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Research Journal of Agricultural Sciences
An International Journal

P- ISSN: 0976-1675
E- ISSN: 2249-4538

Volume: 13
Issue: 05

Res. Jr. of Agril. Sci. (2022) 13: 1648–1657

CARAS

Res. Jr. of Agril. Sci. (Sep-Oct 2022)
13(5): 1648–1657

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

www.rjas.org

Full Length Research Article

Evaluation of Ground Water Quality and its Suitability for Irrigation Usage, using some Statistical Methods in Rural Visakhapatnam, Andhra Pradesh, India – A Case Study

Bujjibabu Miriyala[1], Suresh P[2] and Hari Babu Bollikolla*[3]

Received: 01 Aug 2022 | Revised accepted: 04 Oct 2022 | Published online: 28 Oct 2022

A B S T R A C T

Groundwater is so precious and mostly pure than surface water, and it is utilized for the nourishment of all living organisms. Nearly 80% of rural India's agriculture and village crops depend upon groundwater. Due to contaminated groundwater, the yields of many crops are decreased. The economy of the present study area is mostly dependent upon agriculture. The main objective of the present study is to evaluate the groundwater quality and its suitability for irrigation by performing some statistical calculations such as Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Percent Sodium (%Na), Sodium Adsorption Ratio (SAR), Ion Exchange as Chloro-Alkaline Indices (CAI-I and CAI-II), Chloride classification and Magnesium ratio. For this study, groundwater samples were collected from chintalagorlavanipalem, pinamadaka, bottavanipalem, jallelapalem, lankelapalem, chinatadi, tanam, and parawada villages of rural Visakhapatnam, Andhra Pradesh, India during the period of pre-monsoon (April) and post-monsoon (September) seasons of 2021. For this study, the results of pH, Electrical Conductivity (EC), Total dissolved solids (TDS), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Potassium (K^{+}), Sodium (Na^{+}), Chlorides (Cl^{-}), Nitrates (NO_3), Total alkalinity (TA), Sulphates (SO_4^{-2}) were utilized. The results are compared with BIS (IS 10500:2012) drinking water and other designated standards. The result of Kelly's Ratio (KR), and Permeability Index (PI), showing abnormality in the study area as the study area is the very close proximity tothe industrial hub. The dominant hydro chemical facies of groundwater are $CaHCO_3$, mixed $CaNaHCO_3$, mixed Ca–Mg–Cl, and Na–Cl Water Types. Water is not suitable for irrigation at many sampling stations due to the high concentrations of sodium, chloride and other designated parameters, and it needs to be protected from the perils of contamination.

***Key words*:** Groundwater, Statistical calculation, Kelly's Ratio, Hydro chemical facies

Water is an indispensable element, and a precious commodity in nature, in that, freshwater is convenient for the survival of life on the earth; there is no substitute for water for its uses [1]. The influence of solid waste dumping sites, undignified drainage, domestic wastewater, and aquifer material mineralogy together with semiarid climate, and unempirical anthropogenic activities have adversely affected the groundwater quality [2]. Hence, contaminated water is soiling the good quality of water, it also damages the communal prosperity, and growth of the economy, and most seriously damaged human health & well-being. Before the industrial revolution, surface, as well as groundwater quality, is good enough with respect to quality and quantity. From the 18th century onwards, tremendous growth in industrial establishment causes to frantic growth of anthropogenic activities leading water resources vulnerable to contamination by various pollutants [3]. Therefore, the groundwater quality is depending on various parameters, these parameters are being distorted widely due to mixing up with the various types of pollutants. Industrial wastewater containing toxic chemical components, agricultural activities, runoffs, mining extracts, and urban sewage are the main causes of strange pollutant contamination in ground water [4-6]. Even today; the prime economy of rural India is agriculture. In rural Indian agriculture, groundwater plays a major role. Nearly 80% of rural India's agriculture and village cropping is depending upon groundwater, hence too much groundwater is drawing, and thus the quality of groundwater is deteriorating day by day. Moreover, the huge consumption of chemical fertilizers,

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pesticides, fungicides, and herbicides for high-yielding is another cause; industrial effluents and domestic sewers are the principal causes of groundwater pollution [7]. Due to deterioration and contaminated groundwater, the yields of many crops are decreased.

In the study area, the local public uses the groundwater for drinking, cattle feeding, household purpose, and irrigation. The present study area is highly mineralized and in close vicinity to the industrial hub; there might be chances to get contamination due to contaminated water mixed up with surface as well as groundwater due to percolation. The surplus quantity of soluble salts in the groundwater may be detrimental to several commercial crops. Therefore, a good necessary understanding of the water chemistry for respective groundwater is confident to suitably assess for irrigation purposes [8]. The present study is an attempt has been made to evaluate the concentration levels of some physicochemical parameters in groundwater.

MATERIALS AND METHODS

Visakhapatnam is a bowl area. It covers an area of 681.96 km^2 (263.31 sq mi), geographically; it is located amidst the Eastern Ghats and the coast of the Bay of Bengal. It lies between 17^o - 15' and 18^o-32' Northern latitude and 18^o - 54' and 83^o - 30' in Eastern longitude.

Material used for the study

Freshly purchased plastic cans, sterilized glass bottles, pipettes, burettes, beakers, measuring cylinders were used. AR-grade chemicals were used during analysis.

Study area

This is also a bumpy, slope area. The population density in this area is around 2500 per square kilometre. The sex ratio is 1120 females per 1000 males. The average minimum temperature ranges from 28 ^{o}C to 34 ^{o}C in November/December the average maximum temperature ranges from 35 ^{o}C to 42 ^{o}C in May/June. Usually, the southwest monsoon starts in the 3rd week of April every year and the northeast monsoon starts in October. The average annual rainfall is around 1100 to 1208 mm [9]. The photographic view of the study area is tabulated in the (Fig 1).

