcium and magnesium in irrigation water also affects its suitability for irrigation purposes. The residual sodium carbonate (RSC) content was determined according to the formula of Eaton (1950). All units are in meq L^{-1}.

$$\mathrm{RSC}\ (\mathrm{meq\ L^{-1}}) = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

2.3.3 Total Hardness of irrigation water samples

Total hardness (TH) was calculated using the concentration of Ca2+ and Mg+2 in irrigation water samples (Eaton, 1950).

$$\mathrm{TH\ (mg\ L^{-1})} = Ca^{2+}\ (2.497) + Mg^{2+}\ (4.118)$$

2.3.4 Total Dissolved Solids of irrigation water samples

The total dissolved solids (TDS) content was calculated using the concentration of EC (dS m^{-1}) in the irrigation water samples (Eaton, 1950).

$$\mathrm{TDS\ (mg\ L^{-1})} = EC_w\ (\mathrm{dS\ m^{-1}}) \times 640$$

2.4 Determining the Water Quality Index

The Water Quality Index (WQI) is a very useful and efficient method of assessing water quality. The WQI is a very useful tool to provide information about the overall quality of the water, as water quality does not depend on a single parameter. there are about 11 to 12 physico-chemical parameters that need to be tested for water quality assessment. To determine the suitability of groundwater for irrigation purposes, the WQI is calculated using the following formula

WQI= Antilog [ΣWn n=1 log10 qn]

here, W= Weight age factor (W) is computed using the following equation,

Wn=K/Sn and K= proportionality constant is derived from,

K=[1/(Σn, n=11/Si)] Sn and Si are Indian Standard values of the water quality parameter. Quality rating (q) is calculated using the formula,

qni= {[(Vactual-Videal)/(Vstandard-Videal)]*100}

Where, qni=Quality rating of ith parameter for a total of n water quality parameters Vactual=Value of the water quality parameter obtained from laboratory analysis Videal=Value of the water quality parameter can be obtained from the standard tables Videal for ph=7 and for other parameters it is equivalent to zero.

Vstandard = BIS standard of the water quality parameter.

2.5 Hydro-chemical Regime

In the fields of hydrogeology and water analysis, Piper diagrams (also known as trilinear diagrams) are a very powerful tool for visualizing the relative abundance of common ions in water samples. While there is another approach that can be used to visualize the abundance of ions in water, this one is better because it allows multiple samples to be plotted on the same diagram, allowing water samples to be grouped by water facies and other criteria. A Piper diagram consists of three components: a ternary diagram at the bottom left representing the cations (magnesium, calcium, sodium and potassium), a ternary diagram at the bottom right representing the anions (chloride, sulphate, carbonate and bicarbonate), and a diamond diagram in the centre, which is a matrix transformation of the two ternary diagrams (Fig. 2). Each sample is normalized (sum of cations = 100 and sum of anions = 100) so that the relative concentrations are expressed on a percentage basis. In the present study, therefore, a Piper diagram was constructed to understand the nature of groundwater and surface water.

3. RESULTS AND DISCUSSION

3.1 pH

The pH value is a measure of the acidity or alkalinity of the water. The data on pH of irrigation water from different villages of Chintamani taluk presented in Table 4 shows that the concentrations of hydrogen ions ranged from 7.18 to 8.86, with a mean value of 8.26. The higher pH of groundwater could be due to high concentrations of sodium, calcium, magnesium, carbonate and bicarbonate which produce hydroxyl ions. The results of the present study are in agreement with the findings of Prasad and Minhas (2007) who reported a variation in the pH of groundwater.

3.2 Electrical Conductivity (EC)

Electrical conductivity is the measure of the total soluble salts in water, which is the result of the total dissolved salts in water. The data presented in Table 4 show that the EC value varies from 430 to 827 µmhos cm^{-1} with an average of 587 µmhos cm^{-1}.

The EC value in irrigation water affects soil structure, permeability and aeration, which indirectly affects plant growth (and impairs the uptake of water and nutrients from the soil). Osmotic pressure of soil water by plant roots, leading to physiological drought. Sharma et al*.* (2017) stated that the high EC value in water samples could be due to continuous leaching or dissolution of groundwater material or mixing of salt sources or a combination of these activities.

Table 1. Methods followed for analysing water quality parameters

Sl. No.	Parameters	Method of determination
1	pH	Potentiometric method
2	EC	Conductometric method
3	Calcium	Complexometric titration method
4	Magnesium	Complexometric titration method
5	Sodium	Atomic emission spectrophotometer
6	Potassium	Atomic emission spectrophotometer
7	Carbonates and bicarbonate	Acid v/s base titration method
8	Chloride	Precipitation titration method
9	Fluoride	Zirconyl acid- SPADNS, spectrophotometer
10	Phosphate	Spectrophotometer method
11	Sulphate	Turbidometric method
12	Nitrate	Kjeldhal distillation method using devardoys alloy

