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Hydrogeological and Hydrochemical Characterization of Coastal Aquifers with Special Reference to Submarine Groundwater Discharge in Uttara Kannada, Karnataka, India

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ABSTRACT

In coastal areas of our country, in spite of having excess rainfall (more than 3000 mm), groundwater become a rare commodity during summer. Number of researchers have discussed the issues related to water scarcity of coastal areas where there is a huge pressure on environment due to increased population, tourism, agriculture and industrial growth. Fast depletion of groundwater is also reported in coastal districts due to continuous discharge of direct runoff and also through subterranean flow which is termed as Submarine Groundwater Discharges (SGD). Large quantity of contaminants enter the ocean system through runoff. This necessitated a detailed investigation to understand the hydrological processes involved and the source of contaminants. The present investigation is an attempt to make quantitative and qualitative assessment of SGD based on hydrological, hydrogeological and hydrochemical components. Accordingly, water balance components were evaluated based on hydrological and hydrogeological investigations. Hydrochemical parameters were also evaluated to understand the impact of seawater intrusion in pre and post-monsoon of 2019. Study revealed that, there are signatures of considerable quantity of submarine groundwater discharge in parts of Honnavara, Kumta, Ankola and Karwar talukas. The influence of seawater in coastal aquifers is quite rare all along the coast of Uttara kannada district which is attributed to high groundwater recharge (15-20%) occurring in catchment areas.

1. Introduction

Management of water along the coastal zone of India, has been a matter of great concern to the administrators and policy makers, in spite of having some of the most potential aquifer systems in the region. However, major part of the aquifers particularly the Tertiary to Recent ones are highly exploited and needs well defined scientific

approach to resolve the issues related to overexploitation and pollution of water bodies. The problems associated are primarily due to rapid urbanization, industrialization, infrastructure development and climatic uncertainties that seriously affects the spatio-temporal distribution of water. Along the coastal tracts, there is a continuous interaction between groundwater and seawater either leading to seawater intrusion or submarine groundwater

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discharge^[1]. Surface water inputs are through rivers and streams and discharge a large quantity of water received from the catchment and hence, the contribution of surface water discharge to the ocean, its hydrodynamics, geochemical cycles of elements and its influence on the ocean ecosystem has been well recognised^[2]. On the contrary, groundwater discharge typically has a smaller water flow rate compared to river flow and hence not well demarcated.

Most of the studies conducted in the coastal region are focused on water quality aspects and radon concentration and for some of the studies in East coast, barium and strontium were also applied^[3-5]. A detailed study was conducted using hydrogeological modelling to quantify SGD from the coastal aquifers of Vizhinjam (Kerala)^[6]. According to the various studies conducted in India and elsewhere, the primary factors that influence the discharge of groundwater into adjoining oceans is due to water table fluctuations resulting from variations in recharge, pumping rate, tidal surges and transmissivity of the aquifers.

2. Methodology

2.1 Study Area

The coastal district of Uttara Kannada lies between north latitudes, $13^{\circ} 55' 02''$ to $15^{\circ} 31' 01''$ and east longitudes

$74^{\circ} 00' 35''$ to $75^{\circ} 10' 23''$ (Figure 1). Study area is mainly covered by lateritic soils with underlying geological formation which include Pre-cambrians (Dharwar Super group) dominated by granitic gneisses, schists, greywackes and phyllites. There are basically two types of aquifers encountered in the study area, namely confined and unconfined aquifers. Ground water occurs under unconfined condition in alluvium, laterite soil cover and weathered crystalline rocks like granites, basic rocks and Deccan traps. Confined layers located at deeper depth which includes shear zones, fractured and jointed crystalline rocks, iron ore and chert, kankar, sand and gravel.

In the present investigation, the following methodologies were adopted.

2.2 Estimation of Hydrological Components Using Soil and Water Assessment Tool (SWAT Model)

SWAT is a physically based, semi distributed river basin or watershed scale model^[7,8] was applied to estimate the hydrological components such as Runoff, Evapotranspiration (ET) and Groundwater recharge.

2.3 In-situ Determination of Soil Hydraulic Properties

In-situ infiltration rate and saturated hydraulic conductivity (Ks) of the soils were determined by using

