32nd WEDC International Conference, Colombo, Sri Lanka, 2006

SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Chemical Characteristics of Tsunami-Affected Groundwater and Lagoon on the East Coast of Sri Lanka

Villholth, K.G., Manamperi, A.S.P., Sri Lanka, Buergi, N., Switzerland

Previous studies have shown that groundwater on the east coast of Sri Lanka was heavily impacted by salinization due to the Dec. 26, 2004 tsunami. This study follows up on these initial studies to investigate the effect of the onset of the first rainy season after the tsunami on groundwater quality in the same areas. The results show that approx. 620 mm of rain falling between September and November 2005 improved the water quality with respect to salinity, decreasing the average well water salinity levels from 1250 to 950 µS/cm. A slight elevation in salinity levels in flooded vs. non-flooded wells (1240 vs. 780 µS/cm) in November indicated prolonged salinity impacts in the tsunami-affected areas. As opposed to salinity, groundwater quality deteriorated significantly with the first rains following the dry season with respect to nutrient content. Average well nitrate concentration was doubled (from 7.7 to 17.0 mg/l), with number of wells exceeding the WHO standard of 50 mg/l increasing from 2 to 9% with the rains.

Introduction

IN SRI LANKA, where about 75 percent of the coastline was affected by the tsunami, physical destruction and salinization of water supply schemes, either based on smaller decentralized, waterborne systems, or individual wells raised an immediate concern for short as well as long term rehabilitation of safe water access to the large population living in or displaced from affected areas.

In this study, the focus was on the east coast of Sri Lanka because here the tsunami devastation was among the highest in the country (ADB et al., 2005). Also, these areas are generally less developed, partly because of longstanding civil unrest. Finally, groundwater plays a critical role in supplying drinking water in the coastal areas of eastern Sri Lanka. This is because the aquifers generally provide a reliable and good quality water source, readily available on the spot and on demand from traditional shallow open dug wells.

The objective of this study was to characterize the groundwater quality in the coastal areas before and after the onset of the first rainy season after the tsunami. From previous studies, it is known that the groundwater resources were heavily impacted by salinization up to 1.5 km from the coast line within the sandy aquifers (Villholth et al., 2005). These studies also showed that the initial recovery of the freshwater in the aquifers was rapid following the tsunami but with the progress of the dry season, little further improvement of the water quality was observed. Further natural flushing and dilution of the tsunami-derived saltwater ingression with the first rainy season following the tsunami, (approximately ten months after the event) were anticipated to significantly improve the freshwater conditions of these aquifers. Hence, the specific objective of this study was to observe and characterize the changes in salinity, as well as other major chemical characteristics of the groundwater, from before the start of the rainy season to just after the onset of the rains. In addition to groundwater, lagoon water, which was also impacted by the tsunami and acts as a boundary condition to groundwater in some areas, was investigated.

General Overview of the Area

Study sites

Three sites on the east coast were selected for the monitoring program: Kallady, Kaluthavalai which belong to Batticaloa district and Oluvil, in Ampara district. (Figure 1 and Figure 2). The average area of each site is approximately 2 km^2. The sites were chosen to be representative of some of the general characteristics on the east coast with respect to physical geography, demography, land and water use. Also, areas that were devastated by the tsunami were chosen, as these areas were expected to suffer most from salinization.

Soil and aquifer

The sediments making up the coastal aquifers are mostly structure-less sand, ranging from fine to moderately coarse. Technically, they are called regosols (Panabokke et al., 1996). The aquifers are unconfined and shallow and very permeable and hence prone to contamination from leaching from the top soil.

In many places, the sandy aquifers are bordered to the inland side by coastal freshwater or brackish lagoons

(Figure 1). This configuration further limits the local fresh groundwater resources and increases the vulnerability which needs to be taken into account in water resources assessment and management.

Climate and land use

The climate in Sri Lanka, in general and of the area examined in particular, is typical tropical. This area falls within the DL2 agro-ecological region (The National Atlas of Sri Lanka., 1988) which is defined as an area where there is a 75% expectancy of an annual rainfall exceeding 900 mm. The study area experiences an average annual rainfall between 1500-2000 mm (The National Atlas of Sri Lanka., 1988) and it is significant that 75% of the annual precipitation falls in the months from October to February (Villholth et al., 2005).