Table 2. Water quality parameter, their bis standards, and weightages

Parameter	Standard (S_n &S_i)	Weightage (W_n)
pH	7.0000	0.113160575
TDS (mg L^{-1})	500.0000	0.001584248
TH (mg L^{-1})	300.0000	0.002640413
Ca (mg L^{-1})	75.0000	0.010561654
Mg (mg L^{-1})	30.0000	0.026404134
Na (mg L^{-1})	200.0000	0.00396062
HCO_3- (mg L^{-1})	35.0000	0.022632115
2-1 SO_4 - (mg L)	200.0000	0.00396062
3-1 PO_4 - (mg L)	40.0000	0.019803101
Cl^- (mg L^{-1})	250.0000	0.003168496

Table 3. Water quality index categories

Water Quality Index	Description
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unfit for Usage

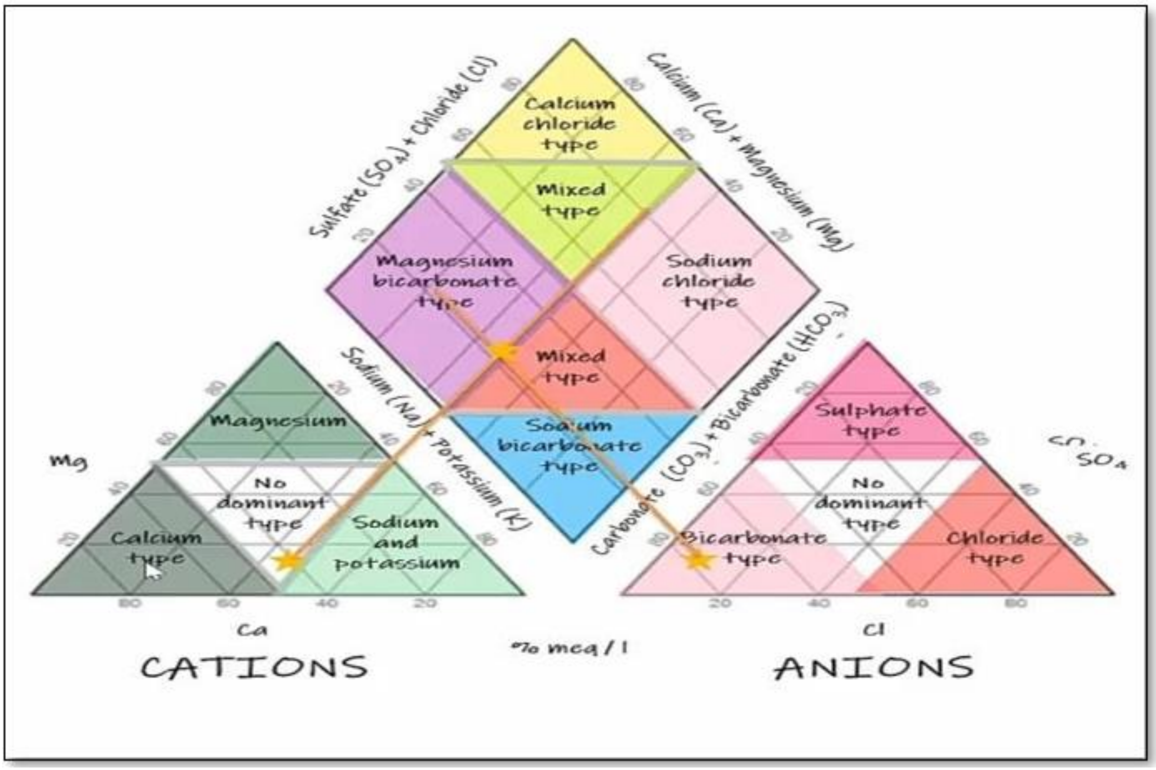

Fig. 2. Hydro-chemical facies in the cation and anion triangles

3.3 Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) of water is considered a better measure of sodium (alkali) hazard in irrigation because it is directly related to sodium adsorption by the soil and was a valuable criterion for evaluating the suitability of water for irrigation. The data presented in Table 4 showed that SAR values ranged from 0.27 to 1.16, with a mean value of 0.54. Similar results were recorded by Ayisha et al*.* (2016). The SAR value ranged from 0.11 to 1.36, with all samples being suitable for irrigation.

3.4 Residual Sodium Carbonate (RSC)

The amount of carbonate and bicarbonate in the excess of alkaline sediments (Ca^{2+} and Mg^{2+}) also influences the suitability of the water for irrigation purposes. If the sum of carbonate and bicarbonate is too high, there is a possibility of complete precipitation of calcium and magnesium. The data in Table 4 show that the RSC values vary from -9.38 to -0.81 meq L^{-1} with a mean value of -5.37 meq L^{-1}. Choudhary et al*.* (2020) found that the RSC value of well water ranged from 0.05 to 2.23 meq L^{-1} in the pre-monsoon season, while the value ranged from -0.10 to 2.23 meq L^{-1} in the post-monsoon season. The higher mean value of RSC was observed for the pre-monsoon season. The reason for this could be the dissolution of salts in the groundwater, which are present in the study area due to the high rainfall during the monsoon season.