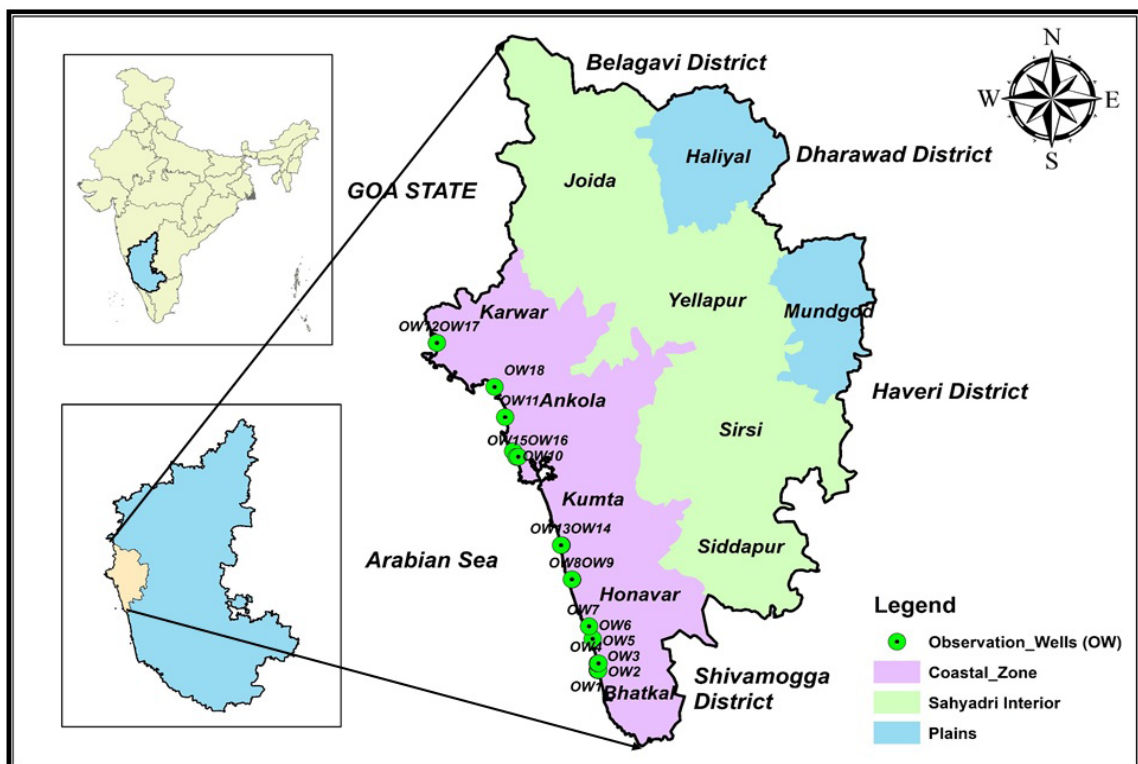


Figure 1. Uttara Kannada district

disc permeameter. Soil hydraulic parameters such as infiltration, sorptivity and saturated hydraulic conductivity were derived by the method developed by ^[9,10].

2.4 Geophysical Investigation

In the current study, using resistivity meter, VES (Vertical Electrical Sounding) soundings were taken in selected locations. Apparent resistivity were calculated by multiplying apparent resistance and geometric factor ^[11]. A log-log plot was drawn between apparent resistivity and half current electrode separation (AB/2). Curve-matching technique was applied (Schlumberger array master curve and auxiliary curves) to determine the layer resistivity values and thicknesses.

RESIST software was applied to estimate true geological section of the study area. The logged depths were compared with VES data using linear regression analysis.

2.5 Estimation of Groundwater Recharge by Empirical Methods

Groundwater Recharge was calculated using the following formula:

a) Chaturvedi ^[12] derived an empirical equation to calculate groundwater recharge as.

$$R_g = 2(P-15)^{0.4} \quad (1)$$

Where, R_g is the Groundwater recharge and P is the annual precipitation.

(b) Krishna Rao ^[13] developed an empirical relation to calculate groundwater recharge based on climatic conditions.

$$R_g = K (P-X) \quad (2)$$

Where, R_g = groundwater recharge, K is constant (based on climatic homogeneity), P is annual precipitation (in mm), X is normal annual average rainfall zones, accordingly, the following equation was adopted. Rainfall recharge (R_r) = $0.35(P-600)$ for areas with rainfall more than 600 mm.

Physical parameters such as electrical conductivity, temperature and pH were measured using a handheld pH and Electrical conductivity meter (HANNA HI—9828, USA). Major anions such as bicarbonate, chloride, calcium, magnesium sodium and potassium were determined by the methods suggested by ^[14].

3. Results

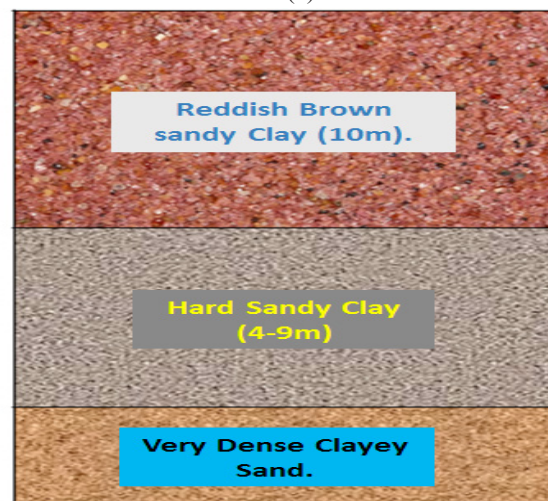
3.1 Soil Characteristics

Soil profile investigations have been carried out in

selected locations along the coast of Uttara kannada. Major soil types identified in the study area are leguminous laterites underlain by hard sandy clay to medium dense sandy layer. In some of the areas slightly weathered granites are the basement rocks. The soil types across the profile play a significant role in holding moisture content as well as it influences the groundwater recharge. Textural analysis of the soil showed that the soils between Murudeshwar and Honnavara are relatively more permeable than the adjoining northern taluks of Uttara kannada. Typical soil profile (approximate thickness of each layer is given in meters, m) observed along the Uttara kannada coast is presented in Figure 2.



(a)



(b)

Figure 2. Soil Profile observed at Murudeshwar and Honnavara

Infiltration, sorptivity and saturated hydraulic conductivity were determined with reference to soil type and land use/land cover change. Rate of infiltration is significantly high in lateritic area covered with forests and

acacia plantation. Highly weathered laterites were found in parts of Kumta and Ankola taluks. In Hattikeri, laterite cover exhibited very high infiltration rate and hydraulic conductivity (Table 1). This could be attributed to the land cover such as forest and acacia plantation which open up the top soil layers and influence the development

of preferential flow paths leading to high groundwater recharge and pipe flow ^[15].

