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Assessment of Salt Water Intrusion from Ponnani to Tavanur along the Banks of River Bharathapuzha in Kerala

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Groundwater is one of the major sources for irrigation and domestic purposes. The groundwater demand for various purposes is increasing in coastal areas. The population density in the coastal region is high and the health of people depends on the quality of water used. Ponnani, in the Malappuram district, is a thickly populated coastal town of Kerala where the availability of good quality drinking water is lacking. The study was undertaken to analyze the fluctuation of the water table and its effects on salinity intrusion and to understand the suitability of groundwater for drinking and irrigation purposes in the coastal belt of the Tavanur-Ponnani region. Six regions, Tavanur, Nariparambu, Chamaravattom, Purathur, Eswaramangalam and Ponnani are included in the study area. The water level was measured from observation wells in the field at monthly intervals, and samples were collected for water quality analysis during the period 2015 to 2021. The results obtained indicate that there is saline water intrusion in the coastal stretch of Purathur, Padinjarekkara and Ponnani regions of the Bharathapuzha river basin, and both salinity and EC is having an increasing trend in almost all wells during this period. The problem was found to be severe during dry periods (March-May) of the year in the Purathoor and Ponnani regions with salinity and EC rising to about 1800 mg L^{-1} and 1400 µs cm^{-1}, respectively in the pre-monsoon period, which can be used for drinking only in the absence of an alternate source. In these areas, the groundwater available during the summer months becomes unsuitable even for irrigation purposes. During the monsoon season (June-November), the problem is less severe. Hence, it is recommended to restrict the use of groundwater at least to a lateral distance of 5 km from the seashore along the banks of the river.

(***Key words:*** *Electrical conductivity, Groundwater salinity, Salt water intrusion, Water quality*)

Groundwater resource development is receiving more attention in Kerala's coastal areas due to the rising demand for water to meet the household, agricultural, industrial and drinking needs. This is primarily due to the high population pressure and water quality issues, and the near absence of perennial freshwater bodies in the coastal stretch of the state. In India, groundwater utilization is increasing as surface water availability is decreasing (Suhag, 2016). Common quality issues in the coastal belt of Kerala include low pH, high iron content, high hardness, high TDS (Total Dissolved Solids), and salinity (Kumar *et al.,* 2020; Nazimuddin and Basak, 1998).

The availability of groundwater is a key aspect in the State's development and sustained habitation, particularly along the coastal region. The population densityin the coastal areas of Malappuram district of Kerala is as high as 1158 people per square kilometre with large number of fishermen families (Ramesh *et al.,* 2021). The population growth has led to a tremendous increase in freshwater demand (Prasanth *et al.,* 2012). In recent years, the availability of surface water is decreasing, and people need to depend more on groundwater (Wada *et al.,* 2010). The over-exploitation of groundwater is one of the foremost reasons for saltwater intrusion in the coastal regions of Kerala (Kumar, 2016). The groundwater system has a distinct chemical composition and the quality depends on natural factors like rock-water interaction, mineral dissolution, soil-water interaction, etc., and also on anthropogenic activities (Khatri and Tyagi, 2014). Poor water quality

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has a negative impact on plant development and human health.

Salinity is one of the major problems which affects crop productivity in the world (Machado and Serralheiro, 2017). The physical characteristics and fertility of soil are also impacted by the excess salinity in groundwater (Chaudhary and Kumar, 2018). In various locations in India, numerous studies on water quality have been conducted (Gopinath *et al.,* 2016; Sharma *et al.,* 2012; Sharma *et al.,* 2021). Measures to improve groundwater quality need to be taken to prevent harm to delicate crops and improve poor soil health. Bharathapuzha is one of the major rivers in Kerala (George and Athira, 2020), which flows mainly through the Palakkad and Malappuram districts of Kerala. The biggest problem in the area where Bharathpuzha joins the Arabian sea is the intrusion of saltwater into the groundwater in the coastal aquifers.

Saltwater intrusion as explained by Barlow and Reichard (2010), is the process by which seawater gets mixed with the freshwater available in the coastal aquifer systems. With less groundwater recharge and greater water demand, particularly during the summer, the severity of saltwater intrusion increases (Abdul *et al.,* 2015). An area from Ponnani to Tavanur along the banks of the Bharathapuzha river was selected to understand the extent of saline water intrusion into the freshwater aquifers. The fluctuation of the water table within the region was studied and it was used to understand the extent of saline water intrusion into the nearby aquifers. The feasibility of using available groundwater for drinking and irrigation purposes in the coastal belt of the Tavanur-Ponnani region of Malappuram District was also analyzed.

MATERIALS AND METHODS

Study area

The study area is bounded by a variety of brackish lagoons in the south and the Arabian sea in the west and is situated along the banks of river Bharathapuzha towards the Ponnani estuary. The region is located between latitudes 10.76° and 10.85° North and longitudes 75.88° and 76.00° East (Fig. 1). Part of the Tavanur and Ponnani areas of the Bharathapuzha river basin are included in the study area with an aerial extent of around 50 km^2. Its topography is almost flat, with slightly lower elevations to the west and south. The average annual rainfall received in the area is around 2940 mm. Riverine alluvium, valley fill, and coastal alluvium make up the recent alluvial deposits in the area. The area is having several water bodies, croplands, paddy fields, built-up, sand belts, etc. Different crops like paddy, coconut, banana, vegetables, areca nut and pepper are cultivated in the area.

The aquifers in the area are mainly alluvial deposits, which have high potential. The alluvial deposits are made up of riverine alluvium, valley fill, and coastal alluvium. Sand, silt, and clay make up the majority of the coastal alluvium and the groundwater is present under water table conditions. This aquifer is tapped by several dug wells and filter point wells, in areas where the saturated sand thickness is greater than 5 m to provide household and farming requirements. The alluvium along the coast can withstand medium-to heavy-duty pumping. Along the northern side of the Bharathapuzha river, a thick riverine alluvium also exists. These aquifers have unique yield values varying from 10 to 20%. The depth of shallow wells in the lateritic horizon ranges from 15 to 20 m below ground level (bgl). The water level fluctuates between 1.6 and 13.3 m bgl (CGWB, 2013).

Land use and base map

A description of the software and tools used to create the map is described here. The base map was prepared in a GIS environment (ArcGIS 10.4 version). The satellite image and Digital Elevation Model (DEM) required for the study were downloaded from the USGS Earth Explorer website (earthexplorer.usgs.gov). The satellite imagery for the year 2021 from the Landsat 8 OLI/TIRS C1 Level-1 collection was downloaded. The landuse map was generated with ERDAS Imagine 2015 software using the supervised classification technique. The imagery with a small amount of error and less than 10% cloud cover was selected for the study. Eleven spectral bands with a spatial resolution of 30 m make up the Landsat 8 OLI data set. Supervised classification is a procedure for identifying spectrally similar areas of an image by identifying 'training' classes. It is based on visual analysis and ground truthing, both of which are strictly under the user's control. Image rectification, layer stacking, image enhancement and extraction of