3.5 Total Dissolved Solids (TDS)

Natural sources and wastewater discharges are the reasons for the formation of total dissolved solids in water. Electrical conductivity has a direct effect on the concentration of total dissolved solids. The hydrogeological reactions between the water and the rock type affect the TDS concentration. The analysed samples were divided into different groups based on the TDS concentration according to the U. S. Geological Survey and the results are listed in the Table 4. The TDS content of the groundwater ranges from 275.20 to 529.28 mg L^{-1} with an average value of 382.69 mg L^{-1}, all samples are within the permissible limits. Similar results were obtained by Arunkumar et al*.* (2011), Basavaraj et al*.* (2016) and Manohar et al. (2014).

3.5.1 Total hardness (TH)

Hardness is the property of water that prevents the formation of foam with soap and increases the boiling point of water. The hardness of water depends mainly on the amount of calcium or magnesium salts or both. Calcium and magnesium are the most abundant elements in the natural surface and are present mainly as bicarbonates and to a lesser extent in the form of sulphate and chloride. The TH values of groundwater range from 286.34 to 886.06 mg L^{-1} with an average value of 596.16 mg L^{-1}. Similar results were obtained by Arunkumar et al. (2011), Basavaraj et al*.* (2016) and Manohar et al*.* (2014).

3.5.2 Cation's concentration in irrigation water collected from Chintamani taluk Calcium (Ca)

The calcium content in groundwater is higher than that of magnesium. It is a major component of most igneous, metamorphic and sedimentary rocks. The range of calcium content in groundwater largely depends on the solubility of the calcium-containing rocks calcite, dolomite and marble. Calcium is present in all groundwater due to its occurrence and solubility.

The calcium concentration data in Table 5 show that the highest calcium concentration is 8.54 meq L^{-1} and the lowest is 3.26 meq L^{-1}, with an average of 7.33 meq L^{-1}. The presence of a large amount of dissolved carbon dioxide in water can increase the solubility of calcium in the presence of bicarbonate. Silicate minerals release significant amounts of soluble calcium during weathering, which eventually reaches the groundwater. Calcium is present in all groundwater due to its occurrence and solubility. Golekar et al*.* (2017) found that the calcium concentration could be due to ion exchange of minerals from the rock in the area, which was the source of the calcium in the water.

3.5.3 Magnesium (Mg)

Magnesium, an important component of rock-forming minerals, is contained in minerals such as chlorite, serpentine, biotite, hornblende, olivine and augite. The magnesium content in groundwater therefore ranges widely. Magnesium salts occur in significant concentrations in natural water and are often lower than calcium concentrations because they are less abundant than calcium in all rock types.

The magnesium concentration shown in Table 5 ranges from 1.25 to 4.98 meq L^{-1} with a mean value of 3.60 meq L^{-1}. Aher (2012) reported that the magnesium value ranges from 5 to 158 mg L-1, which could be due to the fact that the rock type in the study area is the source of magnesium in groundwater. Magnesium salts occur in significant concentrations in natural water and are often lower than calcium concentrations as they are less abundant than calcium in all rock types. Mukate et al (2019) reported that the slow dissolution of magnesium-rich minerals can decrease magnesium concentrations compared to calcium. Similar results were reported by Basavaraj et al*.* (2016) and Manohar et al. (2014).

3.5.4 Potassium (K)

Potassium concentration is a function of the weathering rate of silicate minerals such as orthoclase, microcline and biotite as well as the application of fertilizers. The concentration of potassium in most natural waters is very low as it does not dissolve easily and is readily and rapidly released during weathering. Potassium is a naturally occurring element, but its concentration is quite low compared to Ca, Mg and Na. From the data presented in Table 3, the concentration of potassium varies between 0.11 and 0.50 meq L^{-1}, with a mean value of 0.27 meq L^{-1}. Aher (2012) found that the potassium value ranged between 1.28 and 10.10 meq L^{-1}, with the main source of potassium in groundwater being rainwater, weathering of potassium- bearing minerals and the use of potash fertilizers.

3.5.5 Sodium (Na)

Sodium is enriched in groundwater primarily through interaction with silicate minerals, precipitates from the atmosphere and halite deposits. Sodium ions are found in groundwater as a result of weathering and dissolution processes. Their occurrence is due to the mechanism of mineral cation exchange. The data presented in Table 5 show that the sodium concentration varies between 0.60 and 2.20 meq L^{-1} with a mean value of 1.10 meq L^{-1}. Aher (2017) found that the sodium concentration ranged from 0.30 to 2.65 meq L^{-1}, with groundwater containing some sodium as most rocks and soils contain sodium compounds from which sodium is readily dissolved.

