CHAPTER 6

HYDROGEOCHEMICAL CHANGES AND SALINIZATION PROCESS DUE TO TSUNAMI

6.1 GENERAL

Tsunami waves are known to be able to cause significant alterations in groundwater quality of coastal aquifer systems. The concentrations of major ions in groundwater are likely to increase due to the tsunami waves that enter inland. In this chapter, the effect of the December 26, 2004 tsunami on the coastal aquifer of the study area in terms of the concentrations of major ions and trace elements are discussed. Major ions and trace elements constitute a significant part of the total dissolved solids present in the groundwater of this area. The concentrations of major ions of groundwater have, therefore, been used for the identification of the salinization process during tsunami.

6.2 SALINISATION OF AQUIFER

Out of 20 monitoring wells, six wells were located in the tsunami-inundated zone (well nos. 1, 2, 8, 9, 11 and 12) of this area. The inundated zone extends to about 200 to 500 m from the present shoreline (Figure 6.1). These wells, which generally penetrate up to a depth of 7 m below the ground surface, are fitted only with hand pumps, and the abstraction by these wells is very less. During field investigations, it was understood from the house-owners (stake holders) living in the inundated zone that the water in this
region was potable before the tsunami. It is significant that there are no previous reports of the presence of saline water in the wells located in this region before the tsunami event.

Figure 6.1 Map of tsunami-inundated zones
Hence, there was no possibility of sea water intrusion in this region before the tsunami, especially with very low abstraction to meet the domestic needs.

Figure 6.2 Conceptualisation of the salinisation process

After the tsunami, however, the groundwater quality deteriorated in these wells by the increase in EC up to 11,200 µS/cm. The comparison of groundwater EC and major ion concentrations among the wells located in the inundated and non-inundated wells is shown in Figure 6.3, which highlights the salinization of wells in tsunami-inundated regions. There are two possible reasons for the salinization of this aquifer by tsunami: 1) direct contamination of wells by entry of sea water through hand pumps, and 2) infiltration of sea water into the aquifer through the unsaturated zone (Figure 6.2). The results
indicate that sea water has percolated through the unconsolidated Quaternary sediments in this region during tsunami resulting in salinization of groundwater.

Figure 6.3 Major ion concentrations of groundwater in inundated and non-inundated zones

A part of the saline water would be retained in the unsaturated zone during the process of infiltration through the unsaturated zone. The water retained in the unsaturated zone may deposit the salts during evaporation, which are flushed in during subsequent rainfall recharge. Thus, this mechanism will result in the long-term threat to groundwater quality.
6.3 SEASONAL VARIATIONS IN CONCENTRATIONS OF MAJOR IONS

The EC values of groundwater of the inundated wells gradually decline until the month of July 2005. As the groundwater generally flows towards the sea, the EC values would have decreased due to the lateral flow of fresh water from the west. After the rains during the months of August and September 2005, however, EC and major ions of groundwater increased in the wells located in the inundated zone. The recharge of fresh water through the unsaturated zone resulted in washing of the salts deposited in the unsaturated zone due to the evaporation of sea water that entered during the tsunami. The salts in sediments brought by the tsunami might have also got flushed in by the recharging water. Srinivasalu et al (2007) reported higher concentrations of Na and Cl ions in the tsunami sediments of the Kalpakkam region. Due to these reasons, the concentrations of major ions in groundwater increased in all the wells located in the inundated zone. In well nos. 1, 2, 8 and 11, the EC and concentrations of major ions of groundwater increased beyond the levels measured immediately after the tsunami. These wells are very near the coast, and the distance of these wells is about 50 to 100 m from the shoreline. The column of sea water that entered during tsunami near the coast was high. The sediment deposition was also relatively much higher near the coast. These resulted in increasing the concentrations of major ions in the groundwater samples of well nos. 1, 8 and 11 when compared to the post-tsunami scenario (Figures 6.4, 6.6, 6.8). Well nos. 9 and 12 had high concentrations in September 2005, but not up to the post-tsunami levels measured in January 2005 (Figures 6.5, 6.7, 6.9).
Figure 6.4 Seasonal variation of major ion concentrations in groundwater of tsunami-inundated well (well no. 1)
Figure 6.5 Seasonal variation of major ion concentrations in groundwater of tsunami-inundated well (well no. 2)
Figure 6.6 Seasonal variation of major ion concentrations in groundwater of tsunami-inundated well (well no. 8)
Figure 6.7 Seasonal variation of major ion concentrations in groundwater of tsunami-inundated well (well no. 9)
Figure 6.8 Seasonal variation of major ion concentrations in groundwater of tsunami-inundated well (well no. 11)
Figure 6.9 Seasonal variation of major ion concentrations in groundwater of tsunami-inundated well (well no. 12)
After the northeast monsoon rainfall during the months of October through December 2005, the EC of groundwater was lowered to normal levels in well nos. 8, 11 and 12. The EC of groundwater ranged from 900 to 1,200 $\mu$S/cm in these wells. Well nos. 1 and 2 in the inundated zone had EC values of 2,500 $\mu$S/cm after the northeast monsoon during October-November 2006 (Figure 6.10).