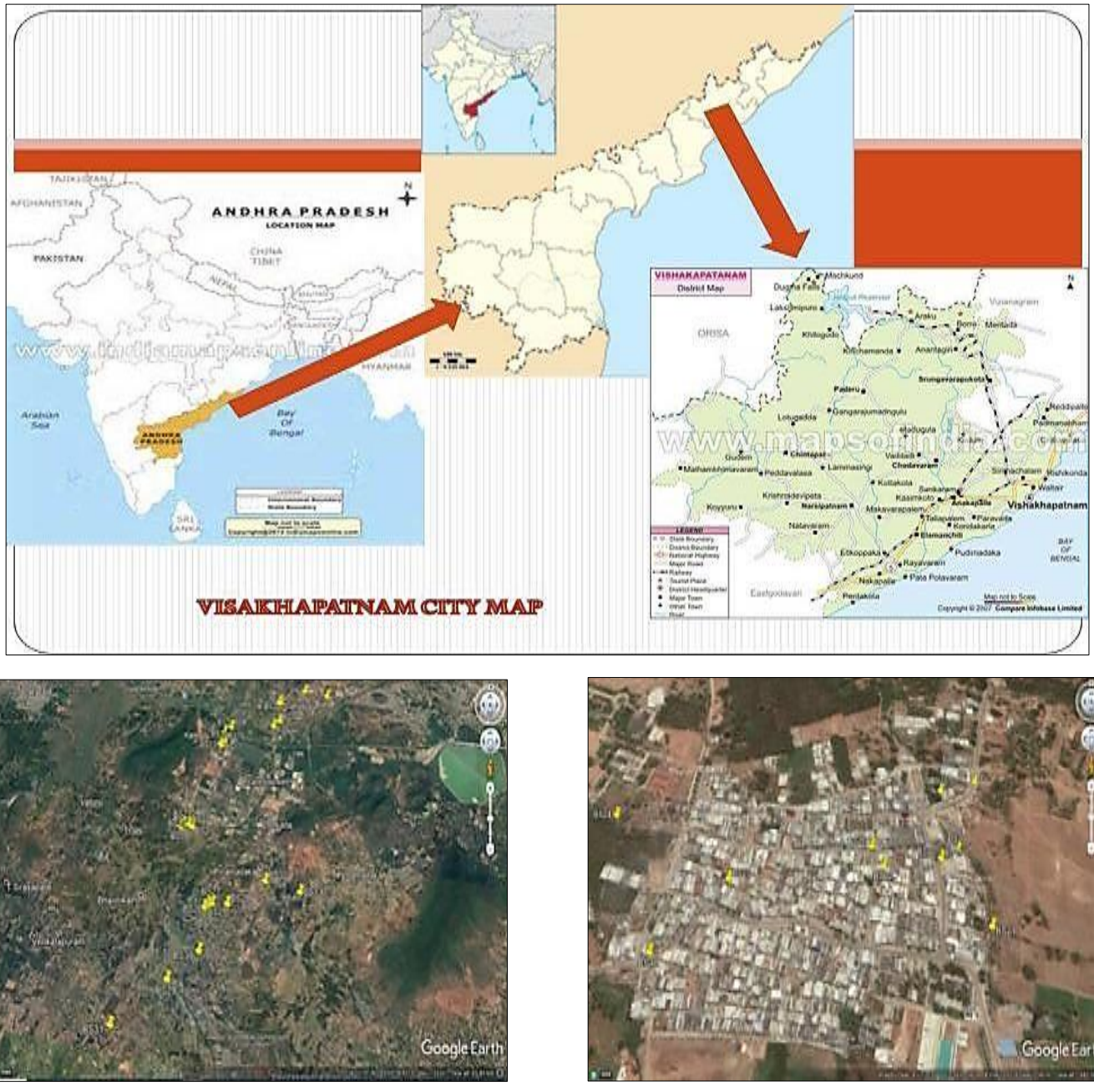

Fig 1 Study area map with geological locations covered 8 neighboring villages

Sampling locations

For this study, 33 sampling locations were identified from 8 villages. The list of sampling stations and their details are tabulated in (Table 1).

Table 1 List of sampling stations and its geographical location in the study area

Code	Location	Latitude	Longitude
	Borewell sample at Lankelepalem village area		
BS1	HP Gas go- Dom	17° 41' 18.852" N	83° 6' 40.215"E
BS2	Reddy mango garden	17° 41' 22.502" N	83° 6' 13.838"E
BS3	M. Srinivasa Rao house	17° 41' 7.926" N	83° 5' 45.765"E
BS4	S. Raghavarao house	17° 41' 7.083" N	83° 5' 43.659"E
BS5	Shanti Talent School.	17° 40' 46.232"N	83° 5' 45.265"E
BS6	Kanakadurga temple	17° 40' 40.216"N	83° 5' 38.518"E
	Borewell sample at Chinatadi/ Kannur village area		
BS7	APGVB bank	17° 40' 29.143"N	83° 4' 42.679"E
BS8	House of S.Ramana.	17° 40' 35.583"N	83° 4' 49.807"E
BS9	P.Venkata Lakshmi house	17° 40' 36.620"N	83° 04' 49.77"E
BS10	MPP School	17° 40' 19.992"N	83° 4' 43.108"E
BS11	BC colony	17° 40' 16.320"N	83° 04' 41.04"E
BS12	Panchayat water tank	17° 40' 15.600"N	83° 04'39.07" E
BS13	Municipal Sub-Zonal Office	17° 40' 14.491"N	83°04' 40.46" E
	Borewell sample at Tanam village area		
BS14	B.Nukaraju House.	17° 38' 55.402"N	83° 04' 18.86"E
BS15	Overhead tank	17° 38' 55.15" N	83° 4' 17.44" E
BS16	Bore hole No.32/013	17° 38' 52.958" N	83° 4' 14.487"E
BS17	M.Apparao house	17° 38' 52.648"N	83° 4' 17.166"E
BS18	Anjaneya Swami temple	17° 38' 49.722"N	83° 4' 6.567" E
BS19	K.Sanyarasirao house	17° 38' 52.623"N	83° 4' 17.173"E
BS20	S.Kumari house	17° 38' 52.900" N	83° 4' 17.84" E
BS21	B.Sannyasirao house	17° 38' 50.485" N	83° 4' 18.80" E
BS22	T. Gangaraju house	17° 38' 52.306"N	83° 4' 14.93" E
BS23	NTR statue	17° 38' 51.885"N	83° 4' 9.094" E
BS24	Z.P.High School	17° 38' 54.074"N	83° 4' 4.303" E
	Borewell sample at Parawada village area		
BS25	Vinayaka temple	17° 37' 42.35" N	83° 04'39.68" E
BS26	Visakha Grameena Bank	17° 37' 44.85" N	83° 4'42.826" E
BS27	Main road	17° 37'45.886" N	83° 4'46.729" E
BS28	Maridimamba community hall	17° 37'46.452" N	83° 5'1.712" E
	Borewell sample at other village area		
BS29	Maridimamba temple Jallelapalem	17° 36'46.119" N	83° 4'12.457" E
BS30	Pydimamba temple- Atchutauram – Parawada road	17° 37' 8.713" N	83° 4'38.769" E
BS31	Overhead water tank Bottavanipalem	17° 36'11.660" N	83° 3'27.684" E
BS32	Gowthulachanna colony-Pinamadaka	17° 38' 7.922" N	83° 5'37.417" E
BS33	Ramalayam-Chintalagorlavanipalem	17° 38' 1.017" N	83° 6'12.106" E

Sampling

After virtuous inventory, groundwater samples were collected from 33 locations for the period of pre-monsoon (April) and post-monsoon (September) seasons of 2021in a simple random sampling method. Totally, 66 samples were collected from 33 sampling locations in both seasons based on the utilization of water by following protocol and guidelines given in the Standards methods [10]. All practical precautions were taken at every stage, starting from sample collection, adding of preservatives, storage, transportation, and final analysis of the samples to avoid or minimize contamination.

Parameters analyzed

The Analysis was carried out at the Zonal laboratory, APPCB, Kurnool, and Visakhapatnam by using standard methods and techniques. The parameters such as pH, Electrical Conductivity (EC), Total dissolved solids (TDS), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Potassium (K^{+}), Sodium (Na^{+}), Chlorides (Cl^{-}), Nitrates ($NO3^{-}$), Total alkalinity (TA), Sulphates (SO4-2) were utilized while calculating the irrigated water parameters like Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Percent Sodium (%Na), Sodium Adsorption Ratio (SAR), Ion Exchange as Chloro-Alkaline Indices (CAI-I and CAI- II), Chloride classification and Magnesium ratio. The sophisticated instruments such as Flame photometer, digital pH and conductivity meter (Hach), and calibrated glassware were used. The obtained results were compared with the respective standards.

Scope of the present study

The previous researchers have focused on urban agglomeration and some physicochemical characteristics in Visakhapatnam city by covering residential zones and some industrial zones and noticed some abnormalities. They are not focused on the suitability of groundwater for irrigation. Moreover, the present study area is also close to the industrial zone. As per the author's knowledge, groundwater studies are yet to be carried out in the present study area. The local public uses the groundwater for drinking, cattle feeding, household, and irrigation purposes. Due to industrial activity, there might be chances to get contamination of groundwater. The study area has no scientific drainage system. Moreover, the local public in the area is frequently suffering from fever, diarrhea, and gastrointestinal diseases. Crop yielding is decreasing year by year. This forms the basis for groundwater quality study and an attempt has been made to evaluate the concentration levels of some physicochemical parameters as well as statistical parameters.

