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Assessment of Saltwater Intrusion and Role of Sea Level Rise (SLR) Along the Coast of Thiruvananthapuram District in Kerala, India

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ABSTRACT

Indian coastal aquifers constitute the second richest groundwater resources after Indo-Gangetic alluvial plain. Millions of people in India use groundwater for domestic, industrial and agricultural purposes. Increased sea level, over-exploitation of groundwater and modification in hydrological cycle have resulted in reducing groundwater levels, which lead to saltwater intrusion. Kerala is one among the most thickly populated states in India, especially the coastal area of the state. The present study investigates the groundwater salinization due to saltwater intrusion in the coastal area of Thiruvananthapuram district and inundation analysis due to sea level rise through geo-spatial technologies. As remote sensing aided with geospatial tools can quantify the extent of inundation level along coastal areas, those results are correlated with salinity analysis to identify the impact of sea level rise on groundwater salinization.

INTRODUCTION

Saltwater intrusion is the encroachment of saline water into fresh groundwater regions in the aquifers. Mostly, it happens due to the presence of sea and human activities. Under normal conditions, aquifers are recharged by rainfall events and in general, groundwater flows from areas with higher groundwater levels (hydraulic head) to areas with lower groundwater levels. This natural movement of freshwater towards the sea prevents salt water from entering freshwater coastal aquifers (Barlow 2003). In the coastal aquifer, there is a transition zone between freshwater and seawater called freshwater-saltwater interface. The position of the saline interface is dynamic and depends on the geological formation, hydraulic gradient, topography, and the quantity of freshwater moving through the aquifer system (Schwartz & Zhang 2003). The geology and topography of an area are the major controls on how groundwater will flow, and where the recharge and discharge zones of the system are located. Geological parameters such as stratigraphic relationships, structure and aquifer heterogeneity can affect areas of recharge and discharge. They also control the hydraulic characteristics of a groundwater system (Freeze & Cherry 1979). According to Ghyben-Herzberg relation between freshwater and saline water, depressing water table in coastal aquifers by half a meter can lead to rise of freshwater-saltwater interface by 20 m. As the sea level rises, this interface will migrate to the inland area which leads to increase in salinity not only in the wells, but also in the rivers near to the coastline. Therefore, modification of the land hydrological cycle due to climate variability and direct anthropogenic forcing leads to changes in precipitation/evaporation regimes and river runoff, hence ultimately to sea level changes. Thus, global, regional and local climate changes affect the sea levels (Bindoff et al. 2007).

Groundwater pumping/development can decrease the amount of freshwater flowing towards the coastal discharge areas, allowing salt water to be drawn into the freshwater zones of coastal aquifers. Therefore, the amount of freshwater stored in the aquifers is decreased (Barlow 2003). Saltwater intrusion into freshwater aquifers is also influenced by factors such as tidal fluctuations, long-term climate, and fractures in coastal rock formations and seasonal changes in evaporation and recharge rates. Recharge rates can also be lowered in areas with increased urbanization and thus impervious surfaces. Intrusion has also occurred in areas because of water levels being lowered by the construction of drainage canals (Barlow 2003). Tectonic processes can also play an important role in the sea level fluctuations. The largest sea level changes occurred mainly on tectonic process about ~100 million years ago (Haq & Schutter 2008). The fourth and recently released fifth IPCC reports provided a global mean sea-level-rise trend to be close to 1.8 mm/yr over the 1961-2003 period and 1.7 mm/yr over the 1901-2010 periods respectively (Rahmstorf 2010). Almost two-third of the world's population is said to be living within 400 km of the ocean shoreline and just over half live within