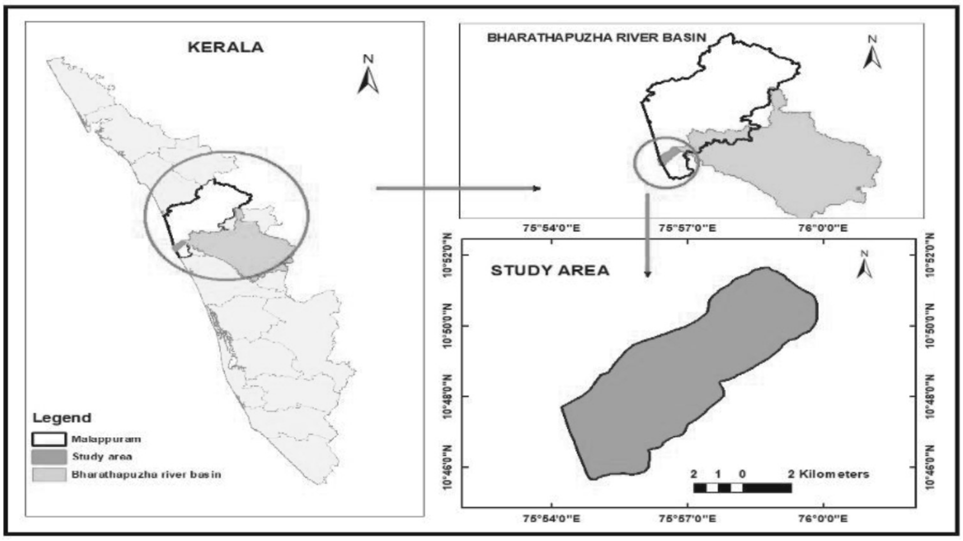

Fig.1. *Study area*

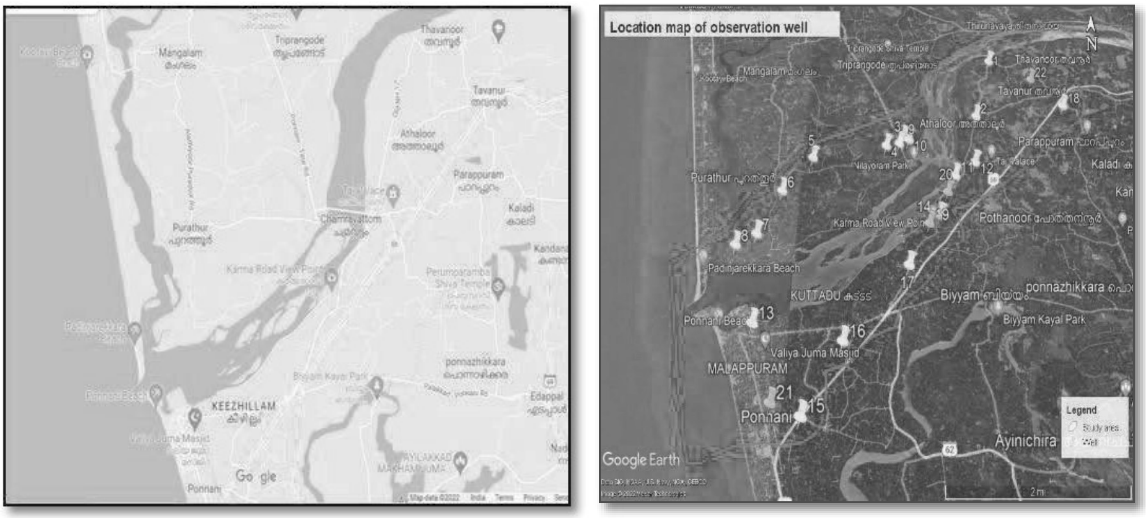

Fig. 2. *Location map of observation wells*

the study area were done before classification. After supervised classification, the raster data was converted to vector and the dissolution of classes was done to obtain the final classified map. While creating the training data set required for creating the land use map, the locations were also confirmed using aerial imagery, google imagery and ground truth data. The accuracy of classification was assessed in terms of overall accuracy, producer's accuracy, user's accuracy and kappa coefficient.

Water table monitoring

For water level monitoring in the study area, a network of eighteen observation wells (open wells) that is distributed throughout the area was chosen (Fig. 2). Chamaravattom, Purathur, Nariparambu, Maravancheri, Ponnani, Tavanur and Chamravattom - Ponnani coastal stretch are different parts of the study area. The depth to the water table was measured using a water level recorder at monthly intervals from 2015 to 2021 and water samples were also taken for analysis. Each sample

Table 1. *Details of the selected observation wells*

Sl. No.	Location	No. of wells and well no.	Approx. distance from coast (km)
1.	Tavanur	2 Nos. (1 & 18)	> 9
2.	Nariparambu	2 Nos. (2 & 3)	> 8
3.	Chamravattom	4 Nos. (4, 9, 10 & 11)	5.0-5.5
4.	Purathur	4 Nos. (5, 6, 7 & 8)	1.0-1.5
5.	Eswaramangalam	2 No. (12 & 14)	4.0-4.5
6.	Ponnani	4 Nos. (13, 15, 16 & 17)	0.5-1.0

Table 2. *Guidelines for interpretations of water quality for irrigation by FAO (1994)*

Potential irrigation problem	Units	Degree of restriction on use			
		None	Slight to Moderate		Severe
Salinity					
EC_w	dS m^{-1}	< 0.7	0.7 - 3.0		> 3.0
TDS	mg L^{-1}	< 450	450 - 2000		> 2000
Infiltration (EC_w and SAR to be considered together)					
SAR	0 to 3	and EC_w	> 0.7	0.7 – 0.2	< 0.2
	3 to 6		> 1.2	1.2 – 0.3	< 0.3
	6 to 12		> 1.9	1.9 – 0.5	< 0.5
	12 to 20		> 2.9	2.9 – 1.3	< 1.3
	20 to 40		> 5.0	5.0 – 2.9	< 2.9

collected is a representative sample of the water quality in that specific location and provides a general notion of the area's groundwater quality. The details of the observation wells selected are given in Table 1.

By examining the average depth to groundwater level in the observation wells, the variation in the groundwater table was evaluated. Using a digital water analyzer, these samples were examined for electrical conductivity (EC) and salinity (TDS). By analyzing the extent of salinity in the water samples collected, salinity intrusion along the coastal area was evaluated.

Groundwater quality

To understand more about the changes that have happened to the water quality in the coastal region, a temporal analysis of the well water quality from the observation wells was also conducted. Analysis was also done to understand the trends in the water table conditions during the pre-monsoon and post-monsoon periods.

The salinity of a water body is characterized by the concentration of total dissolved solids (TDS), a crucial factor in assessing the quality of drinking and agricultural water (Farjoudi and Alizadeh, 2021). Total dissolved solids (TDS) limits for drinking water have been set by the Bureau of Indian Standards (BIS) as 500 mg L^{-1} (corresponding EC of 750 µS cm^{-1} at 250°C) with a possible increase to 2000 mg L^{-1} (EC of 3000 µS cm^{-1} at 250°C) when no other source is available. TDS levels of more than 2000 mg L^{-1} are not recommended for consumption under any situation (CGWB, 2010). The standard values of irrigation water quality are given in Table 2.