Hydro geochemical indices

Hydro geochemical indices are the best models while assessing the suitability of groundwater quality for irrigation and domestic uses, several indices and models were applied based on the formulae presented by some researchers as described below.

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is one of the most advantageous parameters for determining the aptness of groundwater for irrigation purposes. The excess concentration of sodium in groundwater can turn into alkaline type soil. It increases the soil's compact nature and reduces the percolation capacity for a particular soil. This type of alkaline soil cannot be utilized for agriculture. During the summer season, agricultural cultivation is very difficult for such types of soils. SAR is determined by utilizing the following formula [11].

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad \text{----------(1)}$$

The concentrations are expressed in meq/L. Based on the results of SAR, the groundwater is categorized into 3 types, if the value is < 6 meq/ L, it is suitable for irrigation, 6-9 meq/ L is moderately suitable, and the value is > 9 meq/ L is not suitable for irrigation [11].

Percentage sodium (%Na)

Percentage sodium (% Na^{+}) is also one of the advantageous parameters, widely used & best indices to know the water quality for irrigation utility; The Surplus amount of sodium in ground waters can affect the undesirable growth of plants. With the enriched concentration of sodium in the irrigation water, the clay minerals in the soil absorb sodium, replacing the magnesium and calcium ions in the matrix. This phenomenon affects the permeability of particular soil and decreases the internal drainage inside the soil texture; habitually

the below formula is used for evaluating the aptness of water quality for irrigation [12].

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

The % Na^+ is calculated with respect to comparative proportions of cations existent in water, where the concentrations of ions are expressed in meq/L. Based on the results of % Na, the groundwater is categorized into 5 types, if the value is < 20 meq/ L, the water is categorized as Excellent; if the value lies between 20-40 meq/ L, the water is categorized as good, similarly, 40-60 meq/ L is permissible, 60-80 meq/ L doubtful and > 80 meq/ L is not suitable for irrigation [12].

Residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) is an experimental parameter. The value is expressed in meq/L. If the water is having a high concentration of bicarbonate, there is a propensity for magnesium and calcium to precipitate as carbonates tendency [13].

$$RSC = (HCO_3^- + CO_3^{-2}) - (Ca^+_2 + Mg^+_2) \text{ - - - - - - (3)}$$

Based on the results of RSC, water is categorized into 3 types. If the value is < 1.25 meq/ L, the water is classified as good water; if the value lies between 1.25 to 2.50 meq/ L, the water is termed as doubtful, and if the value is > 2.50 meq/L, the water is classified as unsuitable for irrigation.

Kelley's ratio

The concentration of sodium (Na^+) measured in contradiction to calcium (Ca_2^+) and magnesium (Mg^{2+}) was considered to calculate Kelley's ratio [14], values are expressed in meq /L.

$$KR = \frac{Na^+}{Mg^{2+} + Ca^{2+}} \quad \text{- - - - - - - - - - - - - (4)}$$

Based on the results, Kelley‘s index is classified in to 2 types. If the value is <1 is suitable for irrigation, if the value is > 1 indicates not suitable for irrigation.

Permeability index (PI)

The soil permeability is affected by lasting exposure or continuous irrigation inclined by Ca_2^+, Na^+, Mg^{2+}, and HCO_3^- contents of the particular soil [13]. The values are expressed in meq/L. PI values can provide an effective index that can be used to determine the suitability of groundwater for irrigation purposes.

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+}Na^+} \times 100 \quad \text{- - - - - - - - - - - - - (5)}$$

Based on the results, the permeability index is classified into 2 types. If the value is < 60 meq/L is suitable for irrigation, if the value is > 60 meq/L indicates not suitable for irrigation.

Magnesium ratio

In groundwater, the concentrations of calcium (Ca_2^+) and Magnesium (Mg^{2+}) maintain a state of equilibrium [15]. During equilibrium, more Mg^{2+} in groundwater will badly distress the soil quality rendering it alkaline nature; as a result, decrease in crop yield. The values are expressed in meq/l.

$$MR = \frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}} \times 100 \quad \text{- - - - - - - - - - - - - (6)}$$

Based on the results, the magnesium ratio is classified into 2 types. If the value is < 50 meq/L is suitable for irrigation, if the value is > 50 meq/L indicates not suitable for irrigation.

Ion exchange

Ion exchange can be studied in terms of the chloro-alkaline indices (CAI-I and CAI-II) [16]. Marghade *et al*. [17]. When an exchange of Mg_2^+ or Ca_2^+ in groundwater with K^+ or Na^+ in aquifer materials takes place, both of the above indices are negative, while in the instance of a converse ion exchange, both indices are positive. The values are expressed in meq/l.

$$CAI - II = \frac{Cl^- - (K^+ + Na^+)}{HCO3^- + SO4^{-2} + CO3^{-2} + NO3^-} \quad \text{- - - - - - - - (7)}$$

$$CAI - I = \frac{Cl^- - (K^+ + Na^+)}{Cl^-} \quad \text{- - - - - - - - (8)}$$

The positive index Indicates the possibility of ion exchange of Na^+ and K^+ of the water with Mg^{2+} and Ca_2^+.

Electrical conductivity

Electrical conductivity is a good measuring indicator while calculating the salinity hazards to the crops. The high concentration of EC can adversely affect crop productivity are the inability of the plant to compete with ions in the soil solution for water [18]. The values are expressed in µS/cm. Based on the results; EC is classified into 4 types. If the value is < 250 µS/cm, the water is classified as excellent, the value lies between 250 – 750 µS/cm, the water is characterized as good, the value lies between 750 – 2000 µS/cm the water is characterized as permissible, and if the value is > 2000 µS/cm indicates not suitable for irrigation and treated as doubtful.

Chloride classification

Chloride ion is a major physicochemical parameter in groundwater quality, and it plays an important role in many aspects. And it is classified the ground water as the source of Cl- ion concentration into 8 categories [19]. If the value is < 0.14 meq/L indicates extremely fresh, the value lies between 0.14 – 0.85 meq /L, treated as very fresh, the value lies between 0.85- 4.23 meq /L indicates fresh, the value lies between 4.23 – 8.46 meq /L indicates fresh brackish, the value lies between 8.46 – 28.21 meq /L indicates brackish, the value lies between 28.21-282.06 meq /L indicates brackish - salt, the value lies between 282.06 – 564.13 meq /L indicates salt, and the value > 564.13 meq /L indicates brackish – Hyper saline water. The values are expressed in meq /l.

RESULTS AND DISCUSSION

Physicochemical parameters

pH

Normally the value of pH in drinking water is always neutral, if the value is increase or decreases can change the quality of water, and the recommended range is from 6.5 to 8.5 as per IS 10500:2012 and WHO (BIS (1991 / 1993 / 2003 /2010/2012) [20-21]. The present study ranged from 7.12 to 7.92 (mean 7.50), and 7.01 to 7.82 (mean 7.32) in pre-monsoon and post- monsoon seasons, respectively. The maximum value is found at BS19. The abnormal concentration of pH indirectly

affects health in many ways. The water with acidic nature can corrode the plumbing and lead to the leaching of metals like lead, manganese, iron, copper, zinc, etc. The high levels of lead in drinking water can cause health risks such as cancer, kidney diseases, memory loss, high blood pressure, etc. in human beings. The abnormal pH value is restricting the growth and yields of crops.

Electrical conductivity (EC)

Conductivity is the ability of water to carry an electrical current. A sudden increase in conductivity of the water is an indication of the addition of pollutants to the water [22]. The present study ranged from 681 to 4191 µS/cm (mean 1873), and 515 to 3856 µS/cm (mean 1590), during pre-monsoon and post-monsoon seasons, respectively. Of these, 10 samples come under good water quality and it is utilized for irrigation purpose (15.1%), 32 samples come under permissible (48.5%), and the remaining 24 samples come under not suitable for irrigation and are treated as doubtful (36.4%).