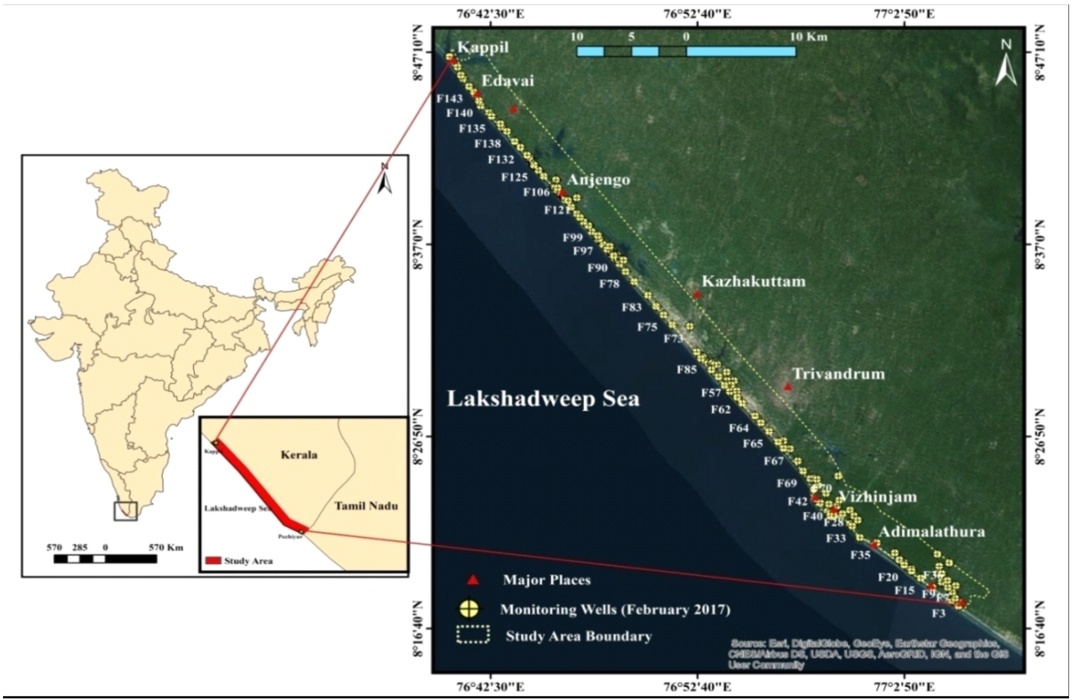

Fig. 1: Location map of the study area from Poovar to Pozhiyur.

