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Assessment of Impact of Salt Pan Activity on Groundwater Quality by Numerical Modelling: A Case Study

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Abstract: Spatial and temporal assessment of groundwater quality is very essential for the management and conservation of groundwater resources. The present study was carried out in and around a saltpan located in Kattur, north of Chennai city for understanding the impact of saltpan activity on groundwater. Groundwater and saltpan water samples were collected for the month of January 2012. Physicochemical parameters of water samples such as pH, Electrical Conductivity, salinity, total dissolved solids, total hardness, sodium, potassium, calcium, magnesium, chloride, carbonate and bicarbonate were analyzed. Groundwater quality in an around saltpan area was checked with drinking and irrigation water standards. Three dimensional finite element model was used to simulate the effect of saltpan activity on groundwater quality. The finite element model was conceptualized by 50 m thickness for upper 12 m as unconfined aquifer and lower 35 m as semi-confined aquifer which is separated by clay patches of around 3 m thick. Model simulation indicated that salinity spreads rapidly and moves along the groundwater flow direction. Groundwater in an area of 10 km^2 around the saltpan is not suitable for drinking and irrigation purpose.

Keywords: *Saltpan, groundwater quality, FEFLOW, Kattur, north of Chennai*

1. Introduction

Demand for fresh water has increased due to over consumption of water resources and improper management of water resources. Surface water sources alone cannot meet this demand in many regions of the world as they are not available throughout the year. These locations are mainly dependent on groundwater for domestic, industrial and agricultural purposes. Due to rapid urbanization and over extraction, groundwater quality is under threat. Coastal aquifers in particular, suffer salinization from seawater intrusion by over-abstraction, water quality degradation due to agricultural and aquaculture activities. An important activity that promotes salinization is salt pans. Salt pan is a primeval technological process whereby salt is extracted from seawater using evaporation ponds. A salt pan is a broad area with shallow depth that holds a given volume of water and is evaporated using sunlight. Over a period of a month, the water gets completely vaporised leaving behind a layer of sea salt crystals which is harvested later.

Several studies have been carried out to identify the impacts of salinization of on groundwater by seawater intrusion. A difference in identification of areas affected by salinity deu to seawater intrusion and salt pan activity was studied by Singaraja et al (2014). Chandrasekharan et al. (1997), Elango and Ramachandran (1991); Kumari et al. (2011); Maruthi et al. (2010) and Singaraja et al. (2013b) studied the effect of saltpan activity on groundwater quality by analyzing physiochemical parameters and concluded that groundwater near saltpan areas are not suitable for drinking and irrigation purposes. Chandrasekaran et al. (1997) and Chandrasekar (2011) analyzed groundwater quality around saltpan area by using Deuterium and oxygen18 isotopes and interpreted groundwater quality in India. Therefore, the present study was carried out with the objective of determining the spatial and temporal variation of groundwater quality on an active saltpan located in Kattur, north of Chennai city.

2. Study area

The study area covers an area of 554 km^2 in eastern part Arani- Koratalaiyar river basin, located about 45 km north of Chennai. An active saltpan situated in the north part of this area was chosen for this study. The eastern side is bounded by the Bay of Bengal and the area is characterized by tropical wet and dry climate, the temperature ranges from 38°C to 42°C during May-June and from 18°C to 36°C during December - January. The average annual rainfall is around 1,200 mm of which 35 % falls during the southwest monsoon (June–September) and 60 % falls during the northeast monsoon (October–December). Topographically, the area has maximum elevation 20 m in the north western part. Agriculture is the main occupation of the rural population. Paddy, groundnut, sugarcane, pulses and banana are the main crops grown in the area. Figure 1 shows the groundwater model area and saltpan area with monitoring wells. Field photo of saltpan is shown in Figure 2.