The topography in the areas is relatively flat, with highest points of elevation of 15 m. The first two sites, Kallady and Kaluthavalai, were bordered to the west by lagoons, at approx. 2 and 3 km from the seashore.

The land use varied from residential semi-urban areas with quite high population density (up to 3000 persons per km^2) to more rural areas with small scale plantation and home gardens. The crop types in the area are coconut plantation, paddy fields and small range irrigated chilli and other vegetables.

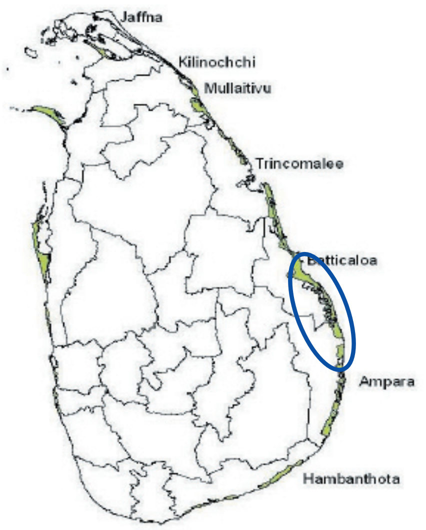


Figure 1. Extent and location of the sandy coastal aquifers in Sri Lanka. The ellipse shows the study area

Table 1. Sampled wells

Site	Sep. 2005	Nov. 2005
Kallady	38	37
Kaluthavalai	41	45
Oluvil	48	48
Total	127	130

Methodology

The well water samples were collected twice from the three different sites in September and November 2005, just before and after the onset of the rainy season. The sampling periods were September 13th to 16th and November 22nd to 26th.

In Table 1, is shown how many wells per site were sampled during the two field trips. Overall, there are 155 wells in the monitoring programme. A few of them are temporarily not accessible, the owners refused to allow sampling, or dried out. Because of these reasons only 127 samples were taken in September and 130 in November. From each well, duplicate samples were taken to have a backup for unforeseen events. One 250 ml bottle from each well was sent frozen to Italian Red Cross, Italy for chemical analysis. This was done primarily to ensure fast, reliable and international standard methods for the sample analysis (standard conductivity meter for electrical conductivity (EC), standard spectrophotometric (ICP-OES) method for cations: sodium, potassium, calcium, magnesium, manganese, aluminium, iron, and total phosphorous, and standard ion chromatographic method for anions: chloride, nitrate, and sulphate). The samples taken in September represent the end of the dry season and the samples in November represent the start of the wet season (Figure 3). In addition to the well samples, the lagoon to the west of the sites was sampled in four spots within 1km distance at the Kallady site.

In order to understand the effects of the tsunami, the chemical behaviour of flooded wells against the non-flooded wells was essential. Flooded wells were wells overtopped by the tsunami waves. The major cations (Na, K, Ca, Mg, Al, Fe, and Mn) and the anions (Cl^-, NO_3-, PO_4^{3-}, and SO_4^{3-}) were measured.

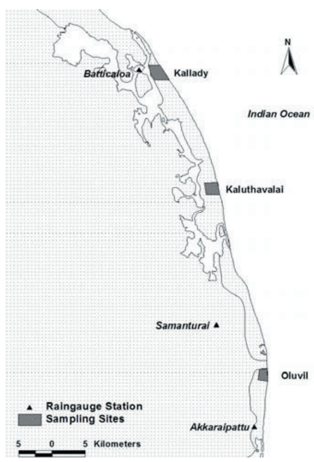


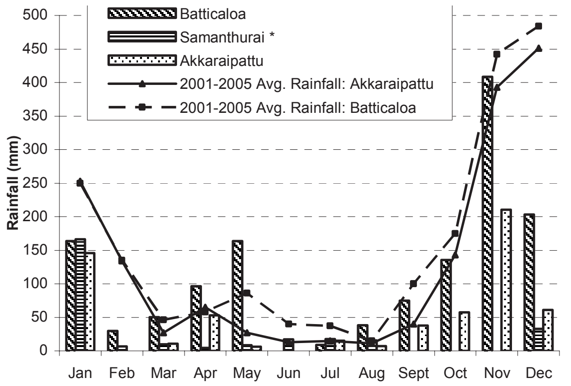
Figure 2. Study sites and the rainfall stations used in the study

Results and Discussion

Well characteristics

The characteristics of the wells monitored at the three sites are given in Table 2.

