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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Groundwater quality changes in the tsunami affected coastal belt – Southern Sri Lanka

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The groundwater quality of an aquifer system in Mirissa area was studied. 19 dug wells distributed over a 6 km coastal strip were selected. The dug wells were sited in a line perpendicular to the coastline. Most of the dug wells were shallow and their diameter ranged from 0 to 1m. In low lying coastal areas, electrical conductivity was 3500 $\mu\text{s/cm}$. Heavy rains in early January improved the quality in coastal groundwater and hydro geological discharge was also significantly affected. First and second lines receiving their recharge from inland. Therefore, pH values changed and the quality of water significantly improved giving an electrical conductivity below 1000 $\mu\text{s/cm}$.

Introduction

The Asian tsunami of 26th December 2004 which struck the coasts of the Indian Ocean with a tidal wave caused the heaviest damage ever recorded on a coastal part of Sri Lanka. In the Northern, Eastern and Southern coastal belts, over a width of about 800 m to 1.5 km, the entire man made resources were damaged. Wells were polluted by salt water and filled up with sand, mud and debris deposited by the wave. Almost all the open dug wells of the affected zone were damaged and groundwater resources were heavily polluted. The tsunami caused extensive damage to the entire well system reducing them to ruins.

Due to sea water intrusion, the fresh water and salt water equilibrium was also heavily disturbed. Prior to the tsunami, groundwater from wells was used for domestic consumption (Ranjana.U.K. Piyadasa, et al 2005). Naturally, in coastal areas an equilibrium exists between seawater and freshwater which depends on the geological and hydro-geological conditions of the region. Due to the high density of seawater, it tends to force its way underneath the freshwater. However, as the pizometric head of the freshwater lies above the seawater, the fresh water has a continuous discharge to the sea. Since the freshwater discharging flux is opposite to the inland movement of seawater, equilibrium is established and prevents salt-water intrusion. Once groundwater level equilibrium is established, the water level stabilizes and only fluctuates annually when there are seasonal changes or an occurrence of natural hazards.

During the post-tsunami period, some polluted dug wells were pumped at a higher rate to remove the saltwater. However, wells were reported to be remain saline, even after the repeated cleaning and emptying. Under this circumstance the risk of deterioration of the water quality was high due to the up conning of underlying saline water.

According to the results of our earlier investigations in the area, Weligama indicated that heavy rain spells had no impact on the change of groundwater quality in some locations (Ranjana et al. 2005). However in other areas the quality of groundwater had improved slightly. Increased electrical conductivity after precipitation is associated with dissolving accumulated salt in the unsaturated (aeration) zone, with the downward of the flux.

The main objectives of the present research study are to: (1) Investigate the water quality dynamics in the tsunami affected southern coastal area after one year. (2) Study the influence of precipitation and local topography on groundwater quality. (3) Study geology and hydro geological conditions of the area.

Study area

The study was conducted in the coastal belt of Mirissa which is bound by latitudes 20°30' and 21°10'N and longitudes 39°45' and 40°30'E. Mirissa is situated 145 km south of Colombo, and 15 km north of Matara. The western border terrain of the Mirissa belt is relatively flat or gently slopes seaward. Elevation and topographic relief increases with distance as one travels inland from the coast. This contrasts with typical elevations in the outer coastal plain setting of 1.5–7m above sea level. Groundwater is an important source of drinking water for the majority of the population in the coastal plain of the Mirissa area.

Climate and drainage

Mirissa falls within the DL3 agro-ecological region which is defined as an area where 75% expectancy of the annual rainfall exceeds 580 mm. The North-western region of Mirissa receives an annual average of 1000 to 1250 mm and the annual rainfall for Mirissa is 1167mm. Mirissa receives rainfall from both the Southwest monsoon (April-

May to Aug- September: Yala season) and the north-west monsoon (October-December to March-April: Maha season). The west of the Mirissa area is drains into the Polwathumodera river system. A fresh water tank is situated 2 to 3 km from the coastal line of Mirissa, which drains into the Polwathumodera river.