RESULTS AND DISCUSSION

Land use

The types of land use found in the study region include water bodies, mixed vegetation, shrub land, paddy fields, sandy area (coastal and riverine sandy belt) and bare land. The area under various land uses

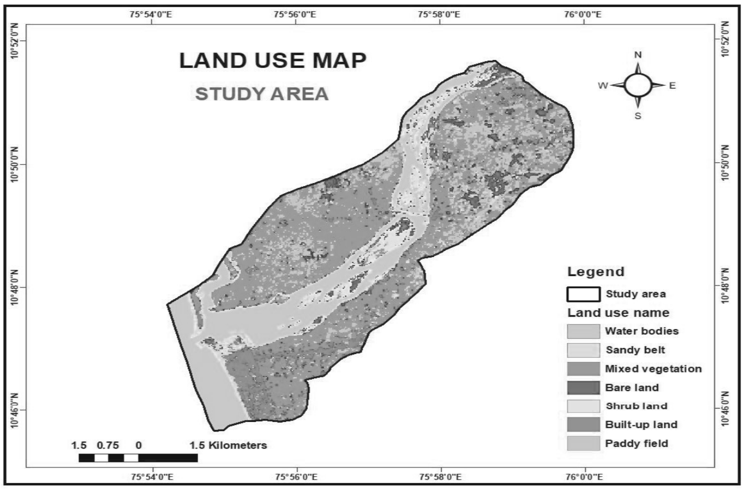

Fig. 3. *Land use land cover map of the study area*

Table 3. *Area under different land use/ land cover*

Land use / Land cover	Area in km^2	Area in %
Water bodies	9.12	18.95
Sandy belt	3.29	6.83
Mixed vegetation	22.11	45.90
Bare land	3.43	7.13
Shrub land	1.90	3.95
Built-up land	2.39	4.85
Paddy field	5.97	12.39

Table 4. *Confusion matrix of supervised classification*

Supervised classification	Water body	Sandy belt	Mixed vegetation	Bare land	Shrub land	Built-up area	Paddy field	Total (User)	User's accuracy (%)
Water body	5	0	0	0	0	0	0	5	100
Sandy belt	0	3	0	0	0	0	0	3	100
Mixed vegetation	0	0	9	0	0	0	2	11	81
Bare land	0	0	0	2	0	0	0	2	100
Shrub land	0	0	0	0	2	0	0	2	100
Built-up area	0	0	0	1	0	3	0	4	75
Paddy field	0	0	0	0	0	0	3	3	100
Total (Producer)	5	3	9	3	2	3	5	30	
Producer's accuracy (%)	100	100	100	66.7	100	100	60		
Overall accuracy = 90%									
Kappa coefficient = 0.88									

is listed in Table 3. According to the prepared map, the predominant land use in the region is mixed vegetation (45.9%). The paddy fields covered around 12% of the area. For the confirmation of the results, ground truth was also carried out in a few chosen locations. The prepared land use classification map is presented in Fig. 3. The overall accuracy and Kappa coefficient obtained in classification were 90% and 0.88, respectively. The confusion (error) matrix of the classification is given in Table 4.

The coastal regions have a higher concentration of built-up areas, indicating a higher population density. Construction, small-scale industry, and agriculture are indications of development activities in coastal areas that increase pumping rates, degrade the environment, and worsen saltwater intrusion. The Tavanur-Nariparambu region has more paddy fields than other parts of the study area and the depth to the water table is less in these areas.

Water quality

The results of the water quality analysis wereexamined to understand the changes in the salinity and electrical conductivity in the area over the period 2015 to 2021.

Salinity

The average annual variation of salinity during the pre-monsoon period and post-monsoon seasons for the selected 8 wells (wells 1, 3, 6, 7, 8, 11, 13 and 14 which are representative of the different locations) are depicted in Figs. 4 and 5, respectively. The graphs show that the salinity concentration has increased over time (2015-2021). Additionally, the fluctuation is greater in wells that are close to the sea (well 8, well 13) and it had risen to the tune of 1300 to 1500 mg L^{-1} by 2021. When compared to the post-monsoon season, the fluctuation or rise in salinity is higher in the pre-monsoon season. Other researchers have also reported that the pre-monsoon salinity values are greater than the post-monsoon values (Senthilkumar *et al.,* 2019). From Fig. 4, it is also seen that the wells near the shore (wells 13, 8 and 7) which are located within a distance of 1.5 m have high salinity values (800-1400 mg L^{-1}). As the distance from the shore increases, in the case of wells 1, 3 and 11 at a distance of around 5-6 m from the shore, the maximum salinity observed during the pre-monsoon period is only around 400 mg L^{-1}. This indicated that the salinity level decreases as the distance from the shore increases. In the studies of Sreedharan and Pawels (2018), in Kalvathi, which is quite close to the Arabian coast near Cochin, saltwater intrusion had a serious impact. The concentration of dissolved solids increased by around 5 to 6 times in the pre-monsoon period when compared to the wet season. They also reported that the higher salinity concentrations were observed only near the coast, and other regions were not that much affected by salinity.

From the correlation analysis done between the average salinity and mean distance from the sea, it was found that there exists a strong negative correlation between salinity and distance from the sea to the observation wells with a correlation coefficient (r) of -0.97, indicating that as the distance from the shore increases, the salinity level decreases. The value of 0.97 for the correlation coefficient shows that the correlation between the two variables is significant.

Fig. 6 represents the average monthly salinity variation during the study period. It is seen that the salt content is very high for wells near the sea (wells 8 and 13) until the month of May indicating saltwater intrusion in the coastal areas during the summer. The salt concentration subsequently declines as the amount of rainwater that recharges the wells increases during the rainy season. During summer (April and May), the salt content in the wells in the Purathoor and Ponnani regions (wells 13, 8 and 7), is greater than 1000 mg L^{-1}, and reaches even up to 1800 mg L^{-1}. The wells that are far from the sea show low salinity concentration and the rate of increase over the period of study is also less. This trend was earlier reported by Nordio and Fagherazzi (2022). They also reported that as the water table elevation increases, the salinity level also increases.

In normal cases, as per the BIS standards, this water cannot be used for drinking purposes since it exceeds the upper limit of BIS drinking water specification (TDS - 500 mg L^{-1}). It can be used for drinking only when there is no substitute available, that too only up to the level of 2000 mg L^{-1}. The increasing trend of salinity in Fig. 4 shows that there is a chance that the salinity will cross this level in the near future in these areas. Similar