The majority of wells were open, dug, shallow, domestic wells, with an average depth of 3.4 m and an average diameter of 1.4 m. The other categories of wells consisted of deeper, smaller diameter tube wells, with average depth of 5.7 m. They were mainly used for irrigation and public water supply. About one third of the wells had a mechanized pumping system whereas the rest relied on some simple, manual lifting techniques, like a bucket or a pulley.



* Data not available for the months of September, October and November for Samanthurai station.

Source: Meteorological Dept, Sri Lanka

Figure 3. Monthly rainfall, 2005

Table 2. Well statistics

Well Characteristics	Kallady	Kaluthavalai	Oluvil	Total
Domestic wells[a]	40	33	53	126
Agro-wells	0	13	3	16
Public wells	6	2	7	15
Wells with mechanized pumps	16	19	13	48
Tube wells	0	11	3	14
Avg. depth of tube wells	-	5.9m	4.7m	5.7m
Avg. diameter of tube wells	-	0.2m	0.2m	0.2m
Open dug wells	43	38	53	134
Avg. depth of open dug wells	3.3m	3.9m	3.2m	3.4m
Avg diameter of open dug wells	1.7m	1.3m	1.1m	1.4m

[a] Some wells belonged to more than one category

Rainfall

Rainfall data from three stations in the study region was collected (Figure 2). As shown in Figure 3, the rainy season in the study region normally starts in October and ends in February. The lowest rainfall occurs in the period of June to September. The Batticaloa and Akkaraipattu stations receive a total precipitation of 47 mm and 22 mm, respectively, during three months (June, July, August) before the 1st sampling period whereas 620 mm and 306 mm falls during the three months (Sept., Oct., Nov.) between the two samplings.

Electrical conductivity

The average electrical conductivity (EC) of the wells decreases in all sites from September to November (Figure 4). The decrease is explained by the dilution and flushing of the pre-rainy season, tsunami-affected highly saline groundwater with incoming rainwater, which contains very low salinity (approx. 100 μS/cm). The decrease is most pronounced in the Kallady and Kaluthavalai sites, which corresponds with the sites mostly affected by the tsunami (Villholth et al., 2005). In Oluvil, which experienced least impact, the rainwater did relatively little to lower the salinity (Figure 4). This is explained by the fact that the dilution is most effective in the highly saline, flooded areas and flooded wells of which there were most in the two first sites. In Figure 5, it is seen that the decrease was more pronounced in flooded vs. non-flooded wells. The non-flooded wells, which were not inundated by the tsunami and most likely not salinized still experienced a freshening with the first rain. This can be explained by natural processes, like gradual drying out of these areas and evapotranspiration processes from the soil and directly from the shallow groundwater resulting in a gradual built-up of salts in the soil and groundwater over the dry season. This salinity is then diluted with the first rain.

The wells, and the groundwater, appear to still be affected by the tsunami in November, as the salinity levels in the flooded wells continue to be higher than in the non-flooded wells (Figure 5). Though flooded wells generally were

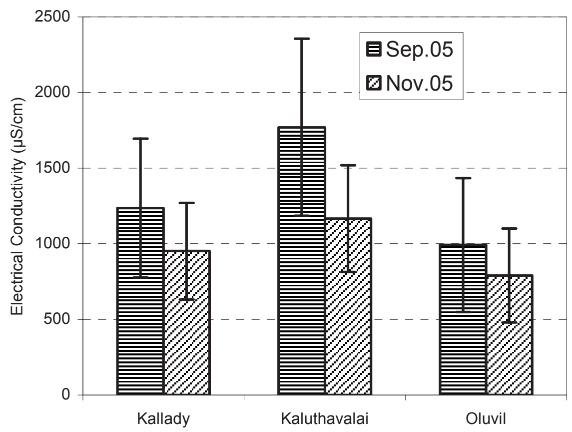


Figure 4. Electrical conductivity in wells in the three field sites in September and November

closer to the coast than non-flooded wells and these wells potentially exhibit somewhat higher salinity, it is anticipated that the flooded wells in general had not recovered to pre-tsunami-levels.

In general, a salinity level in drinking water of <500 µS/cm is considered good quality. For levels up to 1000 or 2000 µS/cm, the salty taste becomes increasingly objectionable to most people. Using a potability criterion for salinity of 1000 µS/cm, 28% of the wells still contained too high salinity after the first rain, i.e. 11 months after the tsunami.

For a better understanding of the spatial variability of the salinity levels and changes therein, see Map 1.