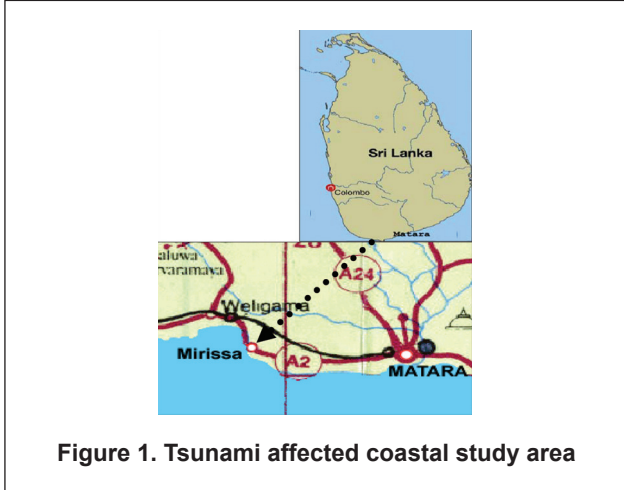


Figure 1. Tsunami affected coastal study area

Geology and hydrogeology

Precambrian metamorphic hard rock covered by quaternary sedimentary deposits are dominant in the study area (Cooray, P.G.-1984). The bedrock consists of precrembrian rocks of the so-called Highland Complex and consists of granite silicants with-biotite gneiss. Topsoil mainly consists of sandy clay. The top unconfined alluvium aquifer is distributed in the Polwattumodera river basin and on the coast. Water-bearing sand in the top section is more often fine while lower sections usually have coarse sand with small portions of gravel.

In general, the aquifer consists of calcified sand; in the case of the Polwattumodera Ganga basin, sandstone is dominant. Recharge to the aquifer is mainly associated with rain falling on the Northern region of the catchment area. The top quaternary sandy aquifer and the surface soils of the coastal margin of the Mirissa area are most permeable. The

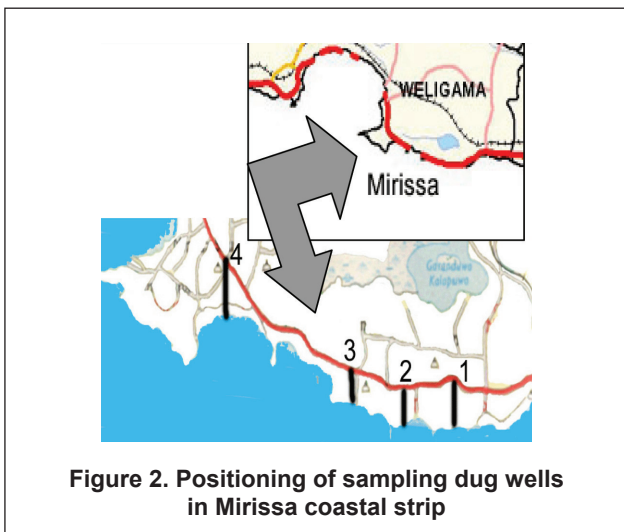


Figure 2. Positioning of sampling dug wells in Mirissa coastal strip

hydro-geological conditions in Mirissa are very favorable for saltwater intrusion; therefore, along the coastal belt, alluvial and coastal sand deposits dominate and form higher-yielding local shallow unconfined aquifers.

Material and method

For the present research, a network of 19 dug wells distributed over a 5 km costal strip (Figure.2) of the tsunami-affected Mirissa area was selected. The dug wells were distributed within approx 0.5 to 0.7 km distance from the coastline covering both affected and non-affected wells. Dug Wells are selected to maintain perpendicular transects to the coastal line. The distance between two dug wells was between 50-100m. Initially, wells were selected in the vicinity of Kamburugamuwa town in a line 550 m from the coast. All the wells situated on the coast were flooded by the tsunami. Selected wells are still not used by the people for consumption. Some wells have been abandoned due to human migration. The wells selected in the third line fall in the tourist holiday bungalow area. These wells were not completely flooded by the tsunami. Here wells were constructed closer to the coastal line but elevation gradually increases as one travels inland.