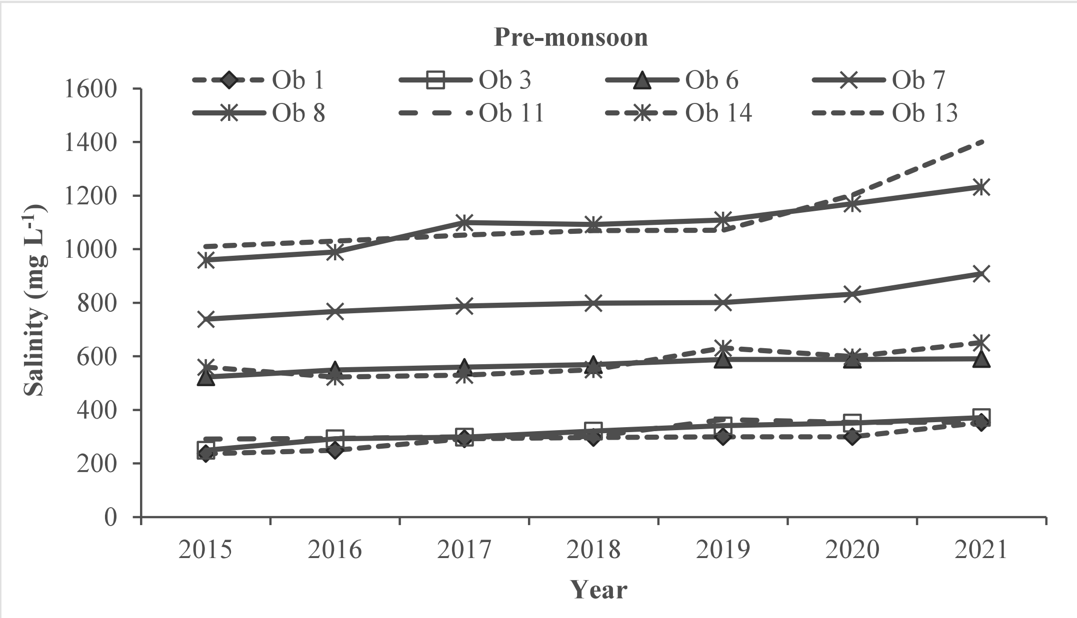

Fig. 4. *Average annual variation of salinity with time (Pre-monsoon)*

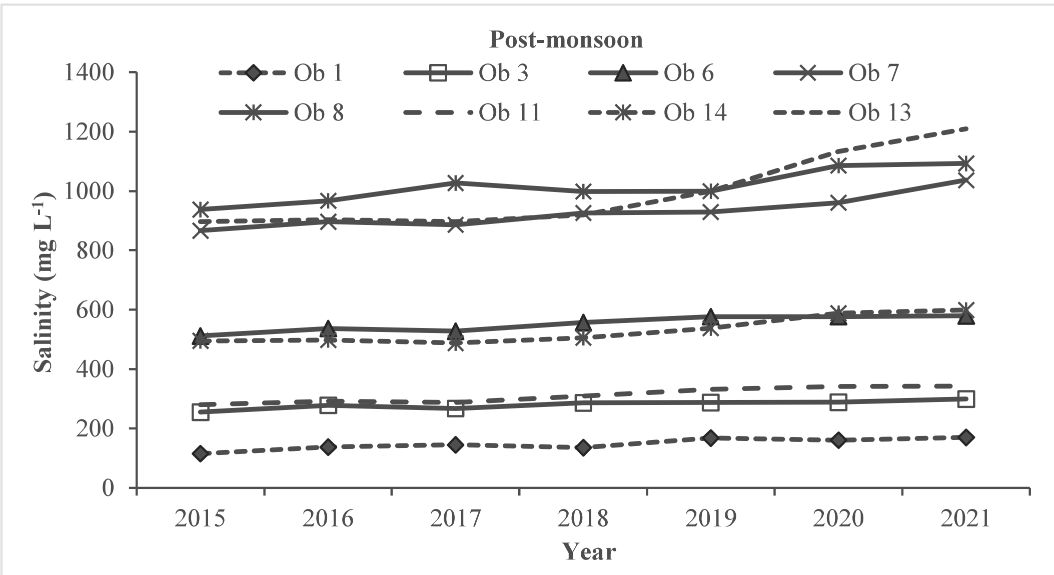

Fig. 5. *Average annual variation of salinity with time (Post-monsoon)*

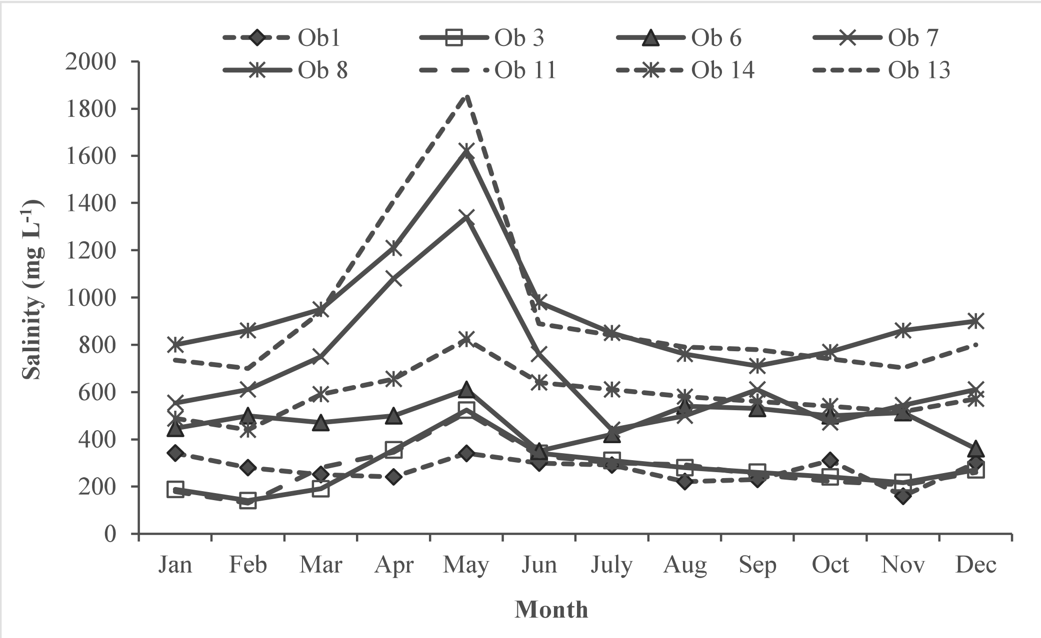

Fig. 6. *Average monthly variation of salinity (2015-2021)*

results of high salinity in the thickly populated coastal regions of Kerala have been reported by Priju *et al.* (2014) and Sukumaran and Raj (2020). As per Table 2, the groundwater in this region during the pre-monsoon period is having slight to moderate restrictions even for use as irrigation water.

Electrical conductivity

The graphs showing the variation of electrical conductivity (EC) with time during the pre-monsoon and post-monsoon are plotted in Figs. 7 and 8, respectively. The trend in EC variation is similar to that of salinity, with more EC variation (both pre-monsoon and post-monsoon) in wells closer to the sea (wells 8, 13 and 7) and less variance in other wells. While wells 8 and 7 in the Purathur region and well 13 near Ponnani have maximum EC values, well 1 in the Tavanur region has the least EC.

The pre-monsoon EC values have gone to even above 1300 µS cm^{-1}. In pre-monsoon and post-monsoon periods, the EC values in wells 8,13, 6 and 7, was higher than the acceptable standards. Fig. 9 depicts the average monthly variation of EC during the study period.

The spatial variation of EC during the pre-monsoon period and post-monsoon period are plotted in Figs. 10 and 11, respectively. The figures are clear indications of the high EC values in the wells near the coastal region. The pockets of high EC near the coast are the highly populated urban areas near Ponnani town. This can be confirmed from the land use map (Fig. 3). As we move away from the coast, the EC value was found to be decreasing. Senthilkumar *et al.* (2019) have reported that the influence of seawater intrusion was clearly revealed by the TDS, salinity and chloride concentrations.