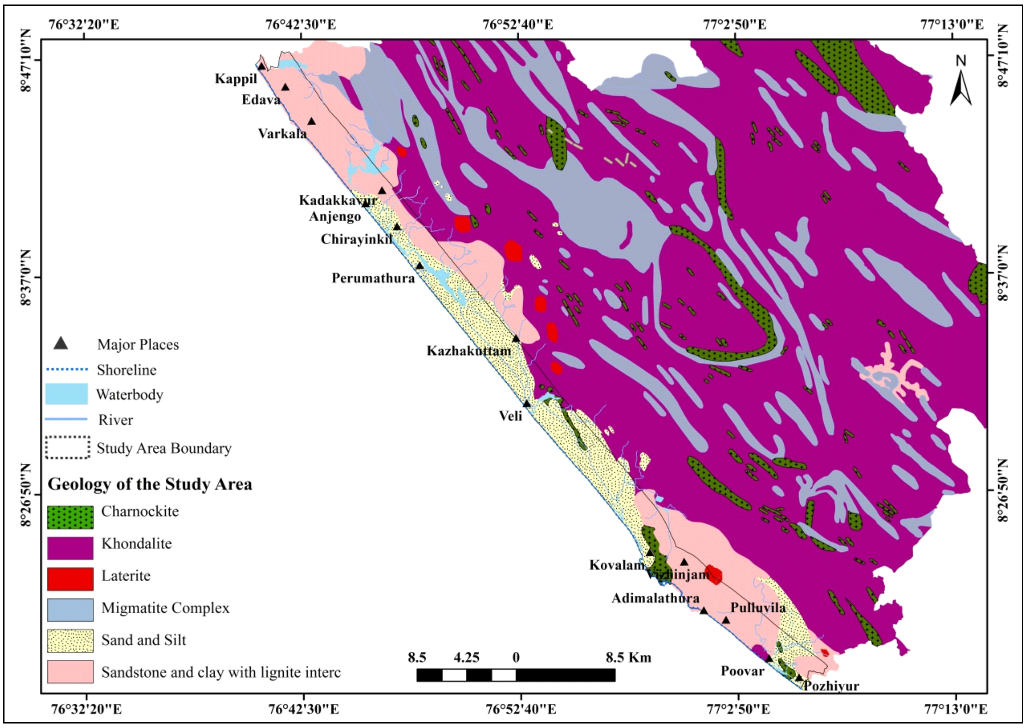

Fig. 2: Geological map of the study area (Courtesy: Geological Survey of India).