The most distant well selected was 390 m away from the coastal line and located within higher terrain. The fourth line of wells was in the vicinity of the highly populated Mirissa town area. The length of the monitoring transect was nearly 550 m where each observation terrain was completely flat and submerged during the tsunami. The last well in each observation line was selected in a non-tsunami affected location. Prior to the tsunami, water from these wells was non-saline and used for drinking and other domestic purposes. Continuous monitoring of water levels in the wells was conducted in the first week of each month from January to June, 2006. Analogically, the water quality in respect to electrical conductivity (EC), total dissolved solids and salinity were measured using portable EC/pH meters at monthly intervals. The hydrographs were formulated on the basis of rainfall, groundwater level from mean sea level, pH and TDS.

Results and discussions

Dug well classification

The results of the physical observation of dug wells are given in Tables 1 and 2. It is evident that most of the dug wells in the sample are shallow at a 1-7 m depth range. (Table 1).

However, more than 63 % of the wells were at depth of 2-4 m. As per the diameter, more than 63 % of wells were

Table 1. Total depth of the wells in the study area

Depth of dug wells (m)	No. of wells	%
0-2	0	0
2-4	12	63.2
4-6	5	26.3
6-8	2	10.5

Table 2. Diameter of the wells in the study area

Diameter of dug wells (m)	No. of wells	%
0-1	12	63.2
1-2	7	36.8

within 1m depth range (Table 2).

From the depth and diameter classification, it is evident that seawater intrusion and damage to the aquifer through the inundation of wells may have a little room. However, infiltration and percolation of sea water through the top sandy soil may have had a fair contribution on the coastal aquifer system. Submergence and flooding during the tsunami may also have caused deposition of salts in the unsaturated zones of the soils which may have subsequently leached down to the saturated zone with the downward flux of rainwater.

Rainfall data

Precipitation data was obtained from the site of the Coconut Cultivation Board at Pategama, which is near to the study site and located about 9 km away from the study area. According to the rainfall data from January 2005 to June 2006, most of the months received more than 50 mm of rain except in Feb, Sept 2005 and Feb, April 2006. A maximum of 423 mm rainfall was received in November 2005. During the sampling period, January 2006 to June 2006, the total rainfall received by the locality was 452 mm. April - July 2005 and Oct 2005 – Jan 2006 were wet where >100 mm monthly rainfall was experienced.

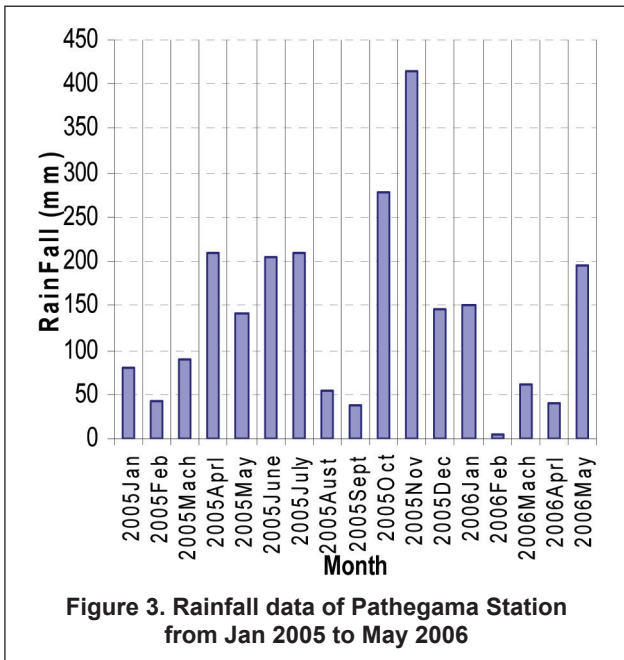


Figure 3. Rainfall data of Pathegama Station from Jan 2005 to May 2006

Hydrogeological condition of the area

It is evident from the map (Figure 4), that very shallow water levels are observed near the coastal area. However in some areas groundwater level is slightly elevated towards inland. This groundwater level behavior is affectively changing the