3.5.6 Anions concentration in irrigation water collected from Chintamani taluk Carbonates (CO_3^-) and Bicarbonates (HCO_3^-)

Dissolved CO_2 in rainwater is the main source of carbonate and bicarbonate ions in groundwater. Temperature and pressure control the solubility of CO_2 in water; it is more soluble when the temperature increases and the pressure decreases and vice versa. CO_2-rich water dissolves carbonate minerals found in soils and rocks as it flows through, forming bicarbonates. Due to the limited fluctuations in the interstitial pores of the rocks in the aeration zone, the bicarbonate concentration remains fairly constant.

The carbonate and bicarbonate concentration data in Table 4 show that carbonate values range from 0 to 0.36 meq L^{-1}, with a mean value of 0.05 meq L^{-1}.

Mukate et al. (2019) stated that the carbonate content could result from the weathering of silicate rock as well as atmospheric and soil carbon dioxide gas. Carbon dioxide is produced in the soil through the decomposition of organic matter and root respiration and mixes with precipitation to form bicarbonates. The data presented in Table 6 show that the bicarbonate content varies between 0.64 and 5.54 meq L^{-1}, with an average of 3.52 meq L^{-1}.

List 1. SAR value of the samples being suitable for irrigation

Water class	SAR	Remarks
S1- Low	0-10	Negligible
S2- Medium	10-18	Medium Hazard
S3- High	18-26	High Hazard
S4- Very High	>26	Very High Hazard

List 2. RSC value of well water

RSC (meq L^{-1})	Water quality
<1.25	Water can be used safely
1.25-2.5	Water can be used with certain management
>2.5	Unsuitable for irrigation

List 3. TDS content of the groundwater

TDS	Water class
<450 mg L^{-1}	Suitable for Irrigation
450-2000 mg L^{-1}	Slight to moderate suitable for Irrigation
>2000 mg L^{-1}	Unsuitable for Irrigation

List 4. TH values of groundwater

Hardness (ppm)	Water class
0-75	Soft
75-150	Moderate Hard
150-300	Hard
>300	Very hard

Table 4. Quality parameters of irrigation water collected from chintamani taluk

Sample No.	**pH**	**EC (µmhos cm^{-1})**	**SAR**	**RSC (meq L^{-1})**	**TDS (mg L^{-1})**	**TH (mg L^{-1})**
1	8.26	501	0.57	-4.08	320.64	561.81
2	7.90	589	0.63	-2.10	376.96	494.97
3	7.75	554	1.16	-4.04	354.56	633.13
4	8.06	761	0.96	-5.68	487.04	675.83
5	8.75	488	0.60	-3.06	312.32	532.67
6	8.32	485	0.90	-0.91	310.40	392.78
7	8.07	638	0.63	-5.12	408.32	715.47
8	8.11	645	0.90	-5.70	412.80	721.10
9	7.56	631	0.66	-8.63	403.84	881.06
10	8.86	536	0.77	-3.07	343.04	492.94
11	7.50	827	0.69	-4.15	529.28	586.20
12	7.84	481	0.42	-3.02	307.84	536.42
13	8.03	550	0.62	-0.81	352.00	420.45
14	7.84	512	0.51	-8.92	327.68	872.91
15	7.89	570	0.34	-6.71	364.80	746.27
16	7.69	582	0.48	-8.86	372.48	697.07
17	7.85	567	0.42	-5.83	362.88	465.87
18	8.16	430	0.43	-5.69	275.20	417.82
19	7.72	548	0.82	-4.18	350.72	334.98
20	7.33	610	0.88	-6.48	390.40	489.66
21	7.69	526	0.46	-6.98	336.64	506.87
22	7.51	682	0.62	-5.58	436.48	398.70
23	7.18	544	0.27	-9.38	348.16	693.16
24	7.92	634	0.85	-3.67	405.76	286.34
25	7.84	539	0.48	-6.00	344.96	474.74
26	7.62	610	0.38	-7.71	390.40	552.56
27	8.10	645	0.37	-5.54	412.80	406.58
28	8.05	578	0.60	-7.54	369.92	528.85
29	7.45	692	0.30	-8.72	442.88	646.70
30	7.58	575	0.58	-7.87	368.00	641.19
31	7.51	507	0.82	-3.04	324.48	504.58
32	8.05	602	0.33	-4.64	385.28	631.46
33	7.80	626	0.33	-6.23	400.64	722.54
34	7.87	656	0.85	-2.31	419.84	453.88
35	8.34	520	0.36	-6.39	332.80	732.53
36	8.00	645	0.30	-3.34	412.80	519.65
37	8.68	691	0.27	-7.91	442.24	834.33
38	8.40	620	0.60	-2.40	396.80	474.62
39	8.27	647	0.36	-5.59	414.08	692.68
40	8.15	631	0.48	-8.63	403.84	886.06
41	8.32	674	0.31	-7.88	431.36	811.85
42	8.21	616	0.35	-5.29	394.24	684.14
43	7.81	611	0.58	-6.32	391.04	723.40
44	7.87	627	0.40	-5.04	401.28	649.55
45	8.06	635	0.45	-2.60	406.40	501.46
46	8.35	644	0.51	-4.74	412.16	632.67
47	7.83	526	0.47	-1.80	336.64	425.26
48	8.33	639	0.28	-5.61	408.96	688.94
49	7.89	578	0.41	-3.97	369.92	551.56
50	8.26	673	0.31	-8.60	430.72	881.90
Min	7.18	430.00	0.27	-9.38	275.20	286.34
Max	8.86	827.00	1.16	-0.81	529.28	886.06
Avg	8.26	587.00	0.54	-5.37	382.69	596.16