Total dissolved solids (TDS)

Total dissolved solids, the concentration ranged from 445 mg/L to 2740 mg/L (mean 1216), and 321mg/L to 2432 mg/L (mean 1030) at pre-monsoon and post-monsoon seasons, respectively. High TDS in groundwater may be attributed to nutrient-rich surface waters that contaminate the groundwater [23]. Elevated concentration of TDS in groundwater is no significant health risk for the general public but affects people who are suffering from kidney and heart diseases. Salinity reduces crop yields by reducing the osmotic potential, making it more difficult for the plant to extract water, causing specific-ion toxicity, upsetting the nutritional balance of plants, and affecting the tilts and permeability of a soil.

Calcium (Ca^{+2})

Calcium is a much-needed nutrient; that helped in the formation and development of proper bone and teeth growth. High concentration levels produced cardiovascular diseases, create kidney stones, weaken bones, and interfere with heart and brain work. The high deficiency of calcium is often called hypocalcemia in humans and may cause rickets, poor blood clotting, bones fracture, etc. In the present study, the concentration ranged from 29 mg/L to 281 mg/L (mean 93), and 12 mg/L to 268 mg/L (mean 77) during pre-monsoon and post-monsoon seasons, respectively. The maximum values were found at the BS26 sampling station. The required quantity of calcium is essential for structural roles in the cell wall and membrane formation of plants, and it also acts as an intracellular messenger in the cytosol.

Magnesium (Mg_2^{+})

Magnesium, the concentration ranged from 16 mg/L to 168 mg/L (mean 58), and 8 mg/L to 148 mg/L (mean 44.4) in pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS26. Magnesium is also a much-needed nutrient for plants and living organisms. It can help in the formation and development of organisms and flowering as well as in the process of photosynthesis. Laxative effects have also been associated with excess intake of magnesium taken in the form of supplements.

Sodium (Na^{+})

Sodium is a dominant cat ion in groundwater. Sodium in the human body prevents many fatal diseases like kidney damage, hypertension, headache, etc.; it plays a very critical role in blood pressure activities. In the present study, Sodium, concentration ranged from 54 mg/L to 736 mg/L (mean 270), and 45 mg/L to 662 mg/L (mean 232) during pre-monsoon and post- monsoon seasons, respectively. The maximum values were found at the BS22 sampling station. Sodium is not an essential element for plant growth, but some species of plants with deficient levels of sodium become necrotic and have chlorotic effects. Sodium is to aid in the metabolism and synthesis of chlorophyll.

Potassium (K^{+})

It is an important nutritional element and plays a crucial role in the human biological system. Adverse effects may also arise when potassium plasma concentrations are lower (hypokalemia). Leachates from waste dumps are also significant contributors [24]. In the present study, potassium, concentration ranged from 0.51 mg/L to 13.65 mg/L (mean 4.17), and 0.41 mg/L to 12.35 mg/L (mean 3.53) during pre-monsoon and post-monsoon seasons, respectively. The maximum values were found at the BS8 sampling station. Potassium is associated with the movement of nutrients, water, and carbohydrates in plant tissue. It's also involved with enzyme activation within the plant tissue, which affects starch, protein formation, and adenosine triphosphate (ATP) production.

Total alkalinity (TA)

Total Alkalinity, the concentration ranged from 231 mg/L to 862 mg/L (mean 528), and 160 mg/L to 765 mg/L(mean 450) at pre-monsoon and post-monsoon season, respectively. The maximum value was found at the BS16 sampling station. In some cases, ammonia or hydroxides are involved in causing alkalinity [25]. The water tends to be more alkaline when it possesses carbonates [26], alkalinity itself is not harmful to human health [27]. But, extreme concentration in plants can affect hydrogen ion toxicity, and nutrient imbalance, toxicities, and deficiencies are induced in crops.

Chlorides (Cl^{-})

Chlorides, the concentration ranged from 47 mg/L to 776 mg/L (mean 280), and 27 mg/L to 692 mg/L (mean 232) at pre-monsoon and post-monsoon season, respectively. The maximum value was found at the BS25 sampling station. Chlorides are leached from various rocks into soil and water by weathering (WHO, 1996). A higher value indicates the pollution of water gives an undesirable taste and is hazardous to human consumption and creates health problems [28]. Its functions in plant growth and development include osmotic and stomatal regulation, the progression of oxygen in photosynthesis, and disease resistance and restraint. At ample levels of supply, Chlorides progress the yields and quality of many crops such as onions and cotton if the soils are deficient in this nutrient.

Sulphates (SO_4^{-2})

The presence of hydrogen sulfide leads to corrosion of pipes [26]. Drinking water with high sulfate concentration may get diarrhea and dehydration. Infants are often more sensitive to sulfates than adults. In the present study, the concentration ranged from 23.84 mg/L to 286.34 mg/L (mean 88.91), and 16.47 mg/L to 268.27 mg/L (mean 75.6) at pre- monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS25 sampling station. Sulfur is of immense implication for the structure of proteins and functioning of enzymes and it plays an important role in the defense of plants against stresses and pests.

Nitrates (NO_3^{-})

Nitrate in the aquatic system usually originates from nitrogenous waste, animal wastes, domestic discharge, and fertilizers. The WHO standard for nitrate is 50 mg/L. Excess concentrations lead to cyanosis disease or blue baby syndrome in infants less than 3 months [29]. In the present study, the concentration is ranged from 11.24 mg/L to 234.62 mg/L (mean 53), and 10.11 mg/L to 233.14 mg/L (mean 47.5) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS25 sampling station. Nitrate is the most important source of nitrogen (N) available for crops and, before its reduction and assimilation into amino acids, must enter the root cells and then moves into the plant.

Hydro chemical facies

The results of major cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and major anions (Cl^-, HCO_3^-, $SO42^-$, F^-) are represented on the piper line diagram. Piper diagram was drawn by using software GW chart version1.260.0). The comparative concentration of the anions and cat ions are plotted in the lower triangles (left side angle cat ions and right-side angle anions) and the resulting two points are drawn-out into the central field to represent the total ion concentration using the analytical data. In the present study 4 major hydro chemical facies were identified (mixed Ca-Mg-Cl, mixed Ca-Na-HCO_3, NaCl, and Ca-HCO_3) due to temporary hardness, high alkalinity, and salinity.

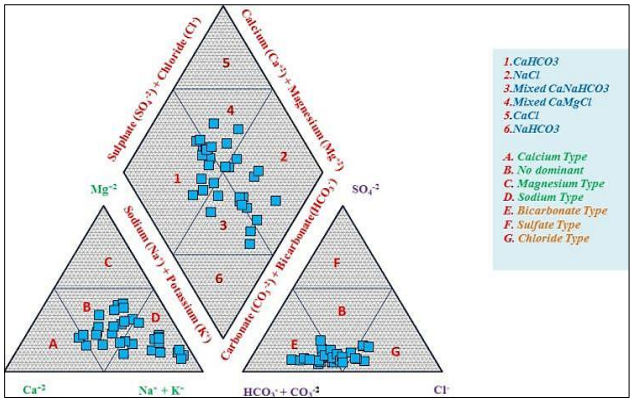

Fig 2 Piper diagram is showing pre-dominant hydro chemical facies in the study area during pre-monsoon season 2021