quality of coastal groundwater. Monitoring transects 1 and 2 had shallow groundwater levels, which fluctuated around 2 m above the mean sea level. Groundwater recharge for wells within monitoring transects 1, 2 and 3 took place from within the inland area; However, wells situated at transect 4 had no direct recharge from the inland area.

The hydraulic gradient of transects 1, 2 and 3 varies from 0.01 to 0.001 and therefore some contribution from inland areas may have added to the recharge. Therefore, hydrogeological conditions had a strong influence over the quality changes in the tsunami-affected area.

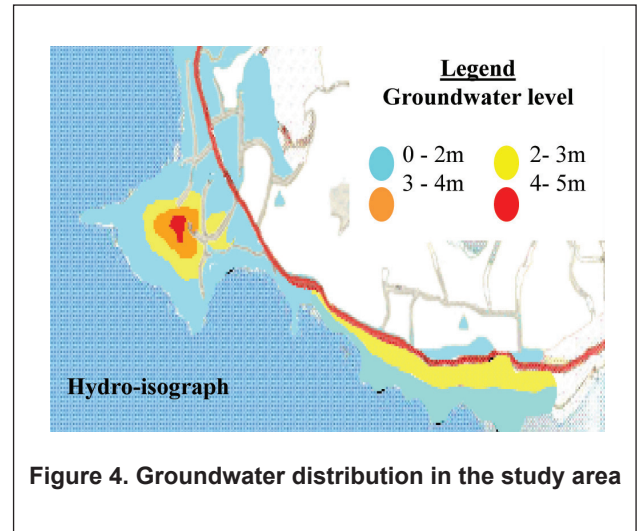


Figure 4. Groundwater distribution in the study area

EC, pH data and hydrograph analysis

According to the data, six hydrographs were drawn for the period from January to June 2006 for 4 monitoring transects to illustrate the relationship between rainfall and electrical conductivity for the study period (Fig. 5-9)

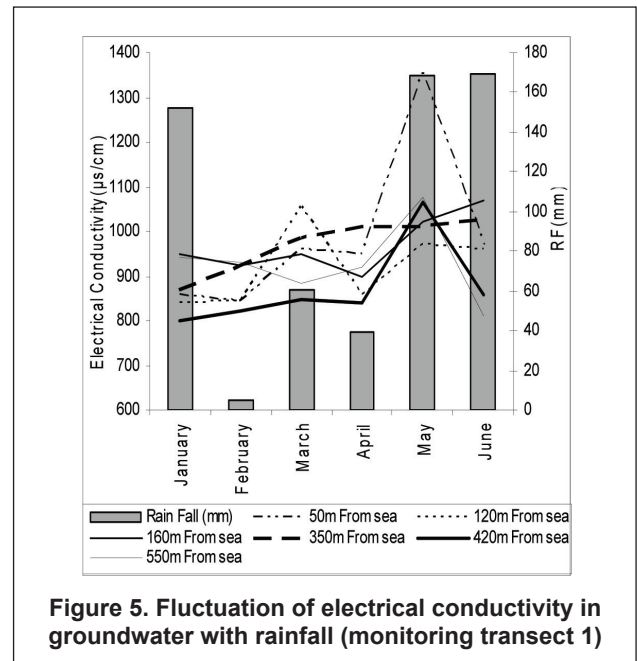


Figure 5. Fluctuation of electrical conductivity in groundwater with rainfall (monitoring transect 1)

Dynamics of the electrical conductivity in transect 1

Six dug wells were available in the monitoring transect and the first four of which were located 350 m from the shoreline. Last two wells are located in non affected area. In transect 1, topographically the shore line elevation gradually increases up to 6 to 8 meters. Electrical conductivity of the wells had a decreasing pattern from the coastal line to inland. It is evident that EC of well water in January 2006 was below 1000 $\mu\text{s/cm}$. This may be associated with high rainfall received during the previous months (October 2005 to January 2006, Figure 3).