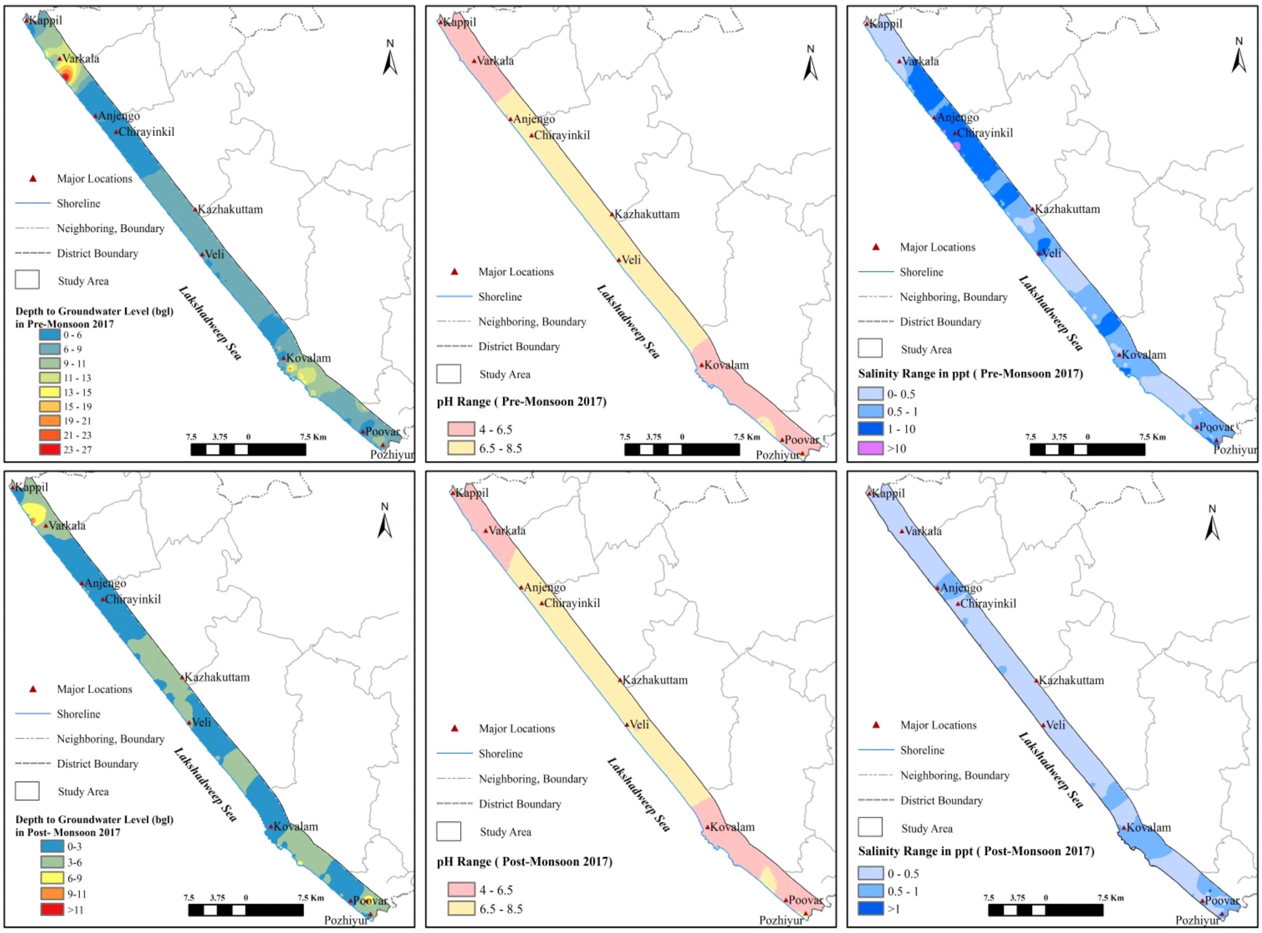

Fig. 3: Water table position and hydrogeochemical heterogeneity of the study area.

200 km, an area only taking up 10% of the earth's surface (Hinrichsen 2007). Under the present climate, SLR ranges from 0.4 to 2 mm/yr along the Gulf of Kachch and the coast of West Bengal is the highest (MoEF 2004). People in Kerala depend on coastal resources more than in any other States in the country. The sea level rise for Cochin is estimated as 2 cm in the last one centaury (Emery & Aubrey 1989). Beside sea level rise, excessive pumping of groundwater and alteration in hydrological cycle can directly lead to saltwater intrusion in coastal aquifers. To preserve groundwater sources in our coastal communities, it will be necessary to manage the threat of saltwater intrusion. Management strategies can generally be placed into three categories: monitoring and assessment, regulation, and engineering (Barlow 2003, Barlow & Aubrey 2010), with the ultimate goal of preserving groundwater resources for current and future use (Bear 2004). The present study was carried out to evaluate the groundwater salinization and role of sea level fluctuation on the coastal aquifers.

STUDY AREA

The study area (north latitudes 8°15' and 8°50' and east longitudes 76°40' and 77°09') falls within the coastal segment of Thiruvananthapuram district in Kerala from Pozhiyur in south to Kappil in the north. Poovar, Vizhinjam, Trivandrum, Chirayinkil, Varkala and Edava are some of the important towns in this coastal tract. The study area covers around 235 sq.km with 76 km coastal tract made up of beaches, sand dunes, riverine deposits, ridges and backwaters, fringing into the Arabian Sea (Fig. 1). The area is blessed with humid tropical climate with an average annual rainfall of about 1800 mm. Major rivers crossing the coastal belt and draining in the Arabian Sea are Vamanapuram, Mammom, Karamana and Neyyar. Geologically, the area consists of

Fig. 4: (A) Water quality survey of open dug well using a portable electronic water quality analyzer, (B) View of a small diameter shallow depth open dug well near to shoreline which consist of high saline water, (C) Water quality monitoring of Neyyar River basin, (D) A distant view of shoreline in Vizhinjam.

Precambrian crystalline rocks, Tertiary sedimentary formations and recent coastal alluvium and sands (Fig. 2).

Aquifers in the area can be grouped into four different geological formations such as alluvial, laterite, tertiary sedimentary and weathered crystalline aquifers. Majority of the wells in the area are situated in coastal alluvium and are in semi confined to confined conditions. Then it is followed by tertiary sedimentary formations where Warkalli beds are only available. Laterite aquifers are more concentrated to the northern part of the area, such as wells seen at the Varkala, Nedunganda, and Edava and also found in the eastern part of Pulluvila near Adimalathura. Tertiary sedimentaries are the second most aquifers in the region. Crystalline aquifers which occur at Vizhinjam-Kovalam area and NW part of the Poovar.

MATERIALS AND METHODS

The present methodology can be grouped into two categories: groundwater salinity analysis and assessment of inundation level due to sea level rise.