Sample No.	pH	EC (µmhos cm^{-1})	SAR	RSC (meq L^{-1})	TDS (mg L^{-1})	TH (mg L^{-1})
SD	0.35	121.62	0.21	2.26	47.44	150.69
CV	42.50	20.72	39.59	-42.11	12.40	25.28

Table 5. Cations concentration in irrigation water collected from Chintamani taluk

Samples	Ca (meq L^{-1})	Mg (meq L^{-1})	K (meq L^{-1})	Na (meq L^{-1})
1	6.50	2.40	0.35	1.21
2	5.32	2.32	0.37	1.23
3	6.82	2.96	0.33	1.94
4	7.20	3.20	0.40	2.20
5	5.60	2.56	0.42	1.22
6	4.56	1.67	0.13	1.59
7	7.40	3.50	0.12	1.46
8	6.84	3.84	0.13	2.07
9	8.44	4.65	0.12	1.70
10	5.22	2.35	0.21	1.49
11	5.90	2.95	0.47	1.18
12	5.20	2.80	0.34	0.83
13	4.56	1.95	0.14	1.11
14	7.98	4.80	0.17	1.30
15	7.72	3.65	0.25	0.80
16	6.24	3.90	0.15	1.09
17	4.48	2.45	0.16	0.79
18	4.25	2.08	0.20	0.77
19	3.66	1.54	0.11	1.33
20	4.62	2.62	0.35	1.68
21	5.40	2.40	0.22	0.91
22	4.54	1.74	0.16	1.09
23	6.32	3.82	0.15	0.60
24	3.26	1.25	0.20	1.28
25	4.44	2.56	0.19	0.89
26	5.82	2.65	0.21	0.79
27	4.50	1.84	0.35	0.65
28	5.84	2.40	0.14	1.22
29	6.30	3.36	0.18	0.67
30	5.22	3.85	0.19	1.24
31	4.80	2.68	0.11	1.59
32	5.52	3.60	0.32	0.70
33	6.75	3.90	0.17	0.75
34	4.24	2.45	0.39	1.55
35	6.95	3.90	0.42	0.85
36	5.26	2.60	0.42	0.60
37	7.90	4.45	0.20	0.66
38	4.20	2.68	0.44	1.11
39	6.35	3.80	0.40	0.81
40	8.54	4.65	0.39	1.24
41	8.38	3.98	0.38	0.76
42	6.08	3.85	0.16	0.79
43	7.44	3.56	0.37	1.36
44	6.08	3.50	0.32	0.88
45	4.50	2.80	0.47	0.86
46	5.94	3.40	0.50	1.11
47	4.32	2.12	0.22	0.84
48	6.75	3.56	0.30	0.63
49	5.80	2.65	0.38	0.85

Samples	Ca (meq L^{-1})	Mg (meq L^{-1})	K (meq L^{-1})	Na (meq L^{-1})
50	8.16	4.80	0.45	0.79
Min	3.26	1.25	0.11	0.60
Max	8.54	4.98	0.50	2.20
Avg	7.33	3.60	0.27	1.10
SD	1.17	1.70	0.12	0.39
CV	23.02	29.29	43.67	35.84

3.5.7 Phosphate (PO_4^{3-})

The concentration of phosphate in groundwater is increased by natural processes such as the decomposition of rocks and minerals, atmospheric deposition, runoff, sedimentation, etc. In addition to natural processes, anthropogenic sources such as fertilizers, animal waste, phosphate mining, industrial wastewater, etc. also contribute to increasing the phosphate content in groundwater. Phosphate is not very mobile, as the formation of stable compounds such as Fe-P and Al-P is one of the reasons for the low phosphate concentration. The phosphate concentration in Table 6 varies between 0.02 and 0.25 meq L^{-1} with a mean value of 0.12 meq L^{-1}. The results were similar to Fadiran et al. (2008).

3.5.8 Sulphate (SO_4^{2-})

Sulphate sulphur is only present in atmospheric precipitation at a level of about 2 mg L^{-1}, but it is present in groundwater due to oxidation, precipitation solution and concentration as the water flows through the rock. The sources of this contamination are sulphur minerals, sulphides of heavy metals, which are commonly found in igneous and metamorphic rocks. Sulphate salts are largely soluble in water and give it hardness. In the present results, the sulphate values in Table 6 and the values ranged from 0.85 to 3.18 meq L^{-1} with a mean value of 1.88 meq L^{-1}.