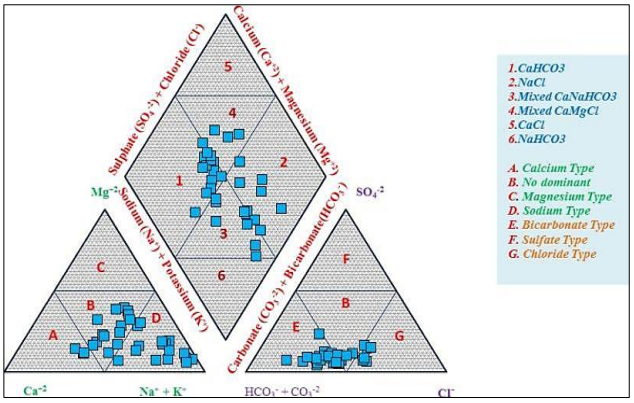

Fig 3 Piper diagram is showing pre-dominant hydro chemical facies in the study area during post-monsoon season 2021

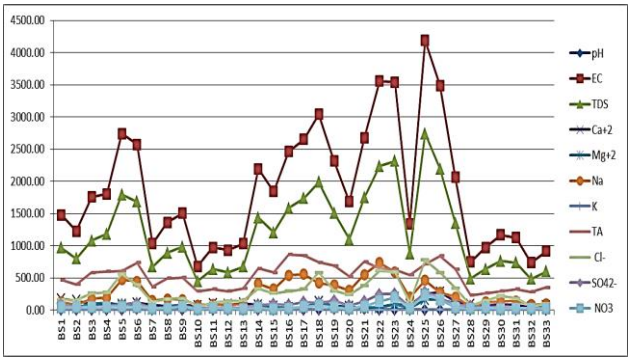

Fig 4 Graphical value of physicochemical parameters during Pre monsoon season- 2021

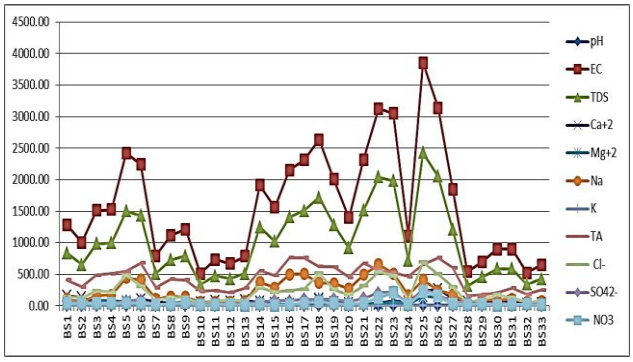

Fig 5 Graphical value of physicochemical parameters during Post monsoon season- 2021

Correlation coefficient matrix

The correlation coefficient matrix between the different parameters of groundwater in the study area had both positive and inverse relations among the parameters in both seasons. Some parameters were strongly correlated and some were weakly correlated with others, and some parameters were negatively correlated with others (Tables 3-4). The strong correlation was observed among EC to TDS (0.999) followed by Na^+ (0.866), TA (0.850), Cl (0.967), SO4-2 (0.912) and NO3- (0.819). TDS is correlated among the parameters as Mg^+ (0.674), Na^+ (0.866), TA (0.850), Cl (0.967), SO4-2 (0.910) and NO3- (0.819). Calcium and magnesium were moderately correlated. Total Alkalinity is strongly correlated with EC (0.850), TDS (0.850) and Na^+ (0.809). SO4-2 is strongly correlated with EC (0.912), TDS (0.910) and Na^+(0.767) and Cl^- (0.874). pH is negatively correlated with other parameters.

Hydro geochemical indices

Sodium adsorption ratio (SAR)

SAR value ranged from 1.35 to 19.05 meq /L (mean 5.85), and 1.39 to 19.91 meq /L (mean 6.02) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS22 sampling station. Based on the SAR results 65% of samples are comes under the suitable for irrigation category, 12 % samples come under the not suitable for irrigation (doubtful) category, and the remaining 23% samples were completely not suitable for irrigation category.

Percentage sodium (%Na)

Percentage sodium (% Na) value ranged from 26.4 to 84.9 meq /L (mean 51.15), and 27.38 to 89.38 meq /L (mean 53.51) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS16 sampling station. Based on the % Na results from no sample have been recorded under excellent water category, 33.3% samples come under good water category 33.3% comes under permissible water category, 21.2% samples come under doubtful for irrigation category, and the remaining 12.2% samples were completely not suitable for irrigation category.

Residual sodium carbonate (RSC)

RSC value ranged from -11.27 to 13.0 meq /L (mean 1.14), and -10.61 to 12.73 meq/L (mean 1.51) in pre-monsoon

and post-monsoon seasons, respectively. The maximum value was found at the BS16 sampling station. Based on the RSC results 60.6% of samples are coming under the good water category, 9.1% of samples are coming under the doubtful water category and the remaining 30.3% of samples come under the unsuitable water for irrigation category.

Table 2 the result of physicochemical parameters during the pre-monsoon and post-monsoon seasons of 2021