Groundwater Salinity Analysis

A portable electronic water quality analyser (Aquaread) was used for the measurement of physical parameters of the groundwater (pH, temperature, electrical conductivity, TDS, and salinity) in the observation wells over two seasons for deciphering the hotspot areas due to saltwater intrusion along the coastal stretch of Thiruvananthapuram district. The depth to water table was measured in each well using a measuring tape. Parapet height was deducted to get the depth from ground level. The area has both bore wells and open dug wells. Wherever bore wells are predominant and few open dug wells exist, water level measurements were difficult to conduct. Depth to water level maps were prepared based on the seasonal water level data collected from the observation wells. Hydrogeochemical heterogeneity of the study area was delineated.

Coastal Inundation Study Due to Sea Level Rise

Trend analysis of sea level rise: Annual values of mean tide level (MTL) were obtained from permanent service for the mean sea level (PSMSL). PSMSL contains monthly and annual mean values of sea level from almost 2000 tide gauge stations around the world. As PSMSL data were not available for the area of concern, data from a neighbouring tide gauge station on the Cochin Willingdon Island were used. The data fitted by 5th order polynomial trend line for interpolate or extrapolate unknown data which are not recorded by the station.

Fig. 5: (A) Intensity of tidal erosion due to recent Okhi cyclone on the coastal area of Poonthura in Thiruvananthapuram district. (B) Rock seawall along the shoreline at Pananthura area, (C) Tertiary sedimentary succession near Adimalathura.

Coastal inundation analysis: Digital elevation model (DEM) of the area extracted from shuttle radar topographic mission (SRTM) data with a resolution of 30 m obtained from USGS website were used to prepare coastal elevation and inundation level of the area. 1m, 2m probable inundated area was analysed from SRTM data.

Landuse-landcover study: Land use-land cover data derived from IRS-P6 LISS IV data and merged product of IRS 1D LISS III data of 5.8 m resolution through conventional image classification techniques and field surveys were obtained from the national database for resource and environment (NREDB) for the present study.

RESULTS AND DISCUSSION

Under natural conditions, groundwater recharged by rainfall through infiltration and flows toward the sea. This will help to prevent the intrusion of seawater into coastal aquifers. As sea level rises, freshwater-salinewater interface will migrate towards landward side and groundwater in the wells will contaminate. The present study includes water table monitoring, demarcation of groundwater salinity, and assessment of inundation level due to sea level rise and its trend.

Water Table Monitoring

Depth of water level in the study area as a whole varies from 0.5 to 26.98 m bgl and 0.60 m to 15.40 m bgl during pre-monsoon (April-May 2017) and post-monsoon (December 2017) respectively. Northern tip of the area shows static water level. Majority of the wells in the area have less supply of freshwater in the summer season and good supply in the post monsoon season.

Groundwater Quality (Physical Parameters)

The statistical study on pre (April 2017) and post-monsoon (December 2017) seawater intrusion into the coastal aquifers has been done by groundwater level variation and determination of *in situ* parameters like temperature, pH, electrical conductivity, TDS and salinity in the observation wells of the study area. Temperature of groundwater ranges from 27.5 to 33 and 27 to 30.50 degree Celsius during pre-monsoon and post-monsoon, respectively. According to BIS, pH of the drinking water should be in the range between 6.5 and 8.5. This is indicating that low and high pH water is not suitable for drinking purposes. In general, most of the groundwater samples in the study area are coming under this limited range. In April, pH is ranging from 4.23 in