Salt is present in irrigation water in some form or another, but the amount and kind vary widely. Salts in irrigation water have an impact on the salt and sodic state of the soil. The key factor that can be used to explain the concentration of soluble salts in irrigation water is EC. Except in coastal regions, the majority of the wells chosen for the study have EC status below 700 µS cm^{-1}, (below which no restriction in use is recommended as per FAO standards given in Table 3) which is within the tolerance limit for irrigation water requirements set by the FAO. Therefore, utilizing this water for irrigation need not be restricted. However, EC ranged from 700 to 1400 µS cm^{-1} in wells in the coastal region (wells 13, 8, 6 and 7) during the pre-monsoon and post-monsoon

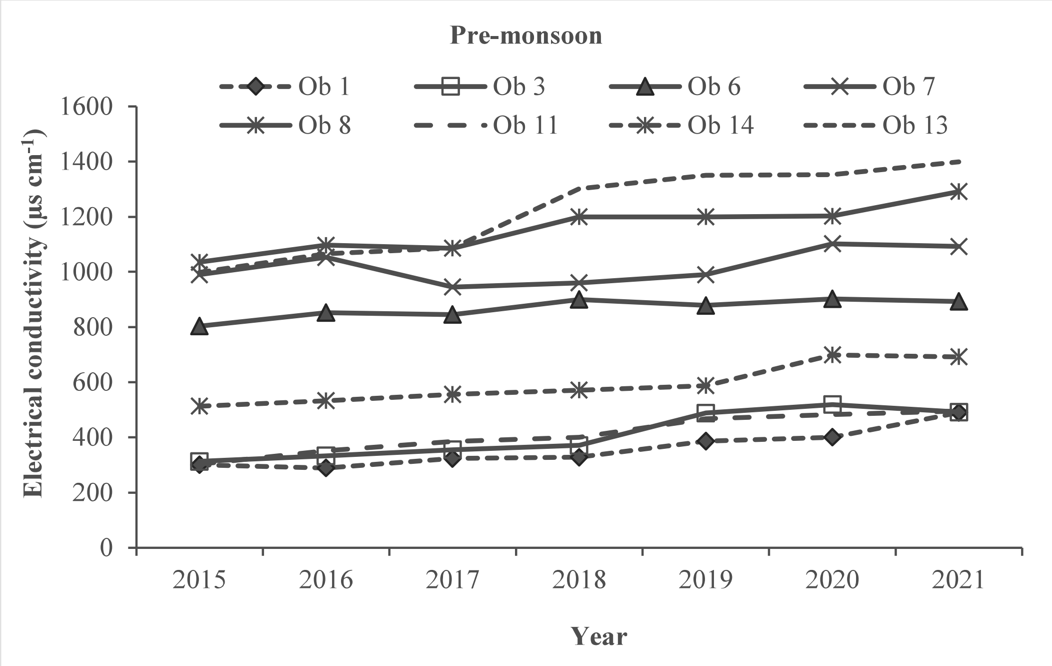

Fig.7. Average annual variation of EC with time (Pre-monsoon)

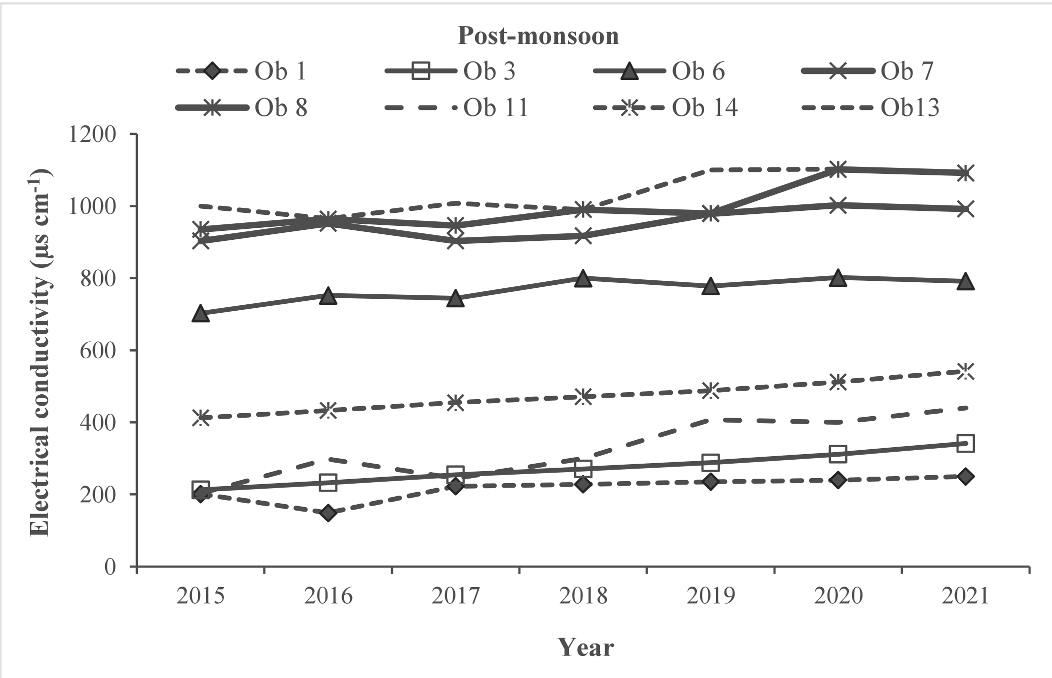

Fig.8. Average annual variation of EC with time (Post-monsoon)