Location	Code	Parameter and concentration in (mg/ L except pH&EC) pre-monsoon period-2021											Parameter and concentration in (mg/ L) post- monsoon period - 2021									
Bore well sample collected at		pH	EC	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	TA	Cl^{-}	$SO4^{2-}$	NO_3^{-}	pH	EC	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	TA	Cl^{-}	SO_4^{2-}	NO_3^{-}
HP Gas go-Dom	BS1	7.59	1480	968	172.00	33.00	126.00	3.52	469.00	164.00	96.52	44.36	7.20	1287	840	161.00	21.00	110.00	2.82	416.00	144.00	76.00	36.42
Reddy mango garden	BS2	7.23	1225	801	148.00	36.00	86.00	3.28	398.00	153.00	54.23	42.58	7.12	1006	653	132.00	20.00	72.00	2.96	302.00	134.00	43.00	40.25
M. Srinivasa Rao House	BS3	7.12	1758	1080	96.00	103.00	172.00	11.23	584.00	265.00	52.62	43.62	7.08	1517	986	74.00	88.00	159.00	10.32	489.00	239.00	41.32	38.51
S. Raghavarao house	BS4	7.62	1807	1181	86.00	108.00	192.00	5.32	598.00	271.00	57.52	45.28	7.21	1525	998	72.00	84.00	174.00	4.89	514.00	222.00	43.52	40.28
Shanti Talent School.	BS5	7.71	2741	1793	69.00	84.00	471.00	7.28	612.00	564.00	86.74	56.81	7.36	2424	1506	45.00	65.00	448.00	6.58	546.00	488.00	80.14	48.62
Kanakadurga temple	BS6	7.84	2572	1682	112.00	46.00	448.00	3.60	736.00	390.00	110.32	48.62	7.42	2243	1432	105.00	23.00	412.00	2.74	682.00	312.00	89.62	42.18
APGVB bank	BS7	7.23	1029	673	82.00	16.00	146.00	1.58	365.00	122.00	24.52	28.32	7.06	791	514	73.00	8.00	110.00	0.95	292.00	88.00	16.47	20.14
Sala Ramana House	BS8	7.36	1360	890	64.00	62.00	171.00	13.65	492.00	174.00	42.36	24.31	7.11	1116	728	51.00	46.00	150.00	12.35	423.00	130.00	32.54	18.62
P.Venkata Lakshmi house	BS9	7.25	1506	985	74.00	84.00	164.00	2.14	506.00	186.00	64.51	58.62	7.05	1218	795	58.00	62.00	142.00	1.92	416.00	135.00	52.81	56.33
MPP School	BS10	7.42	681	445	68.00	16.00	75.00	2.52	297.00	47.00	23.84	12.36	7.13	515	337	51.00	9.00	62.00	1.86	230.00	27.00	18.42	12.84
BC colony	BS11	7.51	974	637	94.00	33.00	88.00	2.84	324.00	118.00	42.15	33.25	7.22	733	479	76.00	19.00	70.00	2.03	246.00	86.00	31.52	23.14
Panchayati water tank	BS12	7.54	933	582	86.00	36.00	81.00	5.64	294.00	140.00	26.41	28.42	7.32	671	428	62.00	22.00	64.00	4.78	214.00	98.00	18.74	18.72
Municipal Sub-Zonal Office	BS13	7.45	1031	675	104.00	33.00	96.00	2.14	335.00	148.00	44.52	12.34	7.23	786	510	87.00	19.00	74.00	1.88	284.00	87.00	38.62	10.46
Batti Nukaraju House.	BS14	7.44	2197	1437	78.00	36.00	411.00	1.62	648.00	329.00	82.65	39.58	7.26	1913	1251	63.00	21.00	380.00	1.05	561.00	290.00	68.92	29.52
Overhead tank	BS15	7.65	1842	1205	52.00	54.00	324.00	2.32	582.00	261.00	92.41	11.24	7.45	1563	1022	39.00	39.00	290.00	1.86	483.00	218.00	84.62	10.11
bore hole No.32/013	BS16	7.68	2461	1586	29.00	34.00	543.00	0.84	862.00	294.00	84.62	28.64	7.64	2156	1408	12.00	24.00	501.00	0.62	765.00	246.00	78.50	20.47
M.Apparao House	BS17	7.22	2654	1736	42.00	42.00	556.00	0.51	847.00	326.00	124.58	52.18	7.06	2311	1510	28.00	28.00	508.00	0.41	762.00	264.00	110.36	42.68
Anjaneya Swami temple	BS18	7.47	3039	1987	124.00	126.00	422.50	2.51	742.00	582.00	116.58	72.53	7.23	2637	1722	103.00	114.00	364.00	1.95	625.00	518.00	99.73	65.49
K. Sanyarasirao House	BS19	7.92	2313	1512	76.00	63.00	391.50	4.65	691.00	300.00	146.81	42.38	7.82	2008	1287	58.00	48.00	362.00	3.87	621.00	258.00	110.68	36.57
Sambangi Kumari House	BS20	7.68	1683	1100	52.00	41.00	303.67	1.48	522.00	240.00	72.35	23.22	7.61	1400	915	36.00	26.00	273.00	1.32	453.00	176.00	66.48	20.15
B.Sannyasirao House	BS21	7.77	2671	1747	32.00	49.00	552.50	1.62	754.00	382.00	136.42	55.94	7.62	2319	1516	24.00	37.00	494.00	1.54	674.00	320.00	119.45	42.55
T. Gangaraju House	BS22	7.32	3559	2236	54.00	36.00	736.50	1.71	648.00	610.00	249.58	138.46	7.23	3125	2042	41.00	26.00	662.00	1.32	563.00	536.00	210.61	130.2
NTR statue	BS23	7.42	3539	2315	94.00	94.00	588.00	1.99	632.00	594.00	251.34	200.36	7.36	3048	1986	78.00	75.00	512.00	1.25	533.00	480.00	218.94	212.3
Z.P.High School	BS24	7.41	1344	879	86.00	32.00	200.00	1.94	548.00	114.00	44.62	28.14	7.25	1110	726	65.00	26.00	175.00	1.32	464.00	95.00	36.72	12.58
Vinayaka temple	BS25	7.35	4191	2741	245.00	162.00	464.00	12.31	714.00	776.00	286.34	234.62	7.12	3856	2432	234.00	148.00	416.00	11.52	662.00	692.00	268.27	233.1
Visakha Grameena Bank	BS26	7.24	3487	2194	281.00	168.00	276.00	4.78	840.00	582.00	192.42	162.35	7.01	3138	2052	268.00	142.00	245.00	3.88	762.00	506.00	176.82	154.3
Main road	BS27	7.68	2064	1350	129.00	112.00	204.00	4.62	635.00	342.00	74.65	36.45	7.62	1848	1209	112.00	105.00	184.00	3.69	605.00	300.00	53.64	28.61
Maridimamba Community Hall	BS28	7.64	748	489	84.00	23.00	54.00	2.88	231.00	73.00	66.82	22.48	7.52	543	321	65.00	9.00	45.00	1.58	160.00	42.00	58.29	20.15
Maridimamba temple	BS29	7.52	972	636	66.00	25.00	128.00	1.32	262.00	148.00	42.62	36.28	7.44	701	458	43.00	13.00	103.00	1.04	178.00	103.00	32.49	33.56
Pydimamba temple	BS30	7.38	1167	763	92.00	38.00	130.00	3.64	294.00	223.00	48.72	14.36	7.23	897	586	81.00	28.00	90.00	2.61	210.00	180.00	40.38	10.11
Overhead water tank	BS31	7.66	1126	737	85.00	28.00	144.00	3.82	325.00	186.00	32.54	26.48	7.55	901	589	73.00	22.00	112.00	2.84	285.00	133.00	26.54	20.45
Gowthulachanna Colony	BS32	7.54	737	482	42.00	32.00	85.00	7.95	286.00	65.00	28.36	26.54	7.49	523	342	26.00	24.00	60.00	6.82	185.00	53.00	20.46	23.51
Ramalayam	BS33	7.67	917	599	68.00	36.00	96.00	10.36	352.00	95.00	33.24	20.34	7.56	655	428	46.00	23.00	73.00	10.01	254.00	58.00	30.11	14.52
	Min	7.12	680.54	445.0	29.00	16.00	54.00	0.51	231.00	47.00	23.84	11.24	7.01	515.1	321.0	12.00	8.00	45.00	0.41	160.00	27.00	16.47	10.1
	Max	7.92	4190.69	2740.7	281.00	168.00	736.50	13.65	862.00	776.00	286.34	234.62	7.82	3855.	2432	268.00	148.00	662.00	12.35	765.00	692.00	268.27	233.1
	SD	0.197	956.879	617.30	53.924	40.241	189.281	3.402	190.530	187.319	68.344	53.051	0.212	899.6	579.46	54.904	37.963	175.61	3.244	189.537	169.74	62.094	54.74

Table 3 The correlation coefficient matrix among physicochemical parameters in the study area during the pre-monsoon season of 2021

	pH	EC	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K+	TA	Cl^{-}	SO_4^{2-}	NO_3^{-}
pH	1										
EC	-0.0446	1									
TDS	-0.0296	0.9993	1								
Ca^{+2}	-0.2840	0.3726	0.3671	1							
Mg^{+2}	-0.1836	0.6765	0.6740	0.6548	1						
Na^{+}	0.1126	0.8668	0.8688	-0.1014	0.2744	1					
K^{+}	-0.0872	0.0265	0.0226	0.2672	0.4043	-0.2082	1				
TA	0.0481	0.8500	0.8502	0.1865	0.5647	0.8093	-0.0678	1			
Cl^{-}	-0.0534	0.9679	0.9674	0.4239	0.7241	0.7903	0.1016	0.7324	1		
$SO4^{2-}$	-0.0749	0.9125	0.9108	0.4151	0.5592	0.7671	0.0131	0.6410	0.8747	1	
NO_3^{-}	-0.2876	0.8199	0.8165	0.5828	0.6751	0.5522	0.1699	0.4776	0.8289	0.9062	1

Kelley's ratio (KR)

Kelley's ratio is ranged from 1.35 to 19.05 meq /L (mean 5.85), and 1.39 to 19.91 (mean 6.02) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS22 sampling station. Based on the KR results, 53% of samples are coming under the suitable for irrigation category, and 47% of samples are coming under the not suitable for irrigation category.

Permeability index (PI)

Permeability index values ranged from 40.42 to 99.67 meq /L (mean 68.98), and 40.78 to 105.5 (mean 73.62) during pre-monsoon and post-monsoon seasons, respectively. The

maximum value was found at the BS16 sampling station. Based on the PI results 28.8% of samples are comes under the suitable for irrigation category, and the remaining 71.2% of samples are coming not suitable for irrigation category.