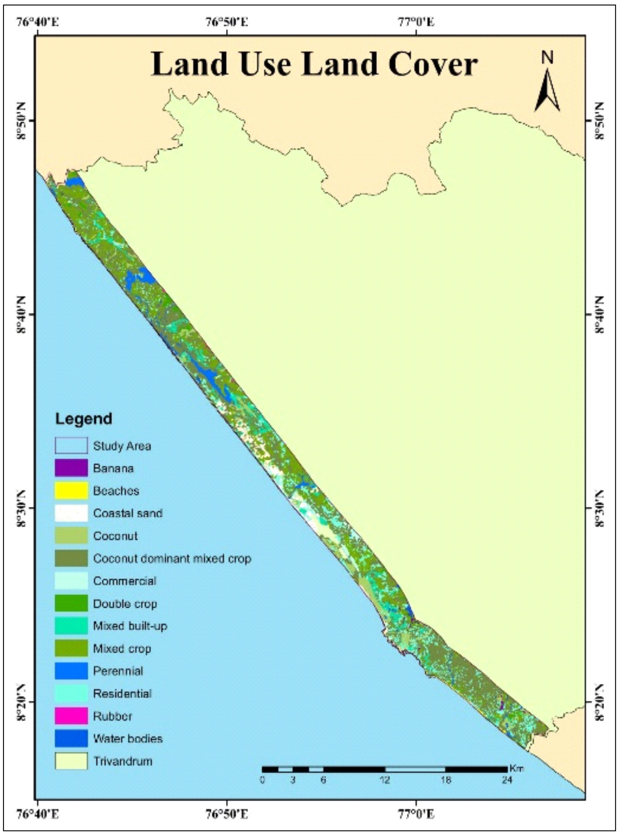

Fig. 6: Land use/land cover map along the coastal stretch of Thiruvananthapuram district.

Vizhinjam to 8.18 in Perumathura. More than 70 wells show alkalinity in nature during this period. In December, it varies from 4.29 in Varkala to 8.21 in Perumathura. The higher pH value can be imputed to a prolonged influence of saltwater incursion, showing alkaline nature. But water in the lateritic aquifer shows less pH may be due to the interaction of iron content in the aquifer with chlorine content in the circulating groundwater, especially in and around Varkala

The study mainly concentrates on salinity variation of groundwater in the coastal area, and it is correlated with TDS and electrical conductivity (Fig. 3). Pre-monsoon data were mainly used for the analysis of aquifer vulnerability and then it is compared with the post monsoon data for the demarcation of seasonal changes. The specific conductivities of groundwater samples were determined and it is seen that conductivity values in April range from 81 µS/cm at Manthara to 59,973 µS/cm in Pudukurichi and the second most value obtained from a well near Muthalapozhi harbour which is 57,318 µS/cm. Total dissolved solids (TDS) range from 52 mg/L to 38,982 mg/L. Salinity ranges from 0.03 ppt to 40.17 ppt.

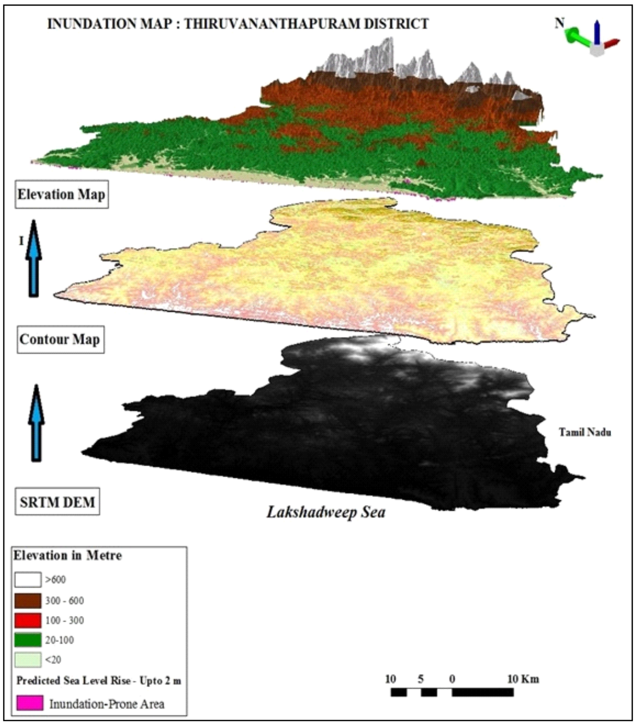

Fig. 7: Inundation analysis along the coastal stretch of Thiruvananthapuram district.