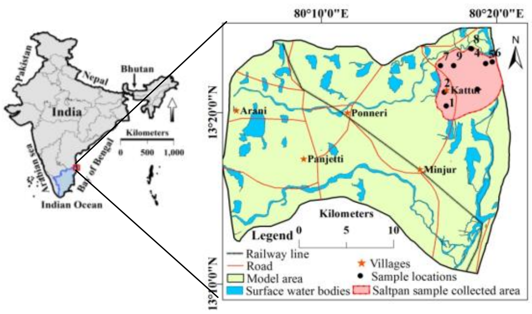

Figure 1 *Location of study area and saltpan with monitoring wells*

Figure 2 *Photographs of saltpan activity in the study area*

3. Materials and Methods

Primary field investigation was carried out and 9 water samples including water from lake near to saltpan, groundwater from saltpan bore well were collected and analysed for physical and chemical parameters for the month of January 2012. Groundwater was collected from bore wells and dug wells located in and around saltpan. Sample bottles were cleaned with distilled water and then with the water sample two times before the sample collection and closed tightly to avoid atmospheric interactions. Parameters such as pH, EC, salinity and temperature were measured in the field using hand held probes. HCO_3 and CO_3 were also determined in the field by volumetric method. Sodium and potassium were determined in the laboratory using photometer by flame photoemission method. Calcium, magnesium and chloride were analysed in the laboratory by volumetric titration method. Geology map was collected from Geological Society of India (GSI) map and it was updated using satellite imagery of Linear Imaging Self-Scanning Sensor (LISS-III) with spatial resolution of 23.5 m. Three dimensional finite element model was used to simulate the effect of salinity on groundwater. The finite element model was conceptualized in FEFLOW software by 50 m thickness for upper 12 m as unconfined aquifer and lower 35 m as semi-confined aquifer which is separated by clay patches of around 3 m thick.

4. Geology

Geologically, the area is underlain by formations ranging in age from Archaean to Recent (UNDP, 1987). Crystalline rocks of Archaean age comprising gneiss and charnockite forms the basement. Upper Gondwana series of shale and clay deposits lie over these crystalline rocks (Rao et al. 2004). Tertiary and Quaternary deposits lie over the Upper Gondwana formation. The area is predominated by sand which may be parts of coastal, alluvial and aeolian deposits. Most of the area is covered by extensive stretch of Quaternary alluvium. The thickness of alluvium ranges from 40 m to 50 m and consists of gravel, fine to coarse sand, clay and sandy clay. These alluvial deposits form the aquifer, and are underlined by tertiary formations of shale, clay and friable sandstone. Quaternary deposits consisting of laterite is exposed as a small patch in the north western corner and alluvium of clayey sand is exposed in most part of the area. Salt marsh occurs as patches in the eastern part of the area near to the coast (Figure 3).

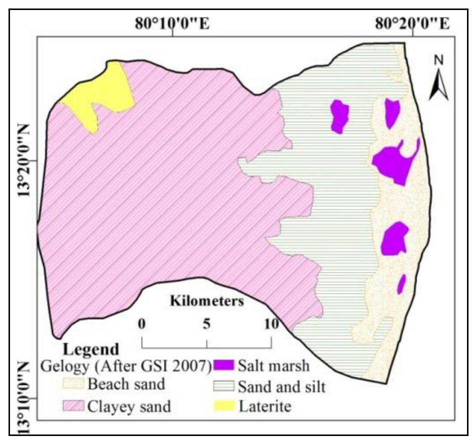

Figure 3 *Geology map of the study area*

5. Hydrogeology

The study area consists of alluvium formation up to 50 m in thickness and it is underlained by low porosity and permeability of clay and sandstone from Tertiary formation. The alluvium formation lies over the tertiary formation which consists of sand, silt and clay with the finer grained beds becoming dominant upwards. The clay deposits of about 3 to 5 m thickness (from borehole data) are divided into two water bearing layers, which function as an aquitard. Upper part of the alluvium function as an unconfined aquifer and lower part function as a semi-confined aquifer. The hydraulic conductivity of upper aquifer ranges from 35 m/day to 100 m/day and specific yield ranges from 0.10 to 0.15. Hydraulic conductivity of lower aquifer varies from 45 m/day to 250 m/day and storage coefficient varies in the range between 0.0014 and 0.0083 (UNDP 1987). Groundwater level in the upper aquifer ranges from 1 m to 12 m bgl and in lower aquifer it ranges from 12 m to 25 m bgl (CGWB, 2007). Figure 4 shows east west cross section of subsurface geology.