Three sets of resistivity data obtained through field investigations were plotted on log-log graph (Figure 3) for three different sections of the study area representing Q, H and K type curves.

Table 1. Range of Field determined Hydraulic properties of different soils along the coast of Uttara kannada

SI No	Soil type along the coast	Infiltration rate mm/hr	Sorptivity mm/hr ^{1/2}	Saturated Hydraulic conductivity mm/hr
1	Laterite in forest catchment (Honnavar)	60 -192	30-120	70-80
2	Laterite in acacia plantation	120-175	80-120	40-50
3	Barren land (laterite cover)	12-24	6-8	6-12
4	Laterite (Hattikeri)	25-245	10-130	85-120
5	Beach sand with plantation (transitional zone between beach and land area)	70-280	20-60	60-180
6	Shrubs	28-76	12-40	8-18
7	Leguminous laterites	22-88	0-4	6-14
8	Clay dominated laterites	2 -18	1-15	1-9

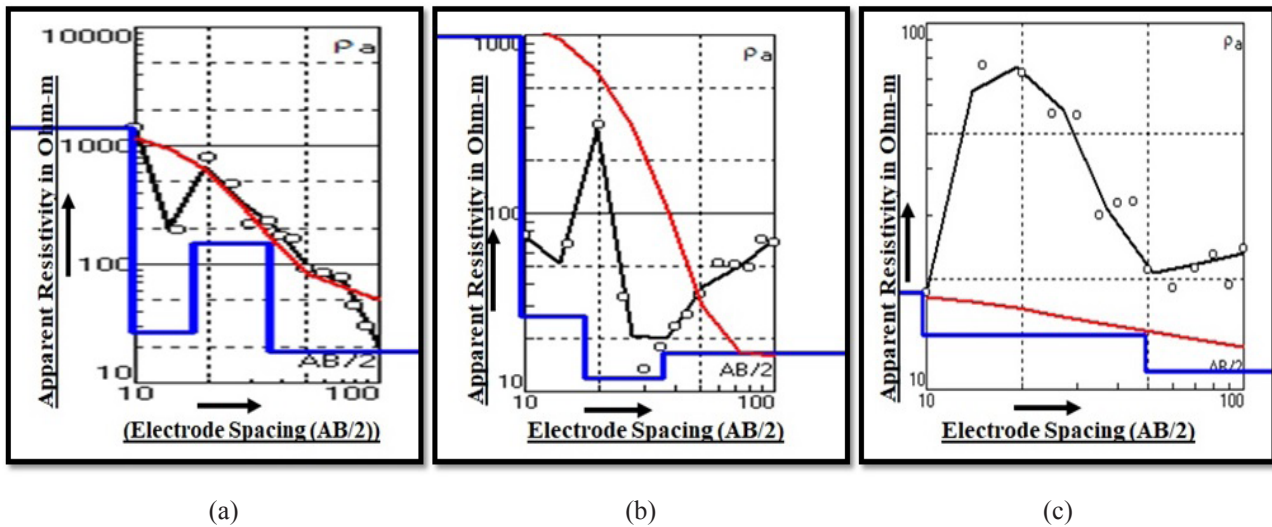


Figure 3. Typical Resistivity curves of the study area

a. Q Type ($p_1 > p_2 > p_3$)

Figure 3a shows the cross-section of the coastal zone with varying apparent resistivity. This is the most common section found in hard lateritic terrain occupying the top layer.

b. H Type ($p_1 > p_2 < p_3$)

Figure 3b indicate the H-type curve with initial fluctuation and having relatively high resistivity at the top which is followed by a water saturated and weathered layers of low resistivity and then a compact hard rock of high resistivity at the bottom.

c. K-Type ($p_1 > p_2 > p_3$)

Though these types of curves (Figure 3c) are common

in basaltic area, and in the present case, it indicates the fresh water zone between clay layer and saline zone.

The resistivity data were converted to 2D images and presented in Figures 4a, b & C. Comparison of the ERT image and field observations indicated reasonably good agreement. The profile up to 5m depth with a very low resistivity in range of 0.2 to more than 4000 Ωm has been observed which indicate the presence of the top soil and sand within the clay formation. The high resistivity values could be attributed to the extension of lateritic plateau in the deeper layer.