Table 4 The Correlation coefficient matrix among physicochemical parameters in theStudy area during the post-monsoon season of 2021

	pH	EC	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K+	TA	Cl^{-}	SO_4^{2-}	NO_3^{-}
pH	1										
EC	-0.0695	1.0000									
TDS	-0.0716	0.9994	1.0000								
Ca^{+2}	-0.4137	0.4069	0.4018	1.0000							
Mg^{+2}	-0.2245	0.6802	0.6778	0.6389	1.0000						
Na^{+}	0.1474	0.8560	0.8586	-0.0812	0.2691	1.0000					
K^{+}	-0.1284	0.0573	0.0436	0.2353	0.4137	-0.1724	1.0000				
TA	0.0256	0.8565	0.8619	0.2363	0.5561	0.8116	-0.0331	1.0000			
Cl^{-}	-0.1045	0.9658	0.9621	0.4476	0.7346	0.7756	0.1314	0.7393	1.0000		
$SO4^{2-}$	-0.0686	0.9120	0.9100	0.4486	0.5680	0.7494	0.0404	0.6407	0.8738	1.0000	
NO_3^{-}	-0.2573	0.7947	0.7912	0.5766	0.6607	0.5150	0.1748	0.4427	0.8012	0.9078	1

Table 5 The results of some statistical parameters during the pre-monsoon and post-monsoon seasons - 2021

Location	Code	The values of statistical Parameter (meq/L) – Pre-monsoon period - 2021									The values of statistical parameter (meq/L) – Post-monsoon Period - 2021								
Bore well sample collected at		SAR	% Na	RSC	KR	PI	MR	CAI-I	CAI- II	Cl.C	SAR	% Na	RSC	KR	PI	MR	CAI-I	CAI- II	Cl.C
HP Gas go-Dom	BS1	2.31	32.49	-1.92	0.49	50.92	24.02	3.42	4.17	4.63	2.17	32.73	-1.44	0.49	52.72	17.69	2.87	3.60	4.06
Reddy mango garden	BS2	1.64	26.40	-2.39	0.36	46.58	28.62	3.43	3.92	4.32	1.54	27.38	-2.19	0.38	49.19	19.98	2.93	3.36	3.78
M. Srinivasa Rao House	BS3	2.91	35.58	-1.58	0.56	52.54	63.88	6.43	6.90	7.47	2.96	38.19	-1.15	0.63	56.28	66.21	5.68	6.10	6.74
S. Raghavarao house	BS4	3.25	38.56	-1.21	0.63	54.87	67.42	6.53	7.03	7.64	3.30	41.60	-0.22	0.72	59.63	65.79	5.03	5.61	6.26
Shanti Talent School.	BS5	9.01	66.04	1.89	1.98	77.78	66.74	14.61	14.52	15.91	10.00	71.52	3.33	2.57	84.17	70.42	12.34	12.29	13.76
Kanakadurga temple	BS6	9.00	67.31	5.35	2.08	80.82	40.37	9.22	9.90	11.00	9.49	71.34	6.51	2.51	86.28	26.52	6.75	7.69	8.80
APGVB bank	BS7	3.86	53.82	1.89	1.17	76.99	24.33	1.58	2.67	3.44	3.26	52.52	1.54	1.11	79.26	15.30	0.54	1.74	2.48
Sala Ramana House	BS8	3.65	46.26	1.55	0.90	67.23	61.49	3.32	4.21	4.91	3.67	49.55	2.13	1.03	73.40	59.78	1.80	2.94	3.67
P.Venkata Lakshmi house	BS9	3.10	40.10	-0.48	0.67	58.16	65.17	3.88	4.67	5.25	3.09	43.44	0.33	0.77	63.95	63.79	2.17	3.20	3.81
MPP School	BS10	2.13	40.60	1.23	0.69	71.50	27.94	-1.18	0.82	1.33	2.10	44.73	1.31	0.82	80.94	22.53	-2.84	0.23	0.76
BC colony	BS11	1.99	33.86	-0.92	0.52	56.74	36.65	2.16	2.83	3.33	1.86	36.03	-0.43	0.57	62.66	29.18	1.15	1.90	2.43
Panchayati water tank	BS12	1.85	32.27	-1.37	0.49	55.20	40.82	3.02	3.42	3.95	1.78	35.65	-0.62	0.57	63.13	36.90	1.71	2.18	2.76
Municipal Sub-Zonal Office	BS13	2.10	34.41	-1.20	0.53	56.00	34.34	3.16	3.63	4.17	1.87	35.10	-0.22	0.55	61.41	26.47	1.12	1.96	2.45
Batti Nukaraju House.	BS14	9.66	72.17	6.11	2.61	86.85	43.20	7.35	8.11	9.28	10.59	77.14	6.35	3.39	92.89	35.46	6.15	6.92	8.18
Overhead tank	BS15	7.51	66.51	4.60	2.00	82.85	63.12	5.44	6.33	7.36	7.86	70.81	4.51	2.45	88.49	62.24	4.09	5.06	6.15
bore hole No.32/013	BS16	16.22	84.71	13.00	5.57	99.67	65.90	5.44	7.08	8.29	19.21	89.38	12.73	8.47	105.5	76.72	3.79	5.67	6.94
M.Apparao House	BS17	14.52	81.30	11.39	4.36	95.18	62.24	6.56	8.01	9.19	16.25	85.62	11.54	5.97	100.79	62.24	4.48	6.23	7.45
Anjaneya Swami temple	BS18	6.39	52.52	-1.71	1.11	63.65	62.61	15.29	15.41	16.41	5.88	52.09	-2.01	1.09	63.82	64.59	13.52	13.59	14.61
K. Sanyarasirao House	BS19	8.04	65.19	4.85	1.90	79.79	57.74	6.43	7.48	8.46	8.51	69.41	5.58	2.30	85.31	57.70	5.10	6.24	7.28
Sambangi Kumari House	BS20	7.65	68.75	4.47	2.21	85.73	56.51	4.81	5.69	6.77	8.47	74.95	5.13	3.02	94.15	54.34	2.56	3.86	4.96
B.Sannyasirao House	BS21	14.33	80.92	9.45	4.27	94.12	71.62	8.54	9.49	10.77	14.76	83.39	9.24	5.07	97.79	71.76	6.64	7.73	9.03
T. Gangaraju House	BS22	19.05	84.90	7.30	5.66	94.55	52.35	15.34	15.63	17.20	19.91	87.22	7.08	6.88	97.49	51.10	13.21	13.49	15.12
NTR statue	BS23	10.26	67.22	0.22	2.06	76.67	62.24	15.22	15.54	16.75	9.93	68.82	0.60	2.21	78.98	61.31	11.89	12.34	13.54
Z.P.High School	BS24	4.68	55.51	4.04	1.26	76.88	38.01	0.49	2.51	3.22	4.64	58.43	3.90	1.41	82.03	39.73	-0.17	1.93	2.68
Vinayaka temple	BS25	5.65	43.83	-11.27	0.79	52.40	52.15	20.95	21.03	21.89	5.24	42.84	-10.61	0.76	51.82	51.04	18.57	18.70	19.52
Visakha Grameena Bank	BS26	3.22	30.04	-11.04	0.43	40.42	49.63	15.68	15.90	16.41	3.01	29.76	-9.81	0.43	40.78	46.62	13.52	13.77	14.27
Main road	BS27	3.17	36.01	-2.95	0.57	50.72	58.86	8.71	9.04	9.65	3.00	35.86	-2.12	0.56	51.66	60.71	7.50	7.87	8.46
Maridimamba community hall	BS28	1.35	27.62	-1.46	0.39	53.35	31.09	0.88	1.68	2.06	1.39	32.72	-0.78	0.49	63.06	18.58	-0.50	0.76	1.18
Maridimamba temple	BS29	3.40	50.84	-0.11	1.04	71.97	38.43	2.83	3.34	4.17	3.53	58.02	0.35	1.39	82.74	33.26	1.35	1.96	2.90
Pydimamba temple	BS30	2.88	42.00	-1.84	0.73	60.43	40.50	5.38	5.48	6.29	2.20	37.91	-2.14	0.62	58.13	36.29	4.29	4.31	5.08
Overhead water tank	BS31	3.46	48.53	-0.04	0.96	68.81	35.19	4.03	4.41	5.25	2.95	46.86	0.25	0.89	70.32	33.18	2.43	3.00	3.75
Gowthulachanna Colony	BS32	2.40	42.85	0.99	0.78	72.27	55.67	-0.29	1.25	1.83	2.04	43.10	0.43	0.80	77.09	60.34	-0.37	0.88	1.49
Ramalayam	BS33	2.34	38.68	0.69	0.66	64.86	46.60	1.02	2.13	2.68	2.19	41.68	0.89	0.76	73.74	45.18	-0.46	1.06	1.64
	Min	1.35	26.40	-11.27	0.36	40.42	24.02	-1.18	0.82	1.33	1.39	27.38	-10.61	0.38	40.78	15.30	-2.84	0.23	0.76
	Max	19.05	84.90	13.00	5.66	99.67	71.62	20.95	21.03	21.89	19.91	89.38	12.73	8.47	105.50	76.72	18.57	18.70	19.52
	SD	5.85	51.15	1.14	1.53	68.98	49.26	6.35	7.10	7.92	6.02	53.51	1.51	1.87	73.62	46.76	4.81	5.70	6.54