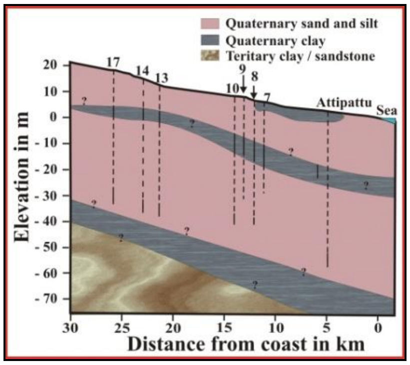

Figure 4 *Subsurface geology of the study area*

6. Groundwater flow model conceptualization

Three dimensional finite element groundwater flow model of FEFLOW 6.2 (2014) was used to simulate the impact of saltpan on groundwater quality. Finite element models offer an alternative approach to the numerical approach to the numerical modelling of groundwater flow. The total model area of 554 km^2 is discretized into 30000 triangular elements and vertically 50 m thickness of aquifer is divided into 25 layers of 2 m thickness each. The triangles intersect at the nodes that represent the points at which the unknown values such as heads will be computed. The value of the head in the interior of each cell is determined by interpolation between the nodal points (Sinha, 2005). North and south boundaries are watershed boundary, they are considered as a no flow boundary because flows across these boundaries are negligible. Eastern boundary is bounded by Bay of Bengal, which is taken as constant head boundary. Western boundary is taken as a variable head which was chosen arbitrarily (Figure 5). Aquifer parameters of transmissivity and specific yield values were taken from the pumping test conducted by UNDP (1987). Groundwater recharge was calculated by rainfall infiltration factor method (GEC, 1997). Groundwater pumping for agricultural was calculated from crop water requirement. Groundwater pumping for domestic and industrial purposes was estimated from per capital demand. In addition to this, groundwater from this aquifer is being pumped by Chennai Metro Water Supply and Sewerage Board (CMWSSB). Well field pumping rate is collected from CMWSSB department.

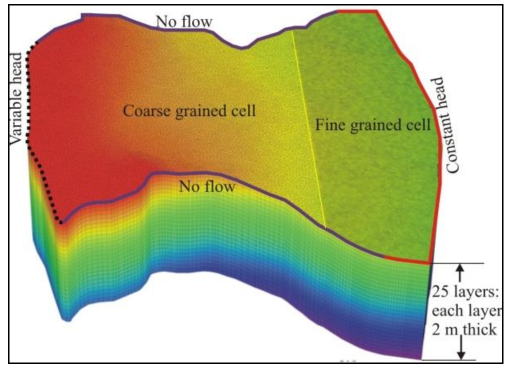

Figure 5 *Three dimensional discretization of the study region for modelling*

7. Results and Discussion

7.1 Physio-Chemical Parameters

pH of water is very important indication of its quality as it will increase with respect to salinity (Ei et al, 1985). pH of the groundwater ranges from 6.4 to 8.2 with a mean value of 7.4. Most samples collected near to the saltpan area showed high pH. Electrical Conductivity (EC) is function of concentration of dissolved solids and the values varied from 399 µS/cm to 79493 µS/cm. The water sample taken from bore well located within the salt pan showed very high EC value of around 79493 µS/cm. EC value in the fresh water storage pond near the salt pan was measured and it showed 399 µS/cm. Suitability of groundwater samples for irrigation based on USSL classification is tabulated in Table 1. Out of 9 samples, 3 samples fall in good to permissible limit and 6 samples are not suitable for irrigation. Salinity values varies from 0.2 ppt to 52.24 ppt. Lower salinity value noted in fresh surface water storages and higher salinity value identified in groundwater sample collected from salt pan. Groundwater has high salinity near saltpan and it gradually decreased towards the fresh water storage.