Comparatively low rainfall (Less than 60 mm/month) received during February to April 2006 had no impact on salt accumulation in groundwater. In May, 2006, monthly rainfall constituted > 150 mm, which contributed to salt leaching from the unsaturated zone whereby increasing the EC to a maximum of 1355 $\mu\text{s/cm}$ in the coast. Analogically, other wells had EC peak up to 1000 $\mu\text{s/cm}$. However, continuous high rainfall in June 2006, appeared to dilute the salt in groundwater whereby decreasing the EC.

It appears that in the tsunami affected zones, the volume of rain was hardly sufficient to leach the accumulated salts from the surface layers and to contribute to the ground water. Therefore, the quality of the groundwater in affected areas still depends on the atmospheric precipitation and recharge into the ground water. (Figure 4).

Dynamics of the electrical conductivity in Transect 2

The Second transect in Mirissa was topographically similar to transect 1. EC of groundwater fluctuated very rapidly in this transect with time and distance from 1400 to 300 $\mu\text{s/cm}$ (Figure 6). Two wells close to the shoreline in this transect were heavily affected. The last well of the selection, was located 450m from the seashore and was in the non-affected area. In the non-affected zone, mean EC values were 800 $\mu\text{s/cm}$ which remained constant through out the monitoring period.

The third well from the shoreline was located in the non-affected area, but EC values change between 270 to 1380 $\mu\text{s/cm}$. These EC value changes are the effects of the underlying saline water intrusion due to saline water flooding during the tsunami. Precipitated water received as a recharge into the wells located in the higher ground. During early February, in the first well the EC value was 900 $\mu\text{s/cm}$ due to heavy rainfall and it did not change over the month. This can be explained as precipitated water dilutes the saline water and sometimes groundwater recharge received from higher ground. Very low rainfall during February, March and April was observed and the EC values were gradually increased from 900 to 1300 $\mu\text{s/cm}$. This was due to low rainfall during this period and the groundwater recharge rates were low from higher ground. Sometimes due to low rainfall evapotranspiration

rates are high. Therefore, saline water intrusion is high and saline water which drains into the aquifers was high. Due to high rainfall during June, salinity levels were increased up to 2100 $\mu\text{s/cm}$. Salinity levels changed rapidly in the second and third wells in the considered line compared to the first well. This means that the quality of water changed due to precipitation and groundwater recharge.

Dynamics of the electrical conductivity in transect 3

The first well of the transect was highly affected by the tsunami and located 80 m from the shoreline. Just after the tsunami, several attempts were made to pump the wells clean. This may have aggravated the situation due to internal seepage from sea to land and as such the EC value in January 2006 remained at a high level of 3880 $\mu\text{s/cm}$. As evident from the data, the EC values have not changed due to precipitation. Throughout the monitoring period, EC values ranged between 3880 and 3250 $\mu\text{s/cm}$. This may be related to up-conning of underlying saline water draining into the well due to exclusive pumping. (This well was located in the tourist bungalow premises and according to the information given by the owner, before the tsunami well water was used for domestic purposes).