Magnesium ratio (MR)

Magnesium Ratio is ranged from 24.02 to 71.62 meq /L (mean 49.26), and 15.30 to 76.72 meq /L (mean 46.76) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS16 sampling station. Based on the MR results, 48.5% of the sample comes under the suitable irrigation category, and the remaining 51.5% of samples are comes under the not suitable for irrigation category.

Ion exchange (Chloro alkaline indices – CAI- I & II)

CAI - I value is ranges from -1.18 to 20.95 meq /L (mean 6.35), and -2.84 to 18.57 meq /L (mean 4.81) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS25 sampling station. Likewise, CAI - II value ranged from 0.82 to 21.03 meq /L (mean 7.10), and 0.23 to 18.70 meq /L (mean 5.7) during pre-monsoon and post-monsoon seasons, respectively. Here also at the sampling station BS25, the maximum value was recorded.

Chloride classification (ClC)

Chloride classification value ranged from 1.33 to 21.89 meq /L (mean 7.92), and 0.76 to 19.52 meq /L (mean 6.54) during pre-monsoon and post-monsoon seasons, respectively. The maximum value was found at the BS25 sampling station. Based on the Cl. classification, only a single sample comes under the very fresh water category, and it possesses about 1.5%, and 36.4% of samples come under the freshwater category, and 33.3% of samples come under fresh- brackish water category, and 28.8% of samples comes under brackish water category.

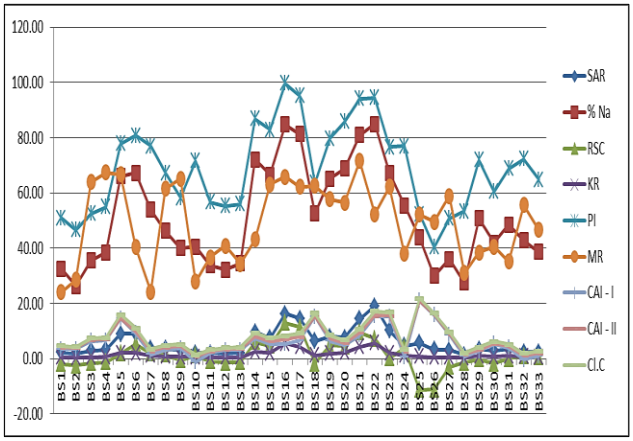

Fig 6 The seasonal disparity values of some statistical parameters in the study area during pre-monsoon - 2021

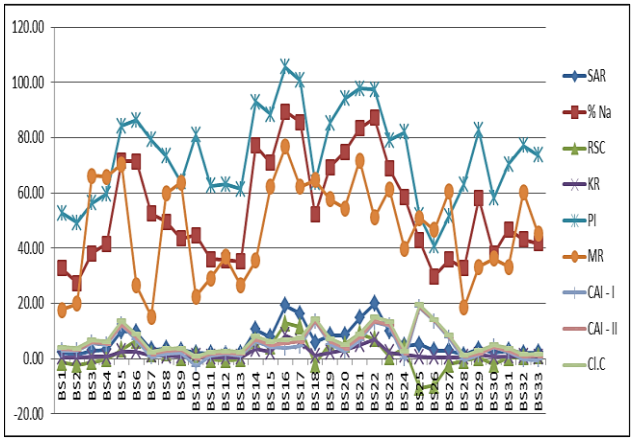

Fig 7 The seasonal disparity values of some statistical parameters in the study area during post-monsoon - 2021

Remedial measures

This study area is a highly mineralized area. Some heavy metals are showing higher values. Hence, the following water purification methods are recommended to minimize the abnormal concentration of the above-mentioned parameters. They are ultrafiltration, precipitation, reverse osmosis, flocculation, ion exchange technique, slow sand filtering, and membrane filtering. Moreover, flotation ion exchange and electrochemical deposition are some best useful techniques for the removal of pollutants and contaminants to purify groundwater.

CONCLUSION

From the above observations, the present study reveals that the statistical parameters show some abnormalities. When compared to the results of SAR, 12% of the samples fell into the "not suitable for irrigation" (doubtful) category, and another 23% of the samples were completely unsuitable for irrigation. The percent sodium (%Na) results show that approximately 21.2% of samples are doubtful for irrigation, and 12.2% of samples are completely unsuitable for irrigation. When compared to the results of RSC, nearly 30.3% of samples fall under the unsuitable for irrigation category. When compared with the results of Kelly's Ratio (KR), nearly 47.0% of samples fall under the "not suitable for irrigation" category. When compared to the results of the Permeability Index (PI), 71.2% of samples fall under the "not suitable for irrigation" category. According to the magnesium ratio (MR) values, 51.5% of the samples are "not suitable for irrigation." Like that, chlorine classification also reveals that 33.3% of samples come under the fresh-brackish water category and 28.8% of samples come under the brackish water category. All statistical values concluded that there was some extent of contamination in the study area. This might have happened due to the malpractice of industrial activities and agricultural runoffs. In view of the above, proper watch is due attention in the study area. From the present study, it is understood that the local ground water is affected. Further, it is suggested to carry out studies to establish sources of impact on ground water in this area viz to see whether sea water intrusion is occurring; to see if any industrial activity is influencing the ground water quality in the area; to see if any percolation is taking place from septic tanks; The present study is helpful in proper planning and management of available water resources for drinking & irrigation purposes. Ground water in the study area is showing slightly higher values. Hence, it is recommended that, some conventional treatment is required before it usage. A continuous monitoring program of water quality is prerequisite to check the aptness for irrigation purpose.

Acknowledgement

This is a case study of Fundamental Research work under the pursuit of a Ph. D. degree. The authors are thankful to the Department of Environmental Sciences, Acharya Nagarjuna University, Nagarjuna Nagar for constant encouragement.

Data availability statement

The relevant data and its Information are included in the paper.

Conflict of interest

The authors declare there is no conflict.

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