Chemical parameters of sodium, magnesium, potassium, bicarbonates, calcium, chloride and total hardness were analyzed in the laboratory. Maximum and minimum content of sodium varied from 20850 mg/l to 70 mg/l. Calcium varies from 15 mg/l to 1500 mg/l in the ground water samples of the study area. Magnesium content of the samples ranges from 2.43 mg/l to 6900 mg/l. Potassium values ranges from 24 mg/l to 400 mg/l. The sodium content is high possibly due to the increased salinity in the groundwater samples. The maximum value of the bicarbonates estimated was 549 mg/l and its minimum value was 48.8 mg/l. Chlorides were analyzed and it ranged from 61.23 to 38063.2 mg/l. Hardness ranges from 77.35 mg/l to 32040 mg/l. Hardness is a term commonly used to depict the impurities in water and it is due to the presence of Ca and Mg carbonates and bicarbonates. Since the observation made in study area showed no carbonates, a hydrogeochemical analysis of groundwater can also be used to know about the source of chemical constituents, groundwater type and its quality. The suitability of groundwater for drinking purpose based on IS 10500 (2005), WHO (2006) and BIS (2003) are analyzed. pH value in groundwater were found to be within the permissible limits as per IS 10500 (2005), WHO (2006) and BIS (2003) guidelines. The concentrations of calcium exceeded in 8 samples. The concentrations of magnesium, sodium, potassium, and chloride were found to exceed in all samples.

Table 1 *Suitability of groundwater for irrigation based on USSL classification*

EC (µS/cm)	Salinity class	Sample number
< 250	Excellent	Nil
250-750	Good	2
750-2000	Permissible	5, 7
2000-3000	Doubtful	1
> 3000	Unsuitable	3, 4, 6, 8, 9

7.2 Groundwater flow and solute transport modeling

7.2.1 Model Calibration and Simulation of Flow

Model calibration is very essential for good characterization of field condition. The model was calibrated both in steady and transient state. Groundwater head from 5 monitoring wells in upper and 10 monitoring wells from lower aquifers during March 2008 were used for steady state calibration. A number of trial runs were made to minimize the difference between observed and simulated groundwater head. At the end of trial runs, the trend of observed and simulated groundwater head variation was more or less similar. RMS value was greater than 0.8 (Figure 6). Then transient state calibration was carried out for a period of 2 years from March 2008 to December 2010 with 30 days time step and fine tuned until the parameter values made the best possible match between observed and simulated groundwater heads. Transient state calibration was completed with RMS value of 0.885 and 0.823 in upper and lower aquifers respectively (Figure 7).

Calibrated groundwater model was verified by validation. The validation of the model was achieved by comparing the simulated groundwater head with the observed heads for the period January 2011 to December 2012 with calibrated parameters. Time series of observed and simulated groundwater head of upper (Well No. 5) and lower (Well No. 22) aquifer wells are shown in Figure 8. There was a reasonable match between the observed and simulated groundwater head during the period considered for validation. The simulated groundwater head of the lower aquifer shows lower than the sea level thereby indicating seawater intrusion.