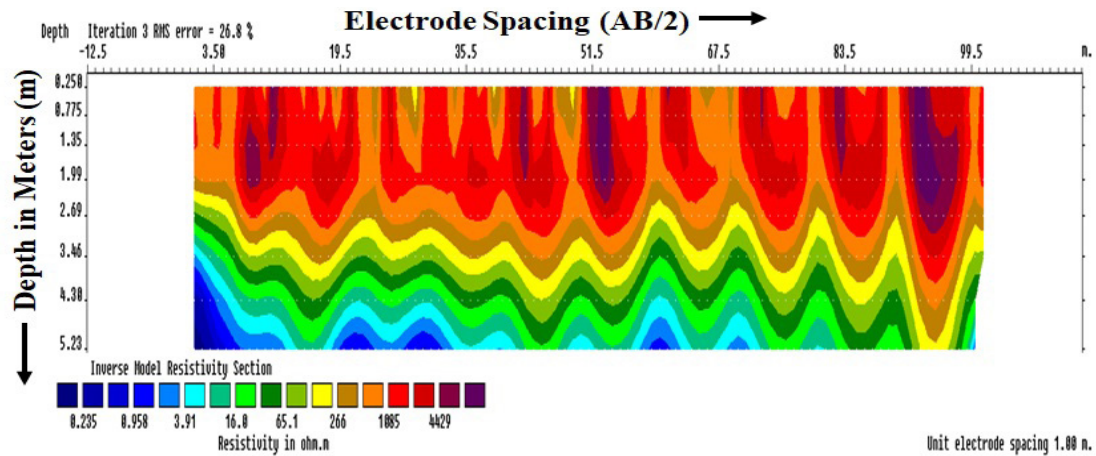


Figure 4a. ERT profile of Q -type curve

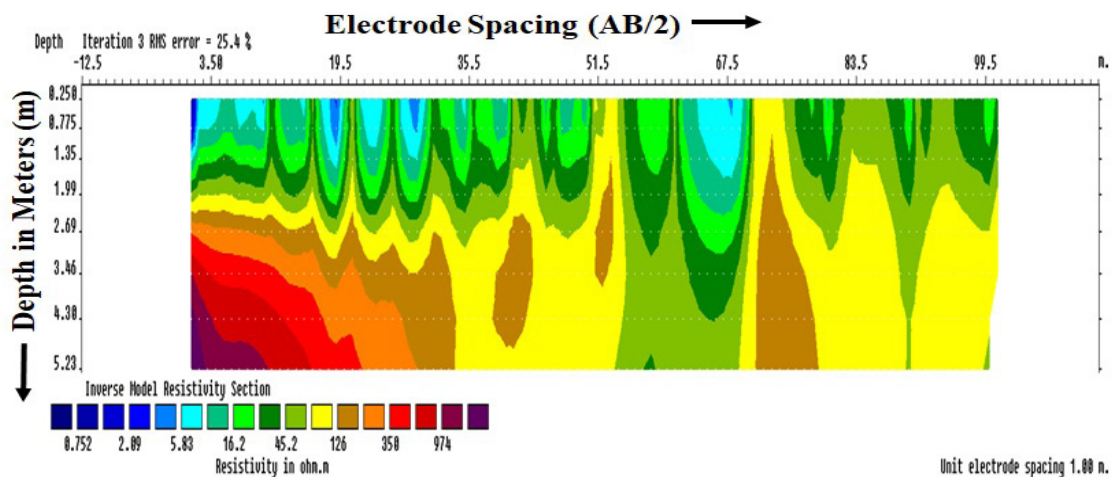


Figure 4b. ERT profile of H -type curve

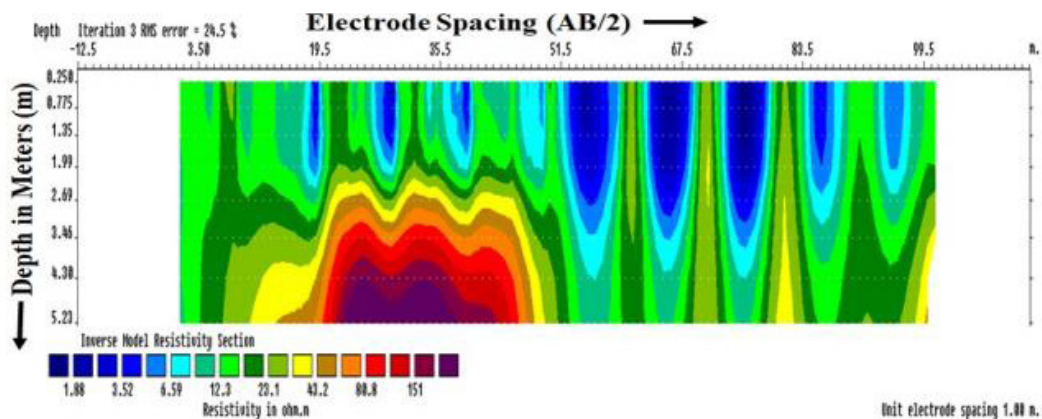


Figure 4c. ERT profile of K type curves

The occurrence of groundwater in the study area is found to vary with the depth of weathered layer and thickness of over burden. In major part of the district, well depth varied from 16 m to 47 m. Lithologically, the zone consists of fine to medium sand with alternative layers of silt and clay. Groundwater level data of thirty three wells monitored by

Central Ground Water Board (CGWB) were analysed and found that the depths range from 89 to 200 meters with an effective porosity of about 1-3%. The transmissivity of aquifer material in general range from 2.09 to 24.41 m²/day. The yield of the wells ranges between 1.88 and 2.25 lpm (litres per minute) and drawdown reported was 1.6 to 10.39 meters.

Groundwater levels in the pre monsoon vary between 5 and 10 mbgl (metres below ground level) in 2017 and 2018. Low water table (less than 2 mbgl) was observed around Karwar town and towards southern part (Kumta and Ankola), water table showed fluctuation between 2 m and 5 m. In the coastal zone, groundwater levels range between -0.19 and 13.03 m. The maximum recorded was 13.15 m in Honnavar and negative fluctuation of -0.19 m was found in Murudeshwara.

Water balance components were estimated by using calibrated SWAT model (Table 2). Model was run for a representative watershed available in each taluka. It is observed that, the runoff estimated is higher for Kumta region whereas minimum was observed in Ankola. Groundwater recharge (shallow) was also found to be maximum in Ankola and Karwar tauka in comparison to other three talukas (Bhatkal, Honnavara and Kumta). Variation in runoff and recharge could be presumed due to increased deforestation followed by urbanization

and conversion of forest land to agriculture (however, to conclude specific investigation is required). In all watershed of each taluka showed high lateral flow which is attributed to highly porous lateritic soils below moderately weathered laterites.