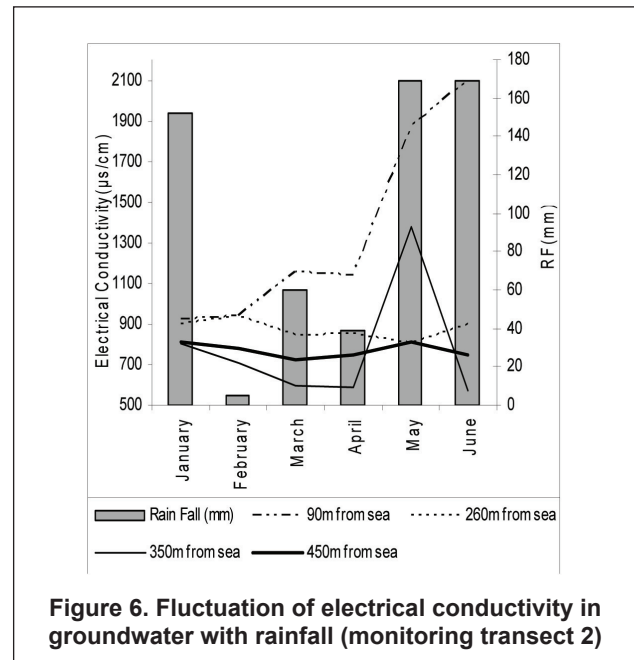


Figure 6. Fluctuation of electrical conductivity in groundwater with rainfall (monitoring transect 2)

The second and third wells were located 150 and 300 m away from the shoreline and slightly affected by the tsunami. EC values of the two wells were around 1000 $\mu\text{s/cm}$, which decreased with high rainfall and increased with low rainfall. However, in all the affected wells EC values remained over 2000 $\mu\text{s/cm}$ level. However with low rainfall the EC values were increased up to 3000 $\mu\text{s/cm}$. Therefore in this transect, the quality of groundwater depends only on atmospheric precipitation. According to the hydrogeological map hydraulic

gradient does not change. Therefore, quality of water does not change due to groundwater recharge. EC values in the affected dug wells change in the range 1860 to 1420 $\mu\text{s}/\text{cm}$. According to the information collected during the study period non-affected groundwater used for domestic purposes are not suitable for drinking at present.

The last well of the transect was located at a higher elevation (above 8 m) and not affected by the tsunami and the EC values fluctuated within 700-500 $\mu\text{s}/\text{cm}$.

Dynamics of the electrical conductivity in transect 3

Transect four is different from the other three transects because the dug wells are located on flat land. The elevation is around 2m from M. S. L. throughout the transect. The first four wells in the transect were located in the tsunami affected zone and the last well was in the unaffected zone. The length of the transect is 550m from the shoreline (Figure 8). Well water in the affected wells changed in the range 4000 to 2000 $\mu\text{s}/\text{cm}$ and unaffected well water EC is below 2000 $\mu\text{s}/\text{cm}$.

According to the groundwater distribution map, the hydraulic gradient in the transect is very low and recharge not received (figure 4). Therefore, the quality of the groundwater did not change with atmospheric precipitation.

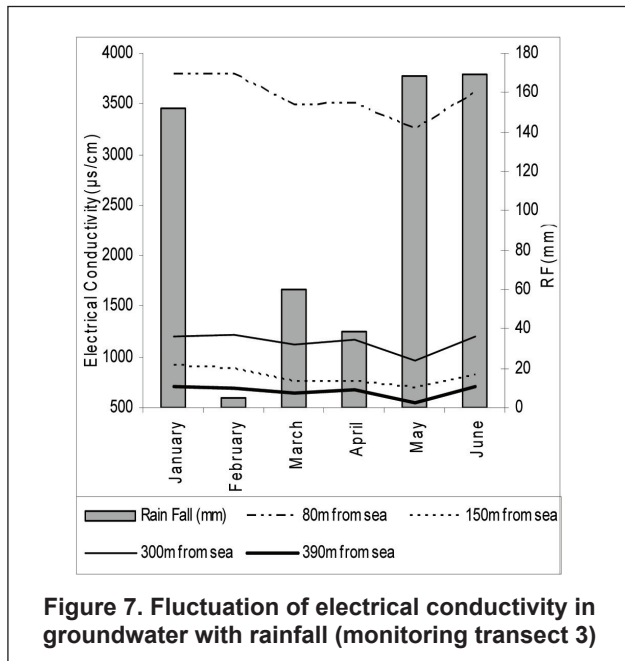


Figure 7. Fluctuation of electrical conductivity in groundwater with rainfall (monitoring transect 3)