In general, most of the areas show salinity less than 2 ppt. However, few wells in Anjengo, Kadinamkulam, Pudukurichi and Poovar show salinity greater than 10 ppt. In the central part of the study area, including Kadinamkulam and Chirayinkil, salinity extends up to 230 m from shoreline, whereas in Puthenthoppu, it is 254 m. The presence of Kadinamkulam Kayal helps the other side of the region to remain as less saline. In the wells parallel to shoreline from Muthalapozhi to Arivalam beach, salinity level is high. In Anjengo, salinity extended up to 340 m. The places near to the left bank of the Anjuthengu Kayal show less salinity. Due to less influence of seawater ingress, northern part of the study area covering from Varkala to Kappil shows good quality water. Wells trapped in these areas are mainly in Warkalli formations. Groundwater from the Warkalli formation is mainly being used for drinking purposes in rural and urban areas of Varkala and neighboring places as well as south of Vizhinjam.

Besides groundwater in the wells, surface water samples near to the shoreline from selected localities were also analysed. The water in the Killi River in Poonthura, Muthalapozhi, Parvathy Puthanar near Chirayinkil, AVM canal in Pozhiyur show high values of EC, TDS and salinity due to the influence of seawater (Figs. 4 & 5). Therefore, the groundwater near to these localities show higher propor-

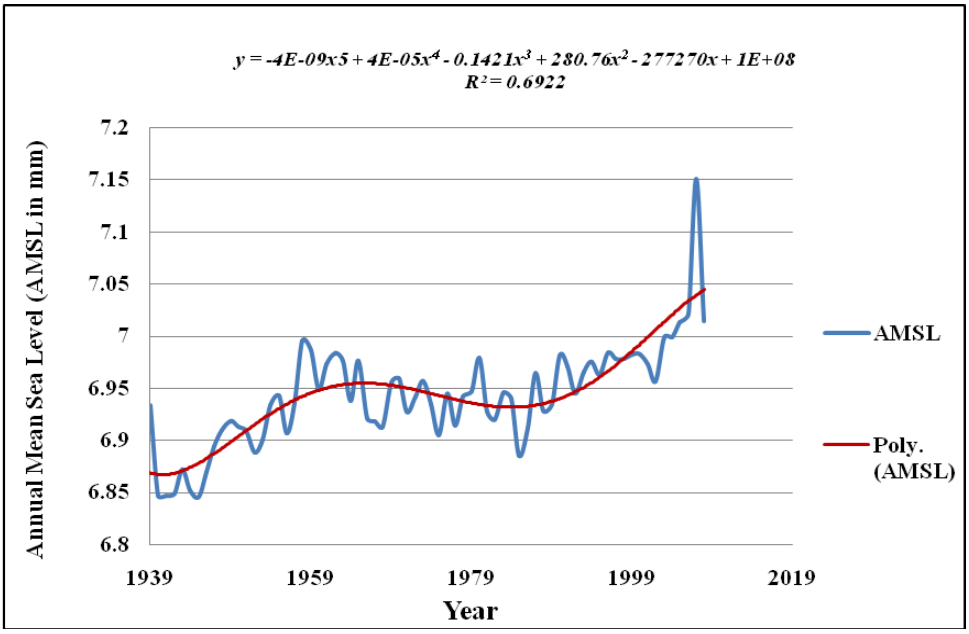

Fig. 8: Sea level rise trend and 5th order polynomial curve at the station Cochin Willington Island using PSMSL (2017) data.

tion of salt content. Poovar located in the south of the study area shows a contrasting level of salinity that extends up to near 3 km from the shoreline. This may be due to the discharge of water from Neyyar River to the aquifer. After a detailed survey during the post-monsoon period, salinity and associated parameters, both in groundwater and in surface water, decreased much due to recharge from rainfall.