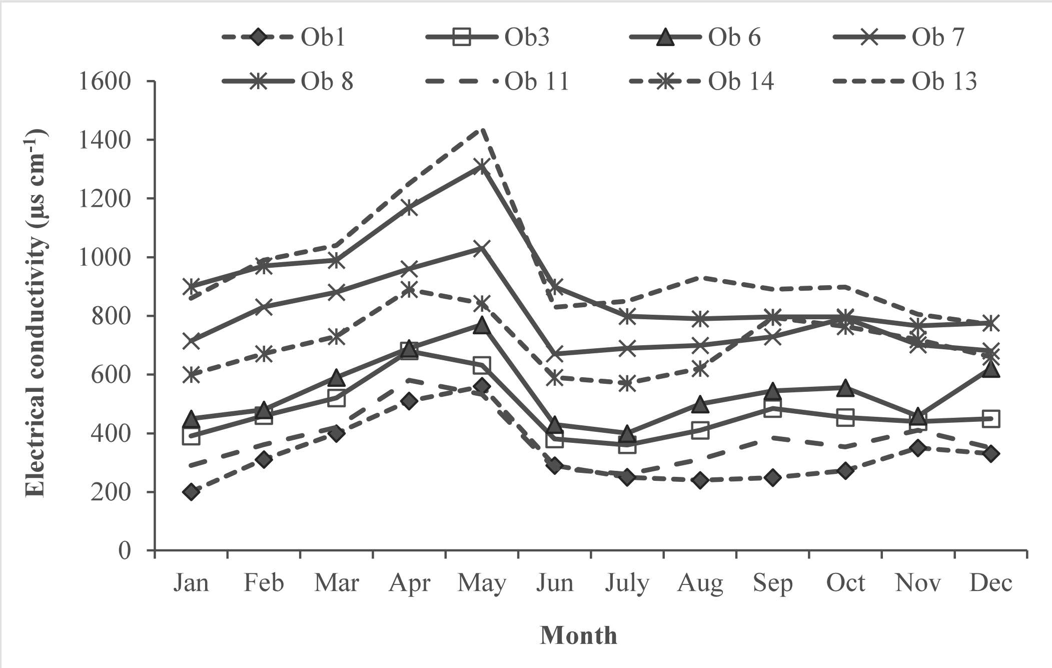

Fig. 9. *Average monthly variation of EC (2015-2021)*

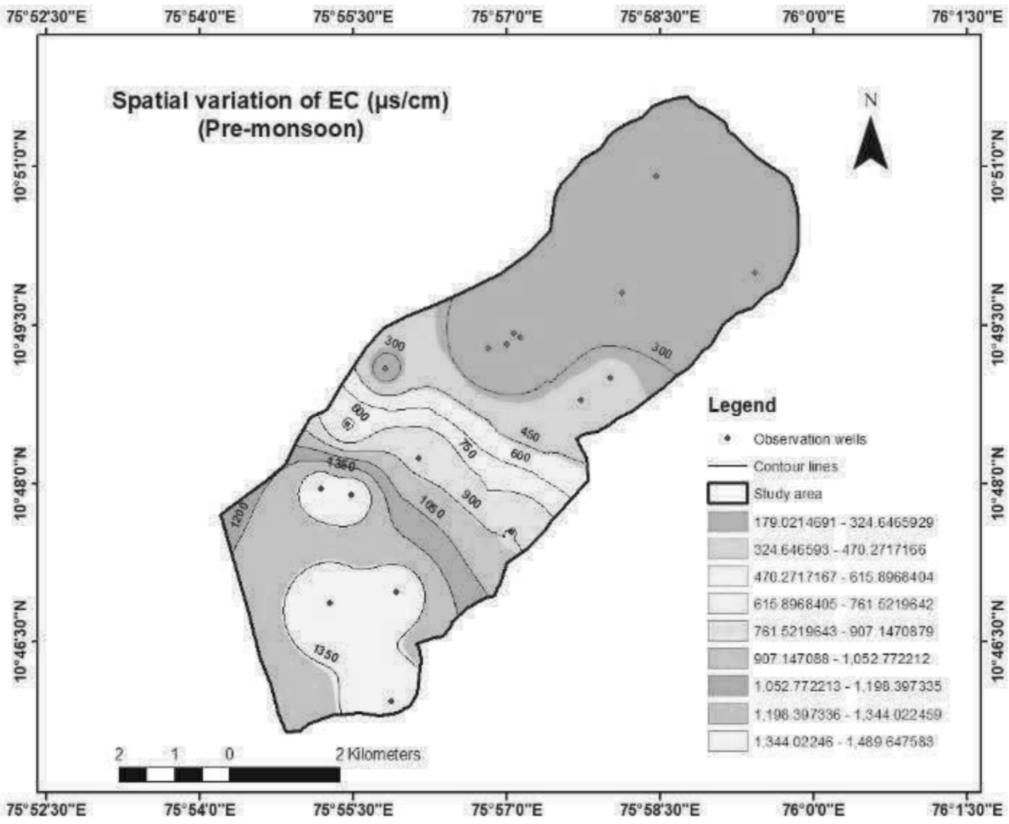

Fig. 10. *Spatial variation of EC (Pre-monsoon)*

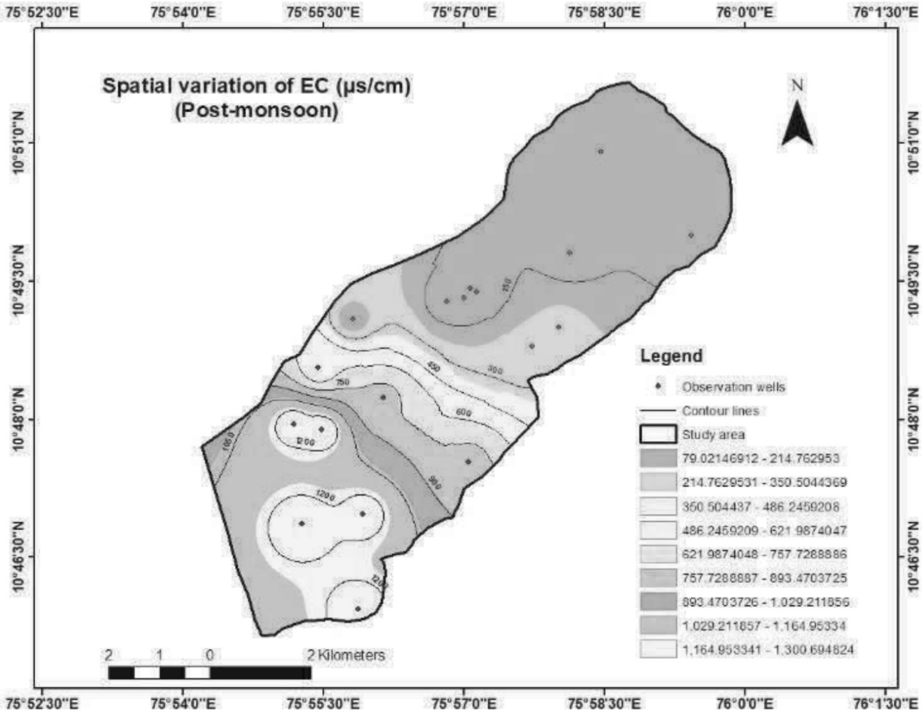

Fig. 11. *Spatial variation of EC (Post-monsoon)*

periods. Hence, it falls into the category where light to moderate restriction is needed in its use for irrigation. A higher EC value is an indication of a high concentration of dissolved salts in water, which have an adverse effect when it exceeds the permissible limits (Adeyemi *et al.,* 2019) and occasionally, we must adopt some management practices to use this water for irrigation, particularly when it comes to crops that are sensitive to salts.

Water table fluctuation

The average depth to the water table in the wells for the study period in the region is presented in Table 5. The average annual water level variation (depth to the water table) during the pre-monsoon period and post-monsoon period is depicted in Figs. 12 and 13, respectively. It is seen that the depth to the water table in the wells was relatively low during the rainy season and gradually rose throughout the dry season. The water levels in the observation wells varied in accordance with the regional rainfall patterns.

The study area comprising both banks of the Bharathapuzha river near the coast is under severe threat of saltwater intrusion. From the correlation analysis between the variables, salinity concentration and average depth to water table in the study area, it was found that there exists a negative correlation between them. The correlation coefficient was found to be -0.94, indicating higher salinity concentration in regions with lower depth to water table. A negative water table elevation was observed in the coastal region (-3 m). During the period of observation from 2015 to 2021 (6 years), there is a depletion of water level by 1 to 2 m in most of the wells. This trend in depletion of water level in the wells in both pre-monsoon and post-monsoon periods indicated that if the trend continues, the area may face more problems due to saltwater intrusion into the nearby wells.

The Chamravattom-Nariparambu region has a groundwater level change of around 4.4 m which is higher in comparison to the other regions. It might be a result of increased groundwater resource consumption by people. In other areas, groundwater use is less because of the low quality of the groundwater in certain areas, which could account for less variation in water levels. The Chamravattom region is located very