Table 2. Water Balance Components Estimated using SWAT Model

Water Balance Components	Bhatkal	Honnavar	Kumta	Ankola	Karwar
Surface Water	45.170	45.996	46.849	37.749	39.758
Groundwater	18.218	18.680	17.862	23.536	23.956
Lateral flow Q	4.503	3.917	3.471	4.128	4.513
Evapotranspiration (ET)	29.405	29.415	28.858	28.894	28.706

Recharge values estimated by SWAT model was also compared with that obtained from using empirical methods. Chaturvedi and Krishna Rao formulae showed a significant correlation between each other (Table 3).

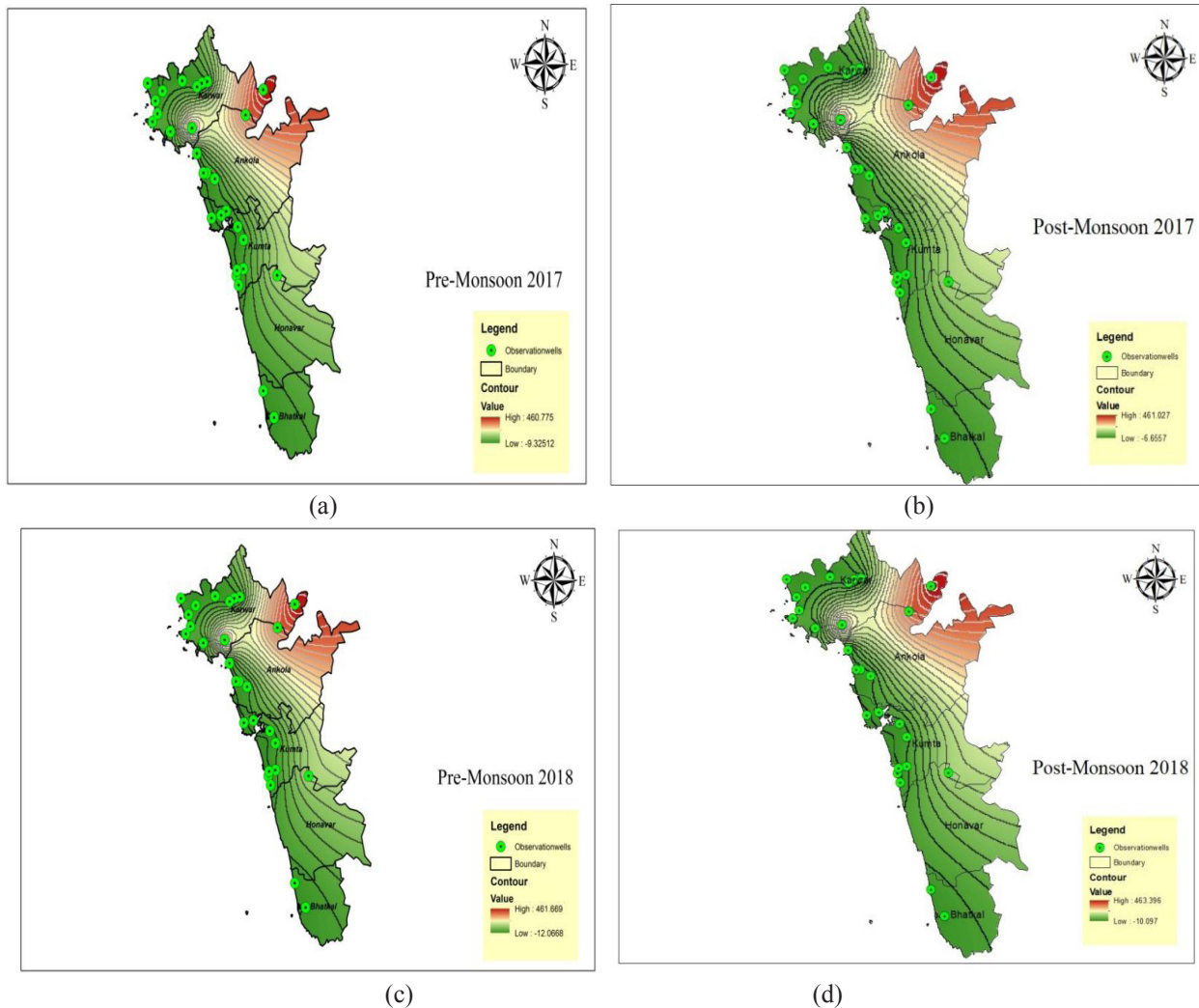


Figure 5(a to d). Groundwater levels of Uttara Kannada district

Table 3. Comparison of Estimated Ground Water Recharge using SWAT with Conventional methods

Year	Rainfall in mm	% Recharge By SWAT model	% Recharge (Chaturvedi)	% Recharge (Krishna Rao)
2002	2361.1	19.37	18.17	18.07
2003	2688.30	18.28	15.76	19.53
2004	2607.7	17.48	17.24	19.74
2005	3223.30	18.55	19.22	22.01
2006	3410.7	19.28	15.94	21.86
2007	3657.50	13.55	23.22	15.90
2008	3271.5	20.02	19.86	22.46
2009	3694.0	16.43	14.83	20.75
2010	4668.8	19.39	19.57	18.28
2011	4236	19.65	17.57	22.65
2012	3886.88	17.34	16.90	19.27

The above estimated recharge values demonstrate the applicability of SWAT model to the present study area.