Barite, epsomite and gypsum *etc.* are the natural sources for the occurrence of sulphate in groundwater in dissolved form. Anomalies in the sulphate concentration in groundwater are found in the ore zones, especially in pyrite. In addition, the extensive use of sulphate fertilisers enriches the sulphate concentration in the groundwater. The results of the present study are supported by the findings of Gurugnanam et al. (2009) and Swarna and Nageswara (2010).

3.5.9 Nitrate (NO_3^-)

The most oxidised form of nitrogen is nitrate. Nitrate in irrigation water is enriched due to natural and anthropogenic activities such as precipitation, use of extensive fertilisers, human and animal wastes, etc., and ranges from 30.25 mg L^{-1} to 80.52 mg L^{-1} with an average of 50.52 mg L^{-1}, as shown in Table 6.

3.5.10 Chloride (Cl^-)

The leaching of chloride-containing rocks and minerals such as sodalite and chlorapatite can lead to a natural process of chloride accumulation in groundwater. The uncontrolled discharge of waste products from agriculture, industry and wastewater etc. can also cause chloride concentrations. A high concentration of chloride in groundwater leads to a bad taste in the water. Chloride ions combine with sodium to form sodium chloride and thus increase the salt content of the groundwater. The chloride concentration of groundwater in Table 6 varies from 4.32 to 16.56 meq L^{-1} with an average value of 11.44 meq L^{-1}. The chloride concentration is higher because the farmers in Chintamani use more bleaching powder as a disinfectant. Therefore, the toxicity of chloride is higher in these areas.

Ramakrishnaiah et al. (2009) reported that chloride concentration in groundwater is high, temperature is high and rainfall is low and soil porosity and permeability also play an important role in building up chloride concentration. The most important lithogenic sources of chloride in groundwater include atmospheric precipitation, the dissolution of salt deposits and the weathering of halite and evaporate. Faeces, industrial and animal waste, fertilisers and leachate from landfills and dumps are all potential anthropogenic sources of chloride.

3.5.11 Fluoride (F^-)

Natural processes such as the decomposition of rock and soil or the weathering and deposition of atmospheric volcanic particles can lead to a fluoride concentration in groundwater. In addition to natural processes, anthropogenic activities such as the extensive use of fertilizers, untreated wastewater and sewage sludge as well as industrial waste can also contribute to fluoride concentrations in groundwater. The fluoride concentration in Table 6 and was between 1.85 and 2.30 meq L^{-1} with an average value of 2.03 meq L^{-1}.

Fluoride in groundwater mainly originates from the weathering of fluoride-containing minerals such as muscovite, fluorite, biotite, fluorapatite and from industrial and agricultural sources. The alkaline water helps to mobilize F- from fluoride-containing minerals through the precipitation of calcium carbonate. The $NaHCO_3$-rich water accelerates the dissolution of the fluoride-containing minerals, thereby releasing fluoride into the groundwater (Brindha et al. 2012).

Table 6. Anions concentration in irrigation water collected from Chintamani taluk

Samples	CO_3^{2-} (meq L^{-1})	HCO_3^- (meq L^{-1})	SO_4^{2-} (meq L^{-1})	PO_4^{3-} (meq L^{-1})	Cl^- (meq L^{-1})	NO_3 (mg L^{-1})$^-$	F^- (meq L^{-1})
1	0.04	4.78	1.48	0.07	12.60	30.25	1.88
2	0.16	5.38	1.91	0.19	12.88	32.56	2.09
3	0.20	5.54	1.48	0.09	9.00	40.12	1.98
4	0.12	4.60	1.91	0.08	13.12	48.35	2.22
5	0.28	4.82	3.18	0.12	9.24	36.78	2.20
6	0.32	5.00	2.33	0.08	9.36	45.12	2.04
7	0.24	5.54	2.76	0.07	12.80	52.65	2.25
8	0.12	4.86	3.18	0.14	14.08	50.38	2.01
9	0.16	4.30	1.48	0.12	14.28	55.45	1.93
10	0.04	4.46	2.97	0.10	12.52	58.68	1.98
11	0.36	4.34	2.54	0.12	13.32	62.48	1.96
12	0.32	4.66	2.12	0.14	8.52	70.25	1.98
13	0.16	5.54	2.97	0.18	8.80	42.98	2.17
14	0.20	3.66	2.12	0.20	13.88	58.74	1.96
15	0.00	4.66	2.33	0.18	15.44	60.25	2.06
16	0.00	1.28	1.91	0.06	15.80	65.79	1.90
17	0.00	1.10	1.70	0.09	9.72	63.24	1.96
18	0.00	0.64	0.85	0.07	8.12	40.32	2.06
19	0.00	1.02	1.48	0.10	10.20	32.45	1.96
20	0.00	0.76	1.48	0.11	10.32	36.56	1.96
21	0.00	0.82	1.91	0.12	14.32	40.85	2.17
22	0.00	0.70	1.48	0.20	12.16	75.45	1.96
23	0.00	0.76	1.70	0.18	12.64	60.28	2.06
24	0.00	0.84	2.54	0.12	14.24	52.64	2.12
25	0.00	1.00	2.76	0.14	13.12	80.52	2.22
26	0.00	0.76	2.12	0.15	9.84	78.40	1.88
27	0.00	0.80	1.48	0.02	11.84	45.63	2.30
28	0.00	0.70	1.27	0.10	12.48	78.63	2.20
29	0.00	0.94	1.70	0.10	13.00	54.25	2.22
30	0.00	1.20	1.91	0.12	13.40	58.38	2.06
31	0.00	4.44	0.85	0.08	7.16	77.35	1.98
32	0.00	4.48	1.06	0.10	7.64	60.45	1.88
33	0.00	4.42	1.27	0.10	12.76	65.28	1.85
34	0.00	4.38	1.06	0.12	10.80	66.89	2.12
35	0.00	4.46	0.85	0.13	6.84	75.29	2.09
36	0.00	4.52	1.27	0.11	6.36	45.74	1.96
37	0.00	4.44	2.33	0.03	4.32	58.85	1.90
38	0.00	4.48	3.18	0.20	9.28	65.45	1.96
39	0.00	4.56	2.54	0.25	7.56	71.28	1.98
40	0.00	4.56	1.70	0.11	10.04	35.45	1.96
41	0.00	4.48	1.27	0.07	8.64	38.50	1.96
42	0.00	4.64	1.48	0.10	12.12	45.78	1.93
43	0.00	4.68	1.91	0.08	15.52	36.45	1.93