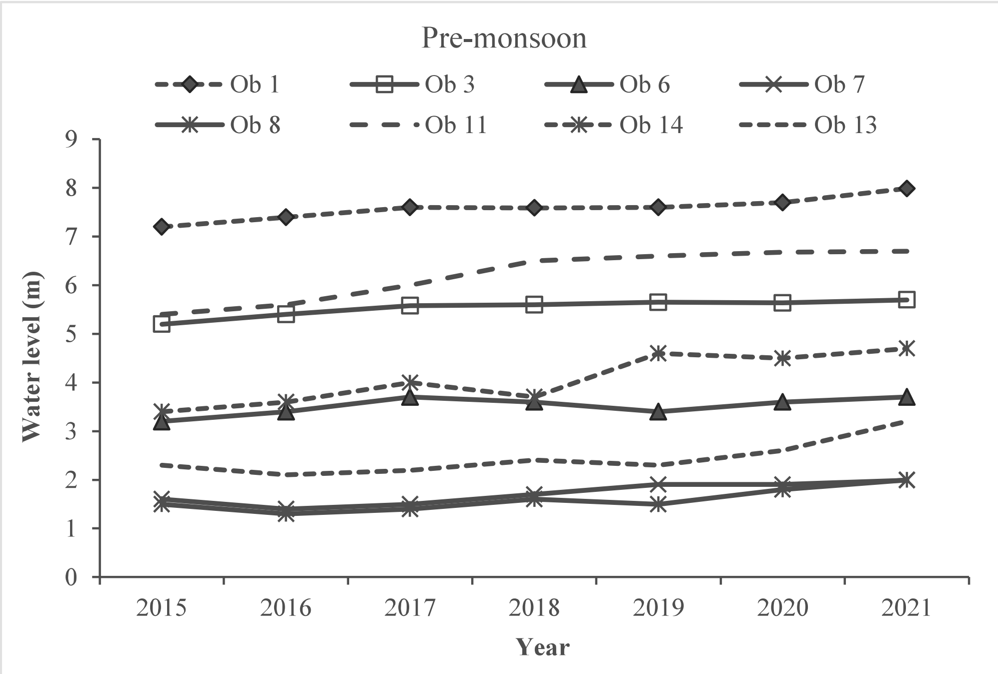

Fig. 12. *Average annual variation of depth to water table (Pre-monsoon)*

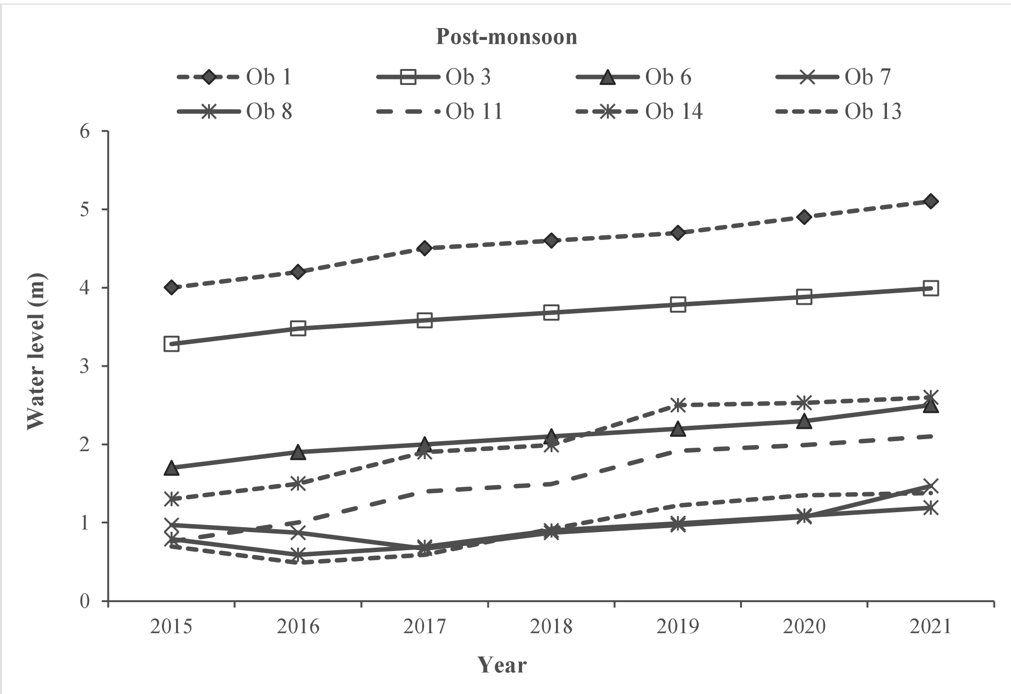

Fig. 13. *Average annual variation of depth to water table (Post-monsoon)*

Table 5. *Water table fluctuations in the study area (2015-21)*

Sl. No.	Region	Average depth to water table (m) from ground surface		Ground water level fluctuation (m)
		Pre-monsoon	Post-monsoon	
1	Tavanur	7.60	4.20	3.40
2	Nariparambu	5.80	3.10	2.70
3	Chamravattom	6.20	1.80	4.40
4	Eswaramangalam	4.10	2.00	2.10
5	Purathur	1.70	0.90	0.80
6	Ponnani	2.65	0.85	1.80

near the Bharathapuzha river and the depletion in the groundwater table in this region may also be due to increased sand mining in the river.

The occurrence of saltwater intrusion caused by excessive groundwater exploitation is observable in coastal areas due to a drop in groundwater levels (Siddha and Sahu, 2020). Physicochemical parameters of the subsurface, such as electrical conductivity (EC), salinity, water quality, total dissolved salts (TDS), seawater mixing, etc., were investigated as part of seawater intrusion (Bear *et al.,* 1999). Kumar *et al.* (2014), identified the seawater intrusion by utilizing EC, Na and Cl concentrations in the coastal areas of south India. To properly determine the largest intrusion plumes in the coastal zones, factors like EC and TDS are incorporated (Sylus and Ramesh, 2015; Zghibi *et al.,* 2013). Tomaszkiewicz *et al.* (2014) also calculated the groundwater quality index for seawater intrusion from the geochemical parameters.

The higher salinity of water in the coastal areas makes it unfit for drinking as well as for irrigation purposes. Hence, it is recommended to restrict the use of groundwater in this area and to adopt rainwater conservation measures in the area. Recharging rainwater in the upstream areas can also help to increase the river flow during the pre-monsoon periods which will in turn help to improve the quality of groundwater in the region.

The results show that there is a significant saltwater intrusion in the area. In almost all observation wells selected for the study, the salt concentration was found to be maximum during the month of May. The salinity level was also observed to be maximum during April-May which reached the level of 1800 mg L^{-1} in the Purathoor and Ponnani regions, making it unfit for drinking purposes as per the BIS standards. The salinity concentration in the area shows an increasing trend over time (2015 - 2021). Certain mitigation measures need to be adopted to bring down the salinity in these areas and to make the groundwater suitable for potable purposes.

In the case of electrical conductivity also, a similar pattern was seen. Analyzing the monthly variations in salinity and electrical conductivity from 2015 to 2021, shows an increasing trend. Electrical conductivity was also found to be higher in the wells in the Ponnani and Purathur regions, ranging from 1400 µS cm^{-1} in the pre-monsoon period to above 600 µS cm^{-1} in the post-monsoon period, which is more than the recommended limits for drinking water. The pre-monsoon salt level in the coastal region (wells 8, 13 and 7) is higher than the limits recommended for irrigation purposes. Therefore, there need to be slight to moderate restrictions placed on using the water for irrigation in these locations. The depths of the water table in the monitoring wells increased between 2015 and 2021, indicating that the water table is found to be depleting. Hence it is recommended that the pumping of groundwater in the coastal regions (up to 5 km from the coast) need to be restricted to prevent saltwater intrusion in these areas. Adopting water conservation measures in the catchment area of the river will also help to maintain summer flow in the river, which in turn will prevent the lowering of the water table in the area.

CONFLICTS OF INTEREST

There is no competing interest.

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REFERENCES

Abdul, M.B., Seal, L. and Kazi Sunzida, K.L. (2015). Salinity intrusion in interior coast of Bangladesh: Challenges to agriculture in south-central coastal zone. *American Journal of Climate Change* **4**: 248-26.

Adeyemi, A.G., Muhammed, D. and Oludare, A.T. (2019). Assessment of the suitability of water quality for irrigation in Ogbomosho, Oyo State. *GSC Biological and Pharmaceutical Sciences* **09** (02): 021-031.