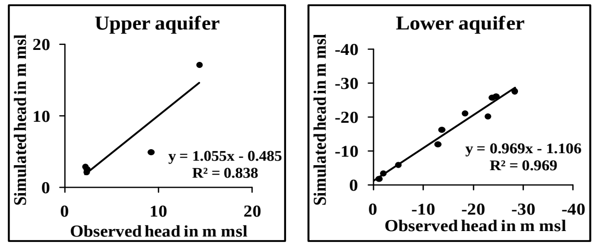

Figure 6 *Steady state calibration in upper and lower aquifer*

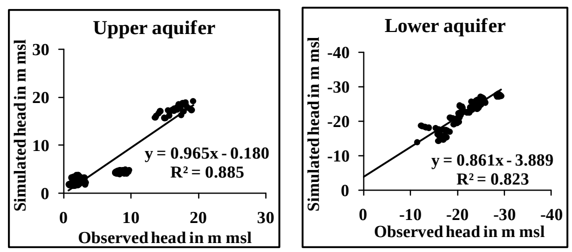

Figure 7 *Transient state calibration in upper and lower aquifer*

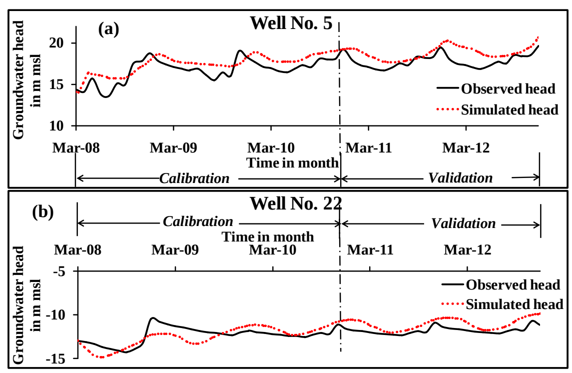

Figure 8 *Temporal variation in observed and simulated groundwater head for (a) well no.5 in upper aquifer and (b) well no.22 in lower aquifer*

7.2.2 Simulation of Solute transport

Solute transport is simulated to identify the spatial and temporal impact of saltpan activity on groundwater quality. Finite elements around the saltpan area was further refined and the mesh was smoothened for accurate measurement of solute transport. The solute concentration of chloride values measured around the saltpan during January 2012 was assigned. Boundary conditions of solute concentration in north, south and western side were assigned as 0 mg/l. Porosity effective for mass transport process is assumed to be 20% throughout the model. Longitudinal and transverse dispersivity were given as 100 m and 10 m. Initial solute concentration of the model is shown in Figure 9.

Solute transport modelling was carried out for the period from January 2012 to December 2020. The result shows the solute disperses along the groundwater flow direction which is from west to east. The concentration of solute moved towards the sea along the groundwater flow. Spatial and temporal variation of solute concentration is shown in Figure 10. The results show groundwater quality degraded towards sea.

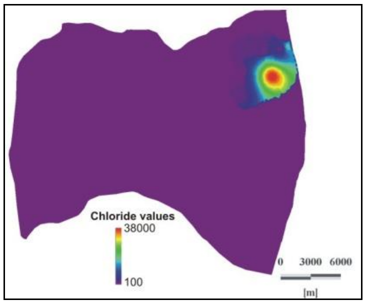

Figure 9 *Initial distribution of concentration of solute*

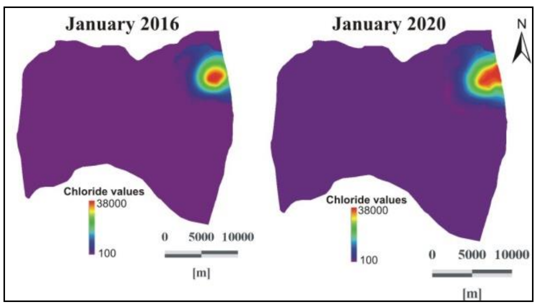

Figure 10 *Spatial and temporal variation in solute concentration during January 2016 and 2020*

Conclusion

Spatial and temporal variation of groundwater quality due to saltpan activity was assessed by groundwater modelling. Groundwater samples in an around saltpan was collected and analyzed for physiochemical parameters. Most of the groundwater samples are not suitable for drinking and irrigational purpose. Three dimensional finite element groundwater flow model of FEFLOW was used to simulate the impact of saltpan on groundwater quality. Groundwater flow model was calibrated under steady and transient state condition. Solute transport was simulated for 8 years from the year 2012 to 2020. Salinity movement was observed along the groundwater flow direction and it spreads towards east direction. This model gives a better prediction for future groundwater quality in the area due to saltpan activity.

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