Samples	CO_3^{2-} (meq L^{-1})	HCO_3^- (meq L^{-1})	SO_4^{2-} (meq L^{-1})	PO_4^{3-} (meq L^{-1})	Cl^- (meq L^{-1})	NO_3 (mg L^{-1})$^-$	F^- (meq L^{-1})
44	0.00	4.54	1.48	0.12	11.84	70.78	1.93
45	0.00	4.70	1.06	0.16	14.32	65.40	2.01
46	0.00	4.60	2.12	0.13	13.76	75.62	1.98
47	0.00	4.64	2.54	0.07	16.56	74.21	2.01
48	0.00	4.70	1.91	0.09	10.24	77.85	2.12
49	0.00	4.48	1.70	0.07	15.28	60.28	2.17
50	0.00	4.36	1.27	0.10	10.16	70.56	1.98
Min	0.00	0.64	0.85	0.02	4.32	30.25	1.85
Max	0.36	5.54	3.18	0.25	16.56	80.52	2.30
Avg	0.05	3.52	1.88	0.12	11.44	56.92	2.03
SD	0.10	1.77	0.64	0.05	2.80	14.70	0.11
CV	187.76	50.34	34.20	40.22	24.47	0.26	5.54

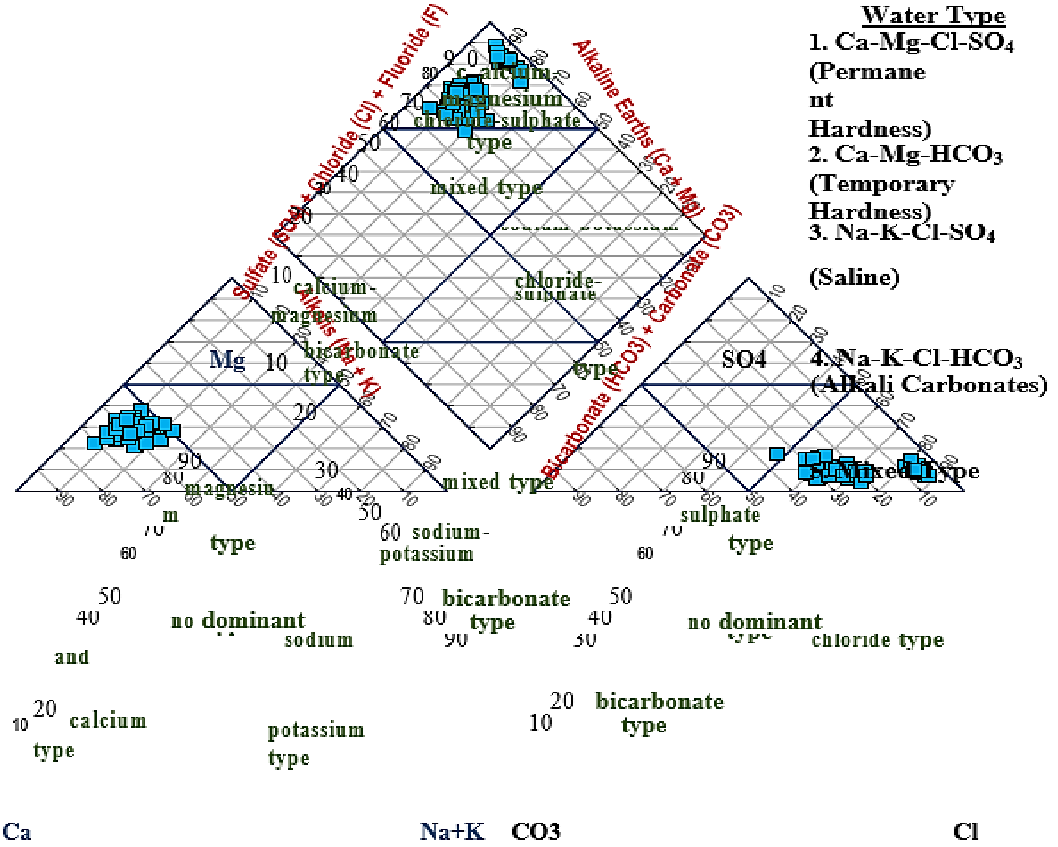

Fig. 3. Piper diagram based on the anion and cation concentration of irrigation water of the Chintamani taluk

3.6 Hydro-geochemical Facies (*Piper diagram*) of Irrigation Water in Chintamani Taluk

The evaluation of the connection between the salts found and their impact on water quality is done through the utilization of hydro-geochemical facies. Within hydro-geochemical research, the piper diagram, also referred to as the Trilinear diagram, serves as an effective visual representation of the chemical composition in water samples. This diagram is constructed based on the percentage values of six ion groups: sulphate, chloride, carbonate and bicarbonate anions, as well as calcium, magnesium, sodium, and potassium cations. The fundamental principle underlying this approach is that cations and anions are typically found in natural waters in a chemically balanced state (Ravikumar et al., 2015).

Table 7. Water quality index

Parameter s	Sn	1/Sn	Wi	Vi	Vn	Qn=Vn/Sn*10 0	Wi*Qn
pH	7.0000	0.142857	0.113161	7	7.9686	113.8371	12.88188
TDS	500.0000	0.002	0.001584	0	660.3264	132.0653	0.209224
TH	300.0000	0.003333	0.00264	0	311.8622	103.9541	0.274482
Ca	75.0000	0.013333	0.010562	0	5.8822	7.842933	0.082834
Mg	30.0000	0.033333	0.026404	0	3.0598	10.19933	0.269305
Na	200.0000	0.005	0.003961	0	1.1012	0.5506	0.002181
-HCO_3	35.0000	0.028571	0.022632	0	1.7602	5.029143	0.11382
2-SO_4	200.0000	0.005	0.003961	0	0.939	0.4695	0.00186
3-PO_4	40.0000	0.025	0.019803	0	0.1156	0.289	0.005723
Cl^-	250.0000	0.004	0.003168	0	6.023579	2.409432	0.007634
F^-	1.0000	1	0.792124	0	1.067789	106.7789	84.58217
WQI=∑Wi.Qn/∑Wi							98.43111