Barlow, P.M. and Reichard, E.G. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology Journal* **18**: 247–260. http://dx.doi.org/10.1007/s 10040-009-0514-3.

Bear, J., Cheng, A.H.D., Sorek, S.D., Ouazar, I. and Herrera. (1999). *Seawater Intrusion in Coastal Aquifers: Concepts, Methods and Practices*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

CGWB [Central Ground Water Board]. (2010). *Ground Water Quality in Shallow Aquifers of India,* Central Ground Water Board, Ministry of Water Resources, Govt. of India, Faridabad, Haryana. pp 4-6.

CGWB [Central Ground Water Board]. (2013). *Ground Water Information Booklet of Malappuram District, Kerala.* Technical Reports: Series D, Central Ground Water Board, Kerala Region, Ministry of Water Resources, Govt. of India, Thiruvananthapuram, Kerala. 29 p.

Chaudhary, V. and Kumar, S.S. (2018). Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. *Applied Water Science* **8**: 218. https://doi.org/10.1007/s13201-018-0865-9.

Farjoudi, S.Z. and Alizadeh, Z. (2021). A comparative study of total dissolved solids in water estimation models using Gaussian process regression with different kernel functions. *Environmental Earth Sciences* **80**(557). https://doi.org/10.1007/s12665-021-09798-x.

George, J. and Athira P. (2020). Long-term changes in climatic variables over the Bharathapuzha river basin, Kerala, India. *Theoretical and Applied Climatology* **142**: 269-286. https://doi.org/10.1007/s00704-020-03255-8

Gopinath, S., Srinivasamoorthy, K., Saravanan, K., Suma, C.S., Prakash, R. and Senthilnathan, D. (2016). Modelling saline water intrusion in Nagapattinam coastal aquifers, Tamil Nadu, India. *Modelling Earth Systems and Environment* **2**: 2. http://dx.doi.org/10.1007/s40808-015-0058-6.

Khatri, N. and Tyagi. S. (2014). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science* **8**(1): 23-39. http://dx.doi.org/10.1080/21553769.2014.933716.

Kumar, P.J.S., Elango, L. and James, E.J. (2014). Assessment of hydrochemistry and groundwater quality in the coastal area of South Chennai, India. *Arabian Journal of Geosciences* **7**: 2641-2653. http://dx.doi.org/10.1007/s12517-013-0940-3.

Kumar, P.J.S., Kokkat, A., Kurian, P.K. and James, E.J (2020). Nutrient chemistry and seasonal variation in the groundwater quality of a riverine island on the west coast of Kerala, India. *Sustainable Water Resources Management* **6**: 3. https://doi.org/10.1007/s40899-020-00358-y.

Kumar, S.P.J. (2016). Deciphering the groundwater-saline water interaction in a complex coastal aquifer in South India using statistical and hydro chemical mixing models. *Modelling Earth Systems Environment* **2**: 1-11. https://doi.org/10.1007/s40808-016-0251-2.

Machado, R.M.A. and Serralheiro, R.P. (2017). Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae* **3**(2): 30. A. https://doi.org/10.3390/horticulturae3020030.

Nazimuddin, M. and Basak, P. (1998). Ground water resources in Kerala: A case study in coastal shallow aquifer zone. In: *Water Scenario of*

Kerala. E.J. James, *et al.* (eds.) State Committee on Science, Technology and Environment, Government of Kerala, Kerala, India.

Nordio, G. and Fagherazzi, S. (2022). Salinity increases with water table elevation at the boundary between salt marsh and forest. *Journal of Hydrology* **608**(5): 127576. https://doi.org/10.1016/j.jhydrol.2022.127576.

Prasanth, S.S.V., Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N. and Gangadhar, K. (2012). Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. *Applied Water Science* **2**: 165-175. https://doi.org/10.1007/s13201-012-0042-5.

Priju, C.P., Ramisha, N., Neerajamol, T.P., Madhavan, K. and Prasad, N.N.B. (2014). Geomorphological factors of coastal groundwater salinity in central Kerala: Integrated hydrochemical-geospatial approach, Proceedings International Symposium on *Integrated water resources management* (IWRM–2014), February 19-21, 2014, CWRDM, Kozhikode, Kerala, India. pp 1253-1262.

Ramesh, D.A., Bindu, M.V., Karthi, N., Amali, and Priya, R. (2021). Climate change risk management in coastal fishing villages of Malappuram District, Kerala, India. *Social Vision* **8**(1):1-20

Senthilkumar, S., Vinodh, K. and Johnson Babu, G. (2019). Integrated seawater intrusion study of coastal region of Thiruvallur district, Tamil Nadu, South India. *Applied Water Science* **9**: 124. https://doi.org/10.1007/s13201-019-1005-x.

Sharma, R., Kumar, R., Sharma, D.K., Sarkar, M., Mishra, B.K., Puri, V., Priyadarshini, I., Thong, P.H., Ngo, P.T. and Nhu, V. (2021). Water pollution examination through quality analysis of different rivers: A case study in India. *Environment, Development and Sustainability* **24**: 7471-7492. https://doi.org/10.1007/s10668-021-01777-3.

Sharma, S., Imtiyaz, T., Zahoor, P., Mdgal, L.K. and Siddique, A. (2012). Physico Chemical properties of water of river Narmada at Madhya Pradesh, India. *Researcher* **4**(6): 5-9.

Siddha, S. and Sahu, P. (2020). Status of seawater intrusion in coastal aquifer of Gujarat, India: A review. *SN Applied Sciences* **2**: 1726. https://doi.org/10.1007/s42452-020-03510-7.

Sreedharan, S. and Pawels, R. (2018). Seasonal deviation of saltwater intrusion in the shallow aquifers of Kochi municipal corporation, Kerala, India. *International Journal of Civil Engineering and Technology* **9**: 596-605.

Suhag, R. (2016). *Overview of Ground Water in India*. PRS Legislative Research. pp 3-10. Available at: https://www.prsindia.org/administrator/uploads / general/1455682937.

Sukumaran, D. and Raj, J.P. (2020). Saline water intrusion in urban coastal area: A case study of Kuttiyadi River, Kerala, India. *American Journal of Water Resources* **8**(3): 128-133. https://doi.org/10.12691/ajwr-8-3-3.

Sylus, K. J. and Ramesh, H. (2015). The study of sea water intrusion in coastal aquifer by electrical conductivity and total dissolved solid method in Gurpur and Netravathi River basin. *Aquatic Procedia* **4**: 57-64. https://doi.org/10.1016/j.aqpro.2015.02.009.

Tomaszkiewicz, M., Abou, N.M. and El-Fadel, M. (2014). Development of a groundwater quality index for seawater intrusion in coastal aquifers. *Environmental Modelling and Software* **57**: 13-26. https://doi.org/10.1016/j.envsoft.2014.03.010.

Wada, Y., van Beek, L.P.H., van Kempen, C.M., Reckman, W.T.M.J., Slavek V. and Marc F.P. Bierkens. (2010). Global depletion of groundwater resources. *Geophysical Research Letters* **37**(20): 1-5.

Zghibi, A., Tarhouni, J. and Zouhri, L. (2013). Assessment of seawater intrusion and nitrate contamination on the groundwater quality in the Korba coastal plain of Cap-Bon (North-east of Tunisia). *Journal of African Earth Sciences* **87**: 1-12. https://doi.org/10.1016/j.jafrearsci.2013.07.009.