The general pattern observed for salinity, i.e. a decrease in concentrations within all sites with the rain, a relatively higher decrease in Kallady and Kaluthavalai and a higher decrease in the flooded vs. non-flooded areas, were, with a few exceptions, also observed for the parameters sodium, chloride, total hardness and sulphate (for overall figures, see Table 3). This indicates that the major ions, like sodium, chloride, calcium, magnesium and sulphate all were impacted by and partly derived from the tsunami water flooding the areas and infiltrating into the groundwater.

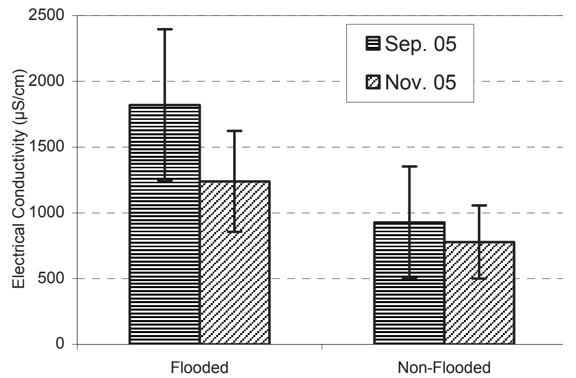
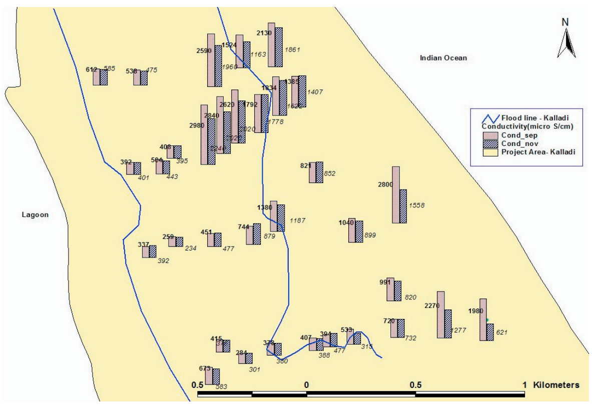


Figure 5. Electrical conductivity in flooded and non-flooded wells from all sites



Map 1. Changes in electrical conductivity in the Kallady site

Nitrate

The well water nitrate concentration of all three field sites increased from September to November (Figure 6). One reason for the increase could be the leaching of nitrate from the soil and unsaturated zone into ground-water after rainfall. Oluvil, as the location with the most agricultural practice, had the highest nitrate concentration in November, as well

Table 3. Results of well and lagoon analysis

	Wells				Lagoon	
	Sept-05		Nov-05		Sept-05	Nov-05
	Flood-ed	Non-flooded	Flood-ed	Non-flooded		
pH	7.79		7.67		7.7	7.62
	7.82	7.77	7.70	7.65		
EC µS/cm	1251		948		28425	1498
	1821	927	1240	777		
Na mg/l	54.3		42.9		1847.5	86.8
	85.4	36.7	60.9	32.4		
Cl mg/l	248		180		11125	438
	410	156	278	123		
Hard-ness mm0l/l	2.74		2.48		33.73	1.84
	3.26	2.45	2.64	2.39		
SO4 mg/l	61.2		59.8		1700.0	65.5
	88.7	45.6	76.7	49.9		
NO3 mg/l	7.74		17.0		0	2.00
	7.28	8.00	11.1	20.4	<1[a]	
PO4 mg/l	0.54		0.77		0	0.08
	0.11	0.78	0.44	0.97	<0.2	
K mg/l	11.9		11.1		118.25	12.00
	14.6	10.3	12.1	10.5		
Mn µg/l	8.91		57.3		0.50	71.50
	5.00	11.1	101.4	31.5		
Al mg/l	0.10		0.06		0	7.39
	0.20	0.04	0.07	0.06	<0.05	
Fe µg/l	30.6		109.4		0	4296.5
	7.4	43.9	130.2	97.2	<20	

[a] Detection limit

as the highest increase (Figure 6). This could be explained by augmented fertilizer application after the sowings just before or at the beginning of the rainy season.

The concentration limit for short-term exposure of nitrate is 50 mg/l (WHO, 2004). In Table 4 is exhibited the percentage of wells exceeding the WHO limit. The high percentage in Kallady for September as well as November could be explained by the fact that the nitrate concentration in groundwater here is mainly caused by poor sanitation rather than agriculture and fertilizer use. Kallady was the most residential area of the three, whereas Kaluthavalai and Oluvil had larger agricultural areas.