Two triangles are utilized in piper plots; one triangle is designated for cations while the other is designated for anions. The conclusion is drawn based on the hydro-geochemical facies concept from a single point within a diamond-shaped region formed by merging the cations and anion fields. These tri-linear diagrams are beneficial in clearly illustrating the chemical relationships among water samples (Sadashivaiah et al., 2008). The research revealed that strong alkalis (Ca2+ and Mg2+) significantly surpass the weak alkalis (Na+ and K+) and strong acids (Cl- and SO42-) significantly surpass the weak acids (HCO3- and CO32-) in ground and surface water of agroecosystems in Bengaluru (Ramya and Elango, 2018).

Based on the piper plot diagram (Fig. 3), it can be inferred that the water quality is classified as calcium-magnesium-chloride-sulphate type. The elevated levels of calcium and magnesium, as well as sulphate, may be attributed to the dissolution and leaching of rocks rich in these minerals into the irrigation water. The combination of these ions with chloride and sulphate contributes to the permanent hardness of the water.

Study on the hydro-chemical facies of surface water in rural-urban and transition zones, revealing that the majority of samples belonged to the mixed Ca-Mg-Cl type, followed by the Ca-Mg-Cl-SO4 type and the Na-K-Cl-SO4 type. This trend was also observed by Alexandre et al. (2017). This analysis provides insights into the prevalence of common ions in water samples, which can have implications for soil health, bioaccumulation of ions in the food chain (such as chloride), and both positive and negative effects on crops in agro-ecosystems.

3.7 Water Quality Index

The water quality index of major samples was found to be poor (Table 7). The water quality index in Treated Sewage Water Tanks in Eastern Dry Zone of Karnataka was found to be good to unfit for irrigation. The most of water samples had poor water quality index. The main reasons for this as we have observed are open dumping of solid wastes, presence of intensive agricultural waste like plant protection chemicals and use of high dose of chemical fertilizers.

4. CONCLUSION

Treated wastewater has alternative sources of water and can be used to recharge groundwater that is generated in major cities. Removal of sediments and solids in primary treatment, chlorination and oxidation in secondary treatment of domestic wastewater can be used for gardening and filling of drained tanks.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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