Assessment of Inundation Level Due to Sea Level Rise and its Trend

In order to determine the vulnerable areas due to sea level rise, a 5th order polynomial curve was plotted in a graph using annual mean tide level from PSMSL data of the tide gauge station on the Cochin Willingdon Island since 1939 to 2013 (Fig. 8). The graph indicates that sea level has changed from 6.933 mm in 1939 to 7.014 mm in 2013. So it is clear that sea level is increased during this period.

Land use-land cover data were obtained from NREDB (Fig. 6) and these dataset were used to analyse the effect of sea level rise on various land classes of the study area (Table 1). 10 m contours were extracted from the Digital Elevation Model (DEM) of the area using Arc GIS 10.3 version. Extracted contours were used to create TIN with the help of spatial analyst tool. TIN is a triangular irregular network which represent the surface morphology. A futuristic scenario up to 2m sea level rise were chosen for inundation analysis using SRTM DEM and its effect on various land use-land cover was also analysed. The probable area which could be inundated due to sea level rise up to 2m was analysed using a tool box under the spatial analyst tool bar called map algebra which consists of raster calculator to evaluate all the cells in the raster image. The results clearly indicate that there is not much effect along the coastal stretch of Thiruvananthapuram district up to a projected sea level scenario of 2 m (Fig. 7).

CONCLUSIONS

The present study show coastal groundwater contamination due to saltwater intrusion and it is correlated with sea level rising trend along the coast of Thiruvananthapuram District in Kerala. Geologically, the area consists of recent coastal alluvium and sands and it is underlined by tertiary sedimentary formations and Precambrian crystalline rocks. Majority of the wells in the area are situated in coastal alluvium and are in semiconfined to confined conditions. As there is no tide gauge station available in the study area, PSMSL data from the tide gauge station on the Cochin Willingdon Island were used for the delineation of sea level rise. The PSMSL data have confirmed that from the period of 1939 to 2013, sea level is raised along the coast of Cochin, which is just about 160 km away from the study area. The impact of sea level rise along the coast of Thiruvananthapuram district was demarcated through inundation analysis, which did not show any significant result on the surface. But this analysis does not specify the impact of sea level rise on the subsurface in the area. However, groundwater salinity data collected from the coastal wells indicate that many of the

Table1: Inundation analysis over various land classes of the area.

Land use/ Land cover	Area inundated for 1m SLR (Sq. km)	Area inundated for 2m SLR (Sq. km)
Agriculture farm	0.003	0.004
Airport (Trivandrum)	0.023	0.049
Beaches	0.025	0.027
Coastal sand	0.039	0.063
Coconut	0.004	0.014
Coconut dominant mixed crop	0.087	0.151
Double crop	0.021	0.047
Mixed built-up	0.018	0.025
Mixed crop	0.015	0.024
Residential	0.003	0.005

areas along the coastal stretch were contaminated by saltwater intrusion due to direct or indirect influence of the sea. This might be due to seasonal tidal fluctuations and discharge of saline water from coastal rivers that connected with seawater. On the other hand groundwater salinization due to anthropogenic activities is mainly seen at the urbanized portions of the study area. The present report is only a preliminary assessment. This survey will be continued for a year to draw a logical conclusion. To improve the accuracy of the inundation map, ground control points are to be incorporated along with the SRTM DEM. The chemical analysis of groundwater samples will be carried out for determining total hardness, total alkalinity and also the concentration of all dissolved salts like Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, etc. present in it. Further investigations using hydrogeological techniques, radon measurements, isotope studies, and geophysical surveys on quantity, quality and sustainability of groundwater in the study area would allow us to comment on saltwater intrusion and the impact of sea level rise on coastal aquifers of Thiruvananthapuram district.

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