Most communities have either individual pit latrines, septic tanks or no sanitation. This source of nitrate is likely more continuous over the year as it leaches with the wastewater.

The higher increase in nitrate concentration in non-flooded wells, as compared to flooded wells, (Figure 7) is explainable by the fact that the agricultural areas are mainly located in the non-flooded parts of the three locations, mainly further inland or closer to the lagoon and/or irrigation tanks.

The small scale spatial variability of nitrate concentrations within the sites is large, see Map 2.

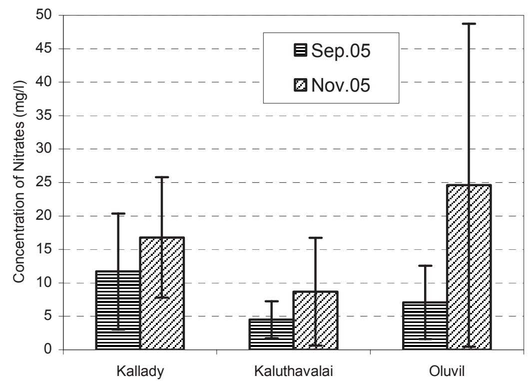


Figure 6. Nitrate concentrations in wells in the three field sites in September and November

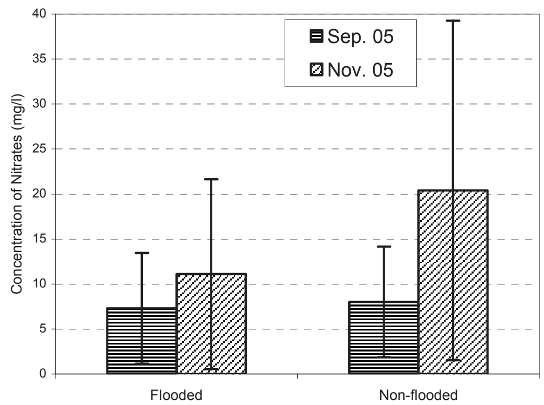


Figure 7. Nitrate concentration in flooded and non-flooded wells from all sites

Phosphate

Phosphorus, monitored in the form of phosphate (PO_4^{3-}), has the same overall major sources as nitrate, namely fertilization and poor sanitation facilities.

The pattern of phosphate concentration in the wells likewise shows an increase with the onset of the rainy season (Figure 8). However, the relative levels and changes are not comparable to the nitrate pattern (Figure 6) and the nitrate and phosphate concentrations were not significantly correlated statistically

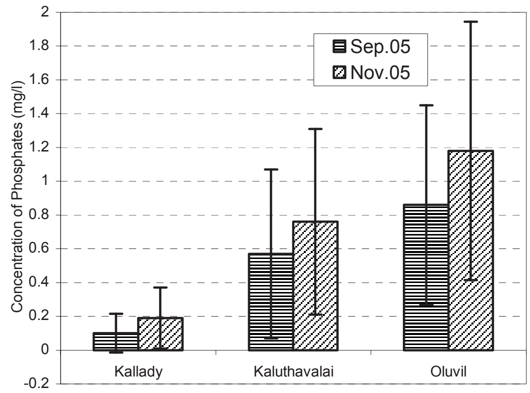
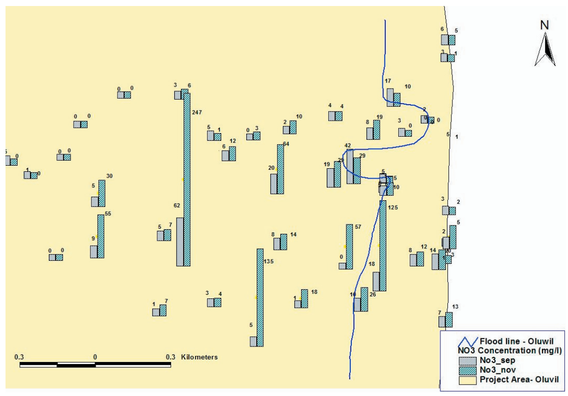


Figure 8. Phosphate concentrations in wells in the three field sites in September and November

Table 4. Percentage of wells with nitrate concentration above WHO short-term exposure drinking water guideline level for nitrate (50 mg/l)