According to the pH Values of the groundwater in the transects, the affected and non-affected areas can be separated noticeably (Figure 9). The pH of water in affected wells was between 7 and 8 and with the rainfall it has changed. The pH values of the wells in non-affected area were around 7. During the high rainfall period, pH values changed noticeably. After May, pH values changed significantly to be below 7 due to high rainfall. This can be explain as the

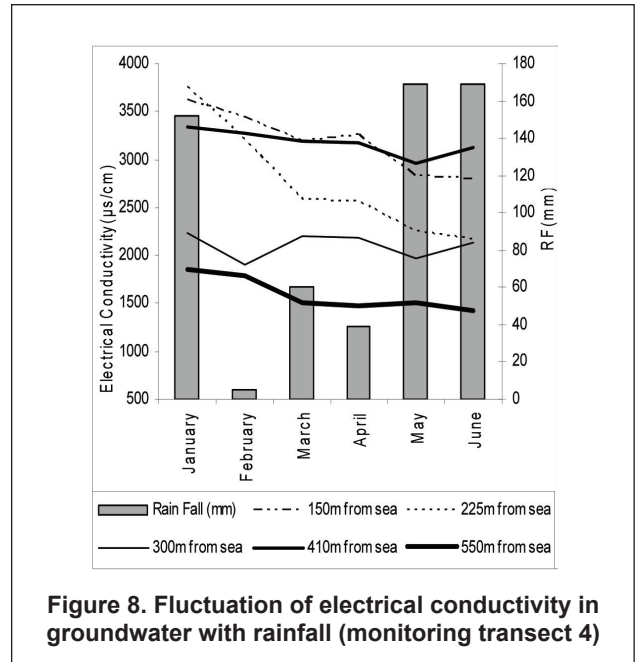


Figure 8. Fluctuation of electrical conductivity in groundwater with rainfall (monitoring transect 4)

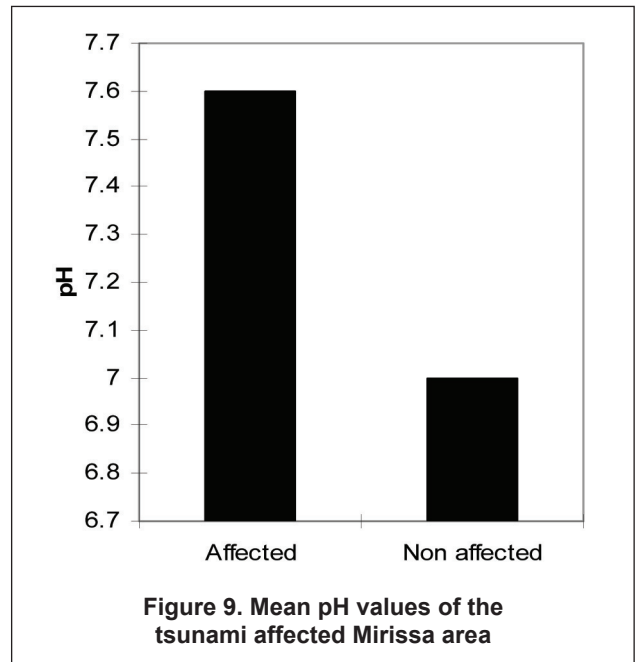


Figure 9. Mean pH values of the tsunami affected Mirissa area

continued recharge received fresh groundwater from high plains diluting the well water.

Conclusion

In Mirissa, situated in the Tsunami affected southern coastal belt, groundwater salinity levels close to the coast were still high and remained at 3000 $\mu\text{s}/\text{cm}$ level even one year after the tsunami. However, groundwater quality improvement can be observed in the coastal strip where groundwater recharge occurs.

The pH values do not changing in the non-affected area with rainfall, but in the affected areas, pH values changed considerably. In affected areas, mean pH value is 7.6 while it is around 7 in non-affected areas.

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