Figure 6.10 Regional variation in EC of groundwater during January 2007
6.4 CHLORIDE-BICARBONATE RATIO

Generally, chloride ions are high in sea water and low in groundwater, while bicarbonate concentrations show a reverse trend. Hence, the seasonal variation in chloride-bicarbonate ratio was used to find out the mechanisms of salinization. Seasonal variations in chloride and bicarbonate ratios of groundwater from the inundated zone are presented in Figure 6.11. This also indicates the process of washing of the salts in the unsaturated zone during the recharge process. That is, when rainfall occurs, the chloride-bicarbonate ratio increases, indicting the flushing of salts from the unsaturated zone that were deposited due to evaporation.

![Figure 6.11 Seasonal variations in rainfall and chloride-bicarbonate ratio of tsunami-inundated wells](image)

Figure 6.11 Seasonal variations in rainfall and chloride-bicarbonate ratio of tsunami-inundated wells
Hydrochemical nature of the wells located in the inundated zone was studied using Piper’s trilinear diagram (Figure 6.12. This indicates that the groundwater of the inundated wells was richer in alkalies ($\text{Na}^+$, $\text{K}^+$) than the alkaline earth metals ($\text{Ca}^{2+}$, $\text{Mg}^{2+}$) immediately after the tsunami. Similarly, $\text{Cl}^-$ and $\text{SO}_4^{2-}$ were more dominant than the $\text{HCO}_3^- + \text{CO}_3^{2-}$ immediately after the tsunami. The $\text{NaCl}$ facies was found immediately after the tsunami.

![Figure 6.12 Piper’s trilinear diagram for tsunami-inundated wells](image)

**Figure 6.12** Piper’s trilinear diagram for tsunami-inundated wells
After the subsequent monsoon, however, alkaline earth metals became more dominant than the alkalies. \( \text{HCO}_3^- + \text{CO}_3^{2-} \) became more dominant than \( \text{Cl}^- \) and \( \text{SO}_4^{2-} \). This resulted in the change of water type to Ca-Cl-HCO\(_3\) (Figure 6.12). This indicates improvement in groundwater quality that got degraded during the 2004 tsunami. Similar to the Piper’s diagram, Durov’s classification also confirms improvement in groundwater quality. (Figure 6.13). The groundwater quality did not, however, improve significantly in two wells, namely nos. 1 and 2.

Figure 6.13 Durov’s diagram for tsunami inundated wells
6.6 TRACE ELEMENTS

The results of the analysis for trace elements indicate that the concentrations of Fe, Mn, Cd, Cr, Cu, Ni and Pb were always below their respective detection limits. However, the concentration of Zn was around 1.7 mg/l (Figure 6.14).

6.6.1 Zinc

Solubility data for zinc carbonate and hydroxide, summarized by Hem (1972), suggest that water containing 610 mg/l of HCO₃⁻ should contain less than 0.1 mg/L of zinc over the pH range from 8.0 to 11. Zinc belongs to a group of trace metals that are potentially dangerous for the biosphere. The main sources of pollution are industries and the use of liquid manure, and composted materials.

The concentration of zinc in the groundwater of the study area varies from below detectable limit (BDL) to 1.72 mg/l. Except for the tsunami-inundated wells, all other wells exhibited values in a range from below the detectable limit to 0.08 mg/l. Thus, the groundwater in the inundated wells has high concentrations of zinc. Tsunami sediments of Kalpakkam region have high concentrations of Cu, Pb and Zn in the tsunami sediments (15, 6 and 20 ppm, respectively) (Srinivasalu et al 2007). Out of these, Pb and Zn can dissolve with ease in water. As the concentration of Pb is relatively less, it is not found in the groundwater of the inundated wells. Zn occurs in relatively high concentrations in the sediments; it can also easily dissolve in water (as it occurs as ZnSO₄). This has resulted in elevated concentrations of Zn in the groundwater samples of the inundated wells.
Figure 6.14  Regional variation in concentration of zinc during July 2006 (mg/l)