Site	Sep. 2005	Nov. 2005
Kallady	4.8%	7.1%
Kaluthavalai	0.0%	6.0%
Oluvil	1.8%	12.5%
Total	2.0%	8.8%



Map 2. Changes in nitrate concentration in the Oluvil site

(data not shown). The levels of phosphate before and after the rains are higher in the agricultural areas Kaluthavalai and Oluvil compared to Kallady, indicating that the major source of phosphate is fertilizer use. However, the levels before the onset of the rain in these areas as well as in the non-flooded (agricultural) areas (Figure 9) are relatively higher for phosphate than nitrate. This could be explained by the fact that nitrate is being partly removed by denitrification in the paddy fields during the dry season where fields are irrigated (Bouman et al., 2002), whereas phosphate may be leached due to a saturation and exceedance of the sorption capacity of these sandy soils, giving rise to high levels of phosphate in groundwater all year round in the agricultural areas. This however, needs further investigation. Sanitation seems to be less of an important source for phosphate leaching maybe because of less input (compared to agriculture) and hence no exceedance of sorption capacity in the Kallady site.

Micro-elements

Iron, manganese, potassium and aluminium, the latter having less measurements above the detection limit, were the micro-elements monitored. They can basically be divided into two groups with different response to the rainy season. Iron and manganese showed a unilateral increase in concentration with the rain. This is similar to the nitrate pattern, showing that a leaching of elements from the soil and unsaturated zone took place. This indicates that these elements were of a geological source. Whether this source was influenced by the tsunami is uncertain.

However, the increase in concentration was larger in the flooded areas than the non-flooded areas (Table 3), indicating that an excess of these constituents were present due to the tsunami prior to the rain.

Potassium and aluminum show a mix between the leaching pattern of the first micro-element group and the fertilizer compounds nitrate and phosphate and the dilution pattern of the major salinity ions. In the agricultural areas (Oluvil and the non-flooded areas), potassium and aluminum increase (leaching pattern), whereas in the Kalldy, Kalluthavalai and flooded areas there is a decrease in concentration (dilution pattern). It indicates that these elements are derived from both agricultural sources as well as were components of the tsunami water.

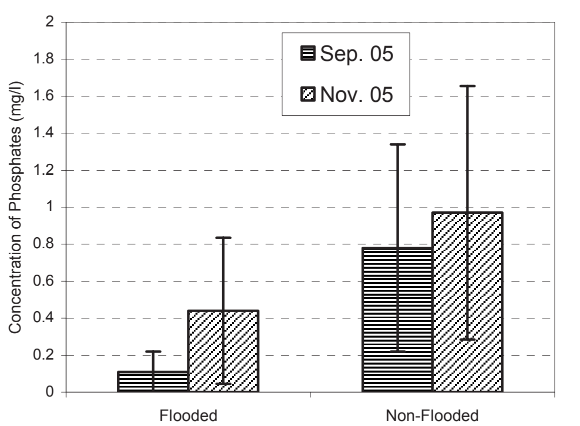


Figure 9. Phosphate concentration in flooded and non-flooded wells from all sites

Lagoon

It is interesting to compare the levels and changes of chemical characteristics and concentrations of the lagoon with the groundwater monitored in the wells. In Table 3, the data are given.

It is seen that generally the dilution pattern of the major salinity ions, sodium, chloride, calcium, magnesium and sulphate, reflected also in the EC and total hardness values, observed in the wells also apply to the lagoon. Similarly, the leaching pattern of the fertilizer/sanitation derived compounds, like nitrate and phosphate, and the geological compounds iron and manganese, is also apparent in the lagoon.

These results indicate that the lagoon water is influenced by the same or similar post-tsunami processes. One important one is the flushing of and replacement of the tsunami-impacted water by less saline but more 'soil-influenced' water. This new water hence comes from rainwater falling directly on the lagoon surface as well as runoff water from the hinterlands and smaller and larger catchments discharging into the lagoon. This water is not influenced by the tsunami, but is imprinted with chemicals from its surface and subsurface paths through the systems. Because these catchments are also agricultural, it is not surprising that levels of nitrate and phosphate increase, though not very much, with the first flush of rain after the rainy season.