3.4 Groundwater Quality Evaluation

Groundwater samples were collected during pre-monsoon and post-monsoon seasons of year 2019. Sixty two sites have been identified for water sampling and tested for physical parameters. Among the collected samples, based on the site characteristics, detailed analysis for both major anions and cations were carried out.

3.4.1 pH

pH is a primary indicator of water quality status of a surface or groundwater body. The pH in coastal aquifers of Uttara kannada, vary between 6.49m and 7.70m in premonsoon and 6.50m to 7.53m during post-monsoon. Acidic water is a characteristic of lateritic cover and alkaline water shows the human impact on water quality.

3.4.2 Electrical Conductivity and TDS

The EC values varied between 54.7 μ mhos/cm and 5060 μ mhos/cm during the pre-monsoon and 32 μ mhos/cm to 3025 μ mhos/cm during the post-monsoon (Figure 6 a & b). According to the classification of EC, 94% of the total groundwater samples fall under type I (low enrichment of salts) and the remaining 6% were grouped as type III indicating high enrichment of salts. Similar classification was adopted by ^[16].

Total dissolved solids showed a significant correlation with Electrical conductivity. TDS values varied from 31.6 mg/l to 2430 mg/l (pre-monsoon) and 17 mg/l to 1739 mg/l during post-monsoon. From the analysis it is evident that all water samples have low TDS which demonstrated the influence of rock-water interaction in relation to recharge

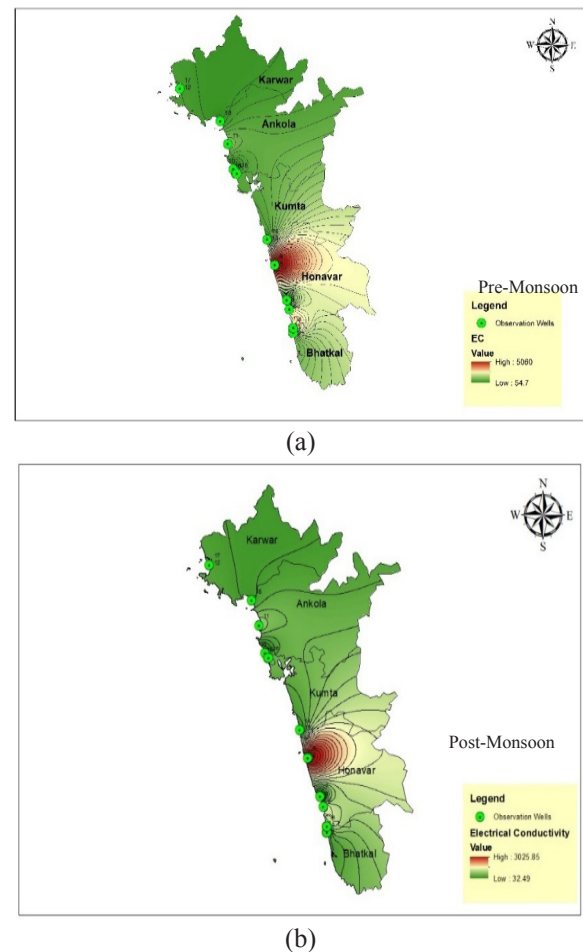


Figure 6 (a) & (b). Spatial Variation of EC during pre-monsoon and post-monsoon

water except for one well. The concentration of bicarbonate is observed from 70 to 520 mg/l during pre-monsoon and 46 to 414 mg/l during post-monsoon (Figure 7 a & b).

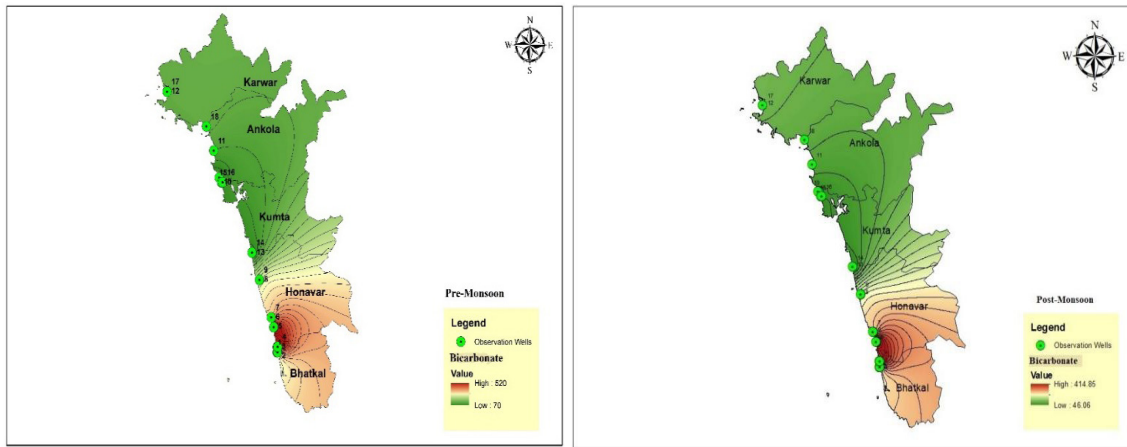
3.4.3. Chloride

The chloride content is found to vary between 19 and 1116 mg/l in pre-monsoon and 19 to 700 mg/l during post-monsoon (Figure 8 a & b). 83.3 % of the groundwater samples lie within the permissible limit whereas remaining 16.6 % were exceeding the permissible limits.