The dilution effect in the lagoon is quite pronounced, reducing the salinity from 28,425 before the rains to 1498 μS/cm after the rains, compared to a reduction from 1251 to 948 μS/cm in the wells. This is because the rain diluting the lagoon originates from catchment areas much larger than the lagoon area (unlike the groundwater, which is only being diluted by the water falling on the land areas above). The leaching effect, on the contrary is much less in the lagoon, increasing nitrate from 0 to 2 mg/l and phosphate from 0 to 0.08 mg/l, compared to 7.74 to 17.0 and 0.54 to 0.77 mg/l for nitrate and phosphate, respectively, for the groundwater. This relatively less pronounced leaching effect in the lagoon is due to the fact that much of the discharge to the lagoon is derived from surface water runoff that do not bear the same degree of imprint from the soil leaching as the discharge derived from groundwater.

Conclusions

The groundwater in the three study areas were all, but to various degree (Kaluthavalai> Kallday>>Oluvil), impacted by the tsunami, most notable through the increase in salinity. The salinity levels at nine months after the tsunami (Sep. 2005) were still higher in the flooded wells (1820 μS/cm) by a factor of two compared to the non-flooded wells (927 μS/cm), which was taken as an indication that the groundwater had not yet recovered to pre-tsunami conditions.

The first rains that fell after the first dry season after the tsunami (up to Nov. 2005) improved the well water quality in terms of salinity, decreasing the average well water salinity below 1000 μS/cm, which is a rough standard for potable water. However, the flooded wells remained slightly more saline (1240 μS/cm) than the non-flooded wells (780 μS/cm).

Though improving the well water quality in terms of salinity the onset of the rainy season implied a deterioration of the well water quality in terms of nitrate and phosphate, basically derived from agriculture and poor sanitation. Average nitrate concentrations were doubled from 7.74 mg/l to 17.0 mg/l, while phosphate increased from 0.54 to 0.77 mg/l. The first rain events after the dry season gave rise to a flush of nutrients and geo-genic chemicals and potentially also pathogens, though the latter needs further investigation.

The two opposing mechanisms, the dilution of salinity and the leaching of nutrients and other soil-derived microelements occur simultaneously and are also taking place in the lagoon. The effect of the dilution is more pronounced in the lagoon whereas the leaching is less apparent in the lagoon as compared to the groundwater.

Acknowledgement

Mr. G. Bolzoni and his team from Italian Red Cross is acknowledged for the free and very efficient support to the chemical analysis.

References

ADB, Japan Bank for International Cooperation and WB, 2005. Sri Lanka – 2005 *Post-Tsunami Recovery Program. Preliminary Damage and Needs Assessment. Colombo, Sri Lanka.* Jan. 10-28, 2005. http://www.adb.org/Tsunami/sri-lanka-assessment.asp

B.A.M. Bouman, A.R. Castañeda, S.I. Bhuiyan, 2002. *Nitrate and pesticide contamination of groundwater under rice-based cropping systems: past and current evidence from the Philippines.* Agriculture, Ecosystems and Environment, 92, pp.185-199.

Panabokke, C.R. and Perera, A.P.G.R.L., 2005. *Groundwater Resources of Sri Lanka.* Paper preseted at the NSF workshop: “Impact of Tsunami on Groundwater, Soils and Vegetation in Coastal regions of Sri Lanka”, Kandy, Sep.19, 2005.

The National Atlas of Sri Lanka, 1988. Survey Department of Sri Lanka.

Villholth, K.G., P.H. Amerasinghe, P. Jeyakumar, C.R. Panabokke, O. Woolley, M.D. Weerasinghe, N. Amalraj, S. Prathepaan, N. Bürgi, D.M.D.S. Lionelrathne, N. G. Indrajith, S.R.K. Pathirana, 2005. *Tsunami Impacts on Shallow Groundwater and Associated Water Supply on the East Coast of Sri Lanka.* Colombo, Sri Lanka. International Water Management Institute (IWMI). ISBN 92-9090-622-7. 68 pp.

WHO, 2004. Guidelines for Drinking Water Quality - Third Edition. World Health Organization, Geneva. http://www.who.int/water _sanitation_health/dwq/gdwq3/en

Contact addresses

Karen Villholth,
Senior Researcher, IWMI, International Water Management Institute, 127, SunilMawatha, Battaramulla, Sri Lanka.

Sanjeewa Manamperi,
Water Resources Engineer, IWMI, International Water Management Institute, 127, SunilMawatha, Battaramulla, Sri Lanka.

Nico Buergi,
M. Sc. Student, ETH, Zürich, Switzerland.