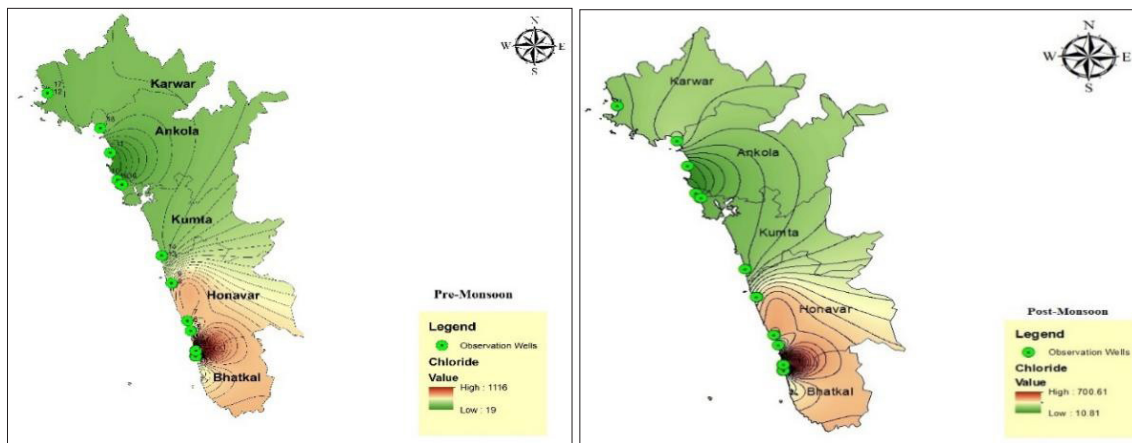
The concentration of Ca is between 17 mg/l and 244 mg/l, and Mg varied from 5 mg/l to 56 mg/l during pre-monsoon. In the post monsoon, Ca content vary between 10 mg/L and 166 mg/l, and concentration of Mg varied from 6 mg/l to 25 mg/l. Majority of the water samples collected from the study area fall under moderately hard to hard category during both pre and post-monsoon. The hardness values range from 22 mg/l to 260 mg/l with an average value of 157.1 mg/l during pre-monsoon. Similarly during post-monsoon the hardness values range from 16 mg/l to 186 mg/l with an average value

of 117.7 mg/l. The concentration of Na varied from 3.09 to 85.5 mg/l during pre-monsoon (Figure 9a) and 0 to 81 mg/l during post-monsoon (Figure 9b). Na is the dominant

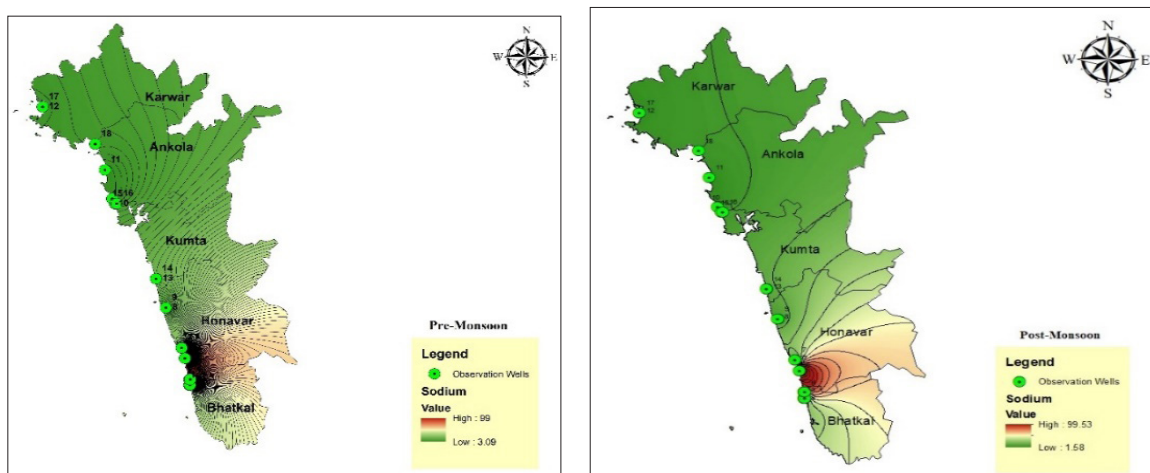
ion among the cations and is present in most of the natural waters, which contribute approximately 53 to 69 % of the total cations.



(a) (b)
Figure 7(a) & (b). Spatial variation of HCO_3^- (pre and post monsoon)



(a) (b)
Figure 8(a) & (b). Spatial variation of Chloride (pre and post-monsoon)



(a) (b)
Figure 9(a) & (b). Spatial Variation of Na during pre-monsoon and post-monsoon

3.4.4 Phosphorous

The phosphorous content observed during pre-monsoon varied between 0.46 mg/l and 1.82 mg/l. Analysis of post-monsoon water quality data showed that the concentration of P, vary from 0.37 mg/l to 1.60 mg/l.

3.4.5 Salinity

Salinity is the total amount of inorganic solid material dissolved in any natural water, and water salinization relates to an increase in TDS and overall chemical content of water. The salinity concentration in the study area ranges between 0.02 and 2.48 mg/l during pre-monsoon and 0.03 to 1.65mg/l during post-monsoon.

3.4.6 Sodium Adsorption Ratio

The analytical data plotted on the US salinity diagram^[17] suggest that groundwater samples grouped in the domain of C1S1, C2S1, indicate water of low-medium salinity and low sodium, which can be utilized for irrigation in all types of soils. Few samples fall in the C3S2 domain with one sample exhibiting C4S2 type. At the outset, the study area can be classified as of good to moderate category irrespective of the rainfall seasons.

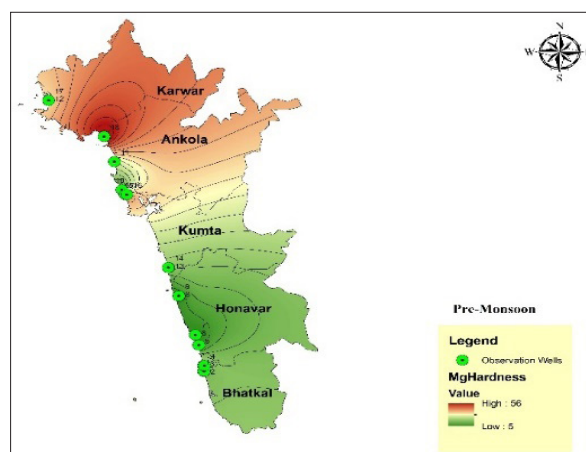
3.4.7 Permeability Index

In the present study, water suitability classification for irrigation developed by^[18] has been adopted. The PI values vary from 18.65 to 345.92 (pre-monsoon) and in the post monsoon, PI values varied between 25.28 and 253.672. Accordingly, 88.88 % of the samples fall under the class 1 ($PI > 75$) and 11.11 % of the samples fall under class 3 ($PI < 25$ %) during pre-monsoon period. However considerable variation was observed in post monsoon 2019. It was observed that 33.33 % of the samples fall under class 3 ($PI > 75$) and 66.66 % belong to class 2 (PI ranged between 25 and 75 %).

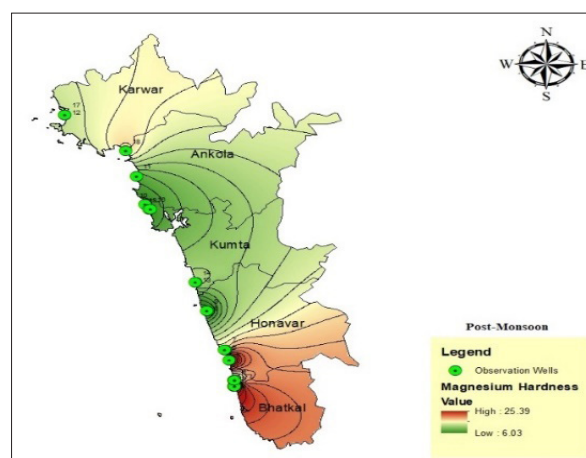
A ratio namely index of magnesium hazard was developed by^[19]. Magnesium hazard values fall in the range of 9.75 to 49.41 (pre-monsoon) and from 11.65 to 49.72 (post monsoon). All the samples showed MH ratio < 50 % (suitable for irrigation) during pre-monsoon and post monsoon. The variation of Mg content is shown in Figure 10a & 10b.

3.4.8 Kelley Ratio

KR more than one is a sign of an excess level of sodium in waters and less than one, is an indication of suitability of water for irrigation. During both pre-monsoon and post-monsoon, KR values were less than one, indicating water is suitable for irrigation.



(a)



(b)

Figure 10(a) & (b). Spatial Variation of Mg during pre-monsoon and post-monsoon

3.4.9 Ionic Ratios

According to^[20], EC alone cannot determine the salinity status of aquifers. Ionic ratios were used^[21,22] to identify the source and nature of the salinity present. In the present study, $Cl/(HCO_3 + CO_3)$, Kelly's ratio and permeability indices were used to understand the impact of seawater intrusion. $Cl/(HCO_3 + CO_3)$ ratio which is also known as Simpson's ratio classify the groundwater into five category-good quality (< 0.5); slightly contaminated ($0.5 - 1.3$); moderately contaminated ($1.3 - 2.8$); highly contaminated ($2.8 - 6.6$); and extremely contaminated ($6.6 - 15.5$). Majority of the samples were found to be under good category except two samples which grouped as extremely contaminated during pre-monsoon and post-monsoon seasons.

4. Conclusions

Hydrogeological investigations have shown that the

coastal aquifers of Uttara kannada do not show any signature of seawater intrusion as observed during the study period. From the study, it is understood that the recharge to groundwater is very high (15-20% of annual rainfall) due to which, the possibility of seawater intrusion become rare. However, there are chances of temporary phenomena which occur mainly due to advancement of sea towards the land during heavy monsoon causing enormous losses due to coastal erosion and fishery resources.

River flow characteristics of some of the rivers have been analysed based on the discharge data. Base-flow estimated indicate that, submarine groundwater discharge occurs during dry seasons mainly due to high rainfall (average rainfall more than 3000 mm) and high groundwater recharge. The estimated saturated hydraulic conductivity showed that the soils are highly permeable in lateritic areas, particularly below the top soil due to which the infiltrated water flows to sea continuously. From the present study, a rough estimate of about 0.15% to 0.18% of rainfall quantity enter the sea as submarine ground discharge from March to May. This is mainly based on monthly moisture trend which were observed at three sites and found a reasonably high moisture content in three locations namely, Murudeshwar, Kumta and north of Karwar taluks. Groundwater quality investigations carried out in more than thirty wells all along the coast also demonstrated that, the coastal aquifers are safe for drinking, irrigation and domestic purposes.

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