Vulnerability Assessment for Shallow Aquifers Using Chemical Quality of Groundwater: A Case Study from Thirunelvely and Kondavil in Jaffna District

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Vulnerability Assessment for Shallow Aquifers Using Chemical Quality of Groundwater: A Case Study from Thirunelvely and Kondavil in Jaffna District

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ABSTRACT. *Analysis of chemical parameters of drinking water was carried out to determine the level of pollution in forty wells at monthly intervals from March 2007 to February 2008 along with three major water supply wells at Thirunelvely and Kondavil areas in Jaffna district. The total iron, phosphate, manganese, arsenic and pH of the water did not reach harmful levels. High level of nitrate–N, low level of fluoride and elevated level of alkalinity were identified as major hazards in most of the wells including the water supply wells. Wells were categorized into three aquifer vulnerability zones based on the concentration of nitrate-N and preventive and protective measures were discussed. A total of 10 wells from Thirunelvely and 16 wells from Kondavil were grouped into AVA1 class. AVA2 and AVA3 classes consisted of 9 and 5 wells, respectively. The best management practices with strict control of chemical fertilizer application, proper maintenance of wells and provision of proper distance between wells and sewage pits are recommended to rectify the contamination of nitrate-N.*

INTRODUCTION

The global water consumption is doubling every 20 years and is more than twice the rate of population increase. By 2030, more than half of the world population will face a shortage of water (Winblad and Hebert, 2004). Groundwater constitutes 97% of global freshwater and is an important source of drinking water in many regions of the world. The estimated groundwater potential of Sri Lanka is 780,000 hectare meters per annum (Panabokke and Perera, 2005). Ileperuma (2000) stated that less than 25% of all households in Sri Lanka have access to pipe borne water. Lack of health education among the rural population further aggravates water pollution problems. About 80% or the majority of the population in Sri Lanka use small, unprotected wells to obtain drinking water.

Among the different types of aquifers in Sri Lanka, the limestone aquifer present in Jaffna peninsula, is the richest sources of ground water (Panabokke and Perera, 2005). Pollution of groundwater by nitrate is receiving attention in the peninsula (Maheswaran and Mahalingam, 1983; Dissanayake and Weerasooriya, 1985; Nagarajah *et al*., 1988; Maheswaran, 2003). Navaratnarajah (1994) reported that rapid and over extraction of

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groundwater by mechanical and electrical motors increase sea water increment into fresh water lens that lead to an increase in salinity.

Nagarajah *et al*. (1988) showed that about 65% of wells were very high in salinity among the 65 tested wells in the Peninsula but not clustered into vulnerability areas. According to Amarasinghe and De Silva (2006) the vulnerability areas were identified in Vavuniya district and it could be used for better management and conservation of the groundwater in the study area.

The protection and management of groundwater are emerging as a great public concern in the Peninsula. Therefore, this study was focused on investigating groundwater quality in terms of chemical parameters in shallow aquifers under different usages in two selected areas in order to cluster the vulnerability zones.

MATERIALS AND METHODS

Background of the study area

Jaffna district is predominantly an agricultural area and about 65,000 families and 30,000 farm laborers are involved in agriculture and livestock production in the district (Statistical information, 2006). Agriculture is the main source of livelihood for 65% of the population and about 34% of the land is cultivated intensively and commercially with high value cash crops. There are over 100,000 dug wells in the peninsula and about 19,261 agro wells, 2,433 ditches and 631 small ponds are being used for agriculture purpose (Statistical information, 2006). The Valikamam East Divisional Secretariat showed the highest usage of groundwater *viz*. 39,000 Million Liters (ML) in the dry season and 26,000 ML in the wet season, with the total usage in this area exceeding 65,000 ML (Punthakey and Gamage, 2006). Figure 1 shows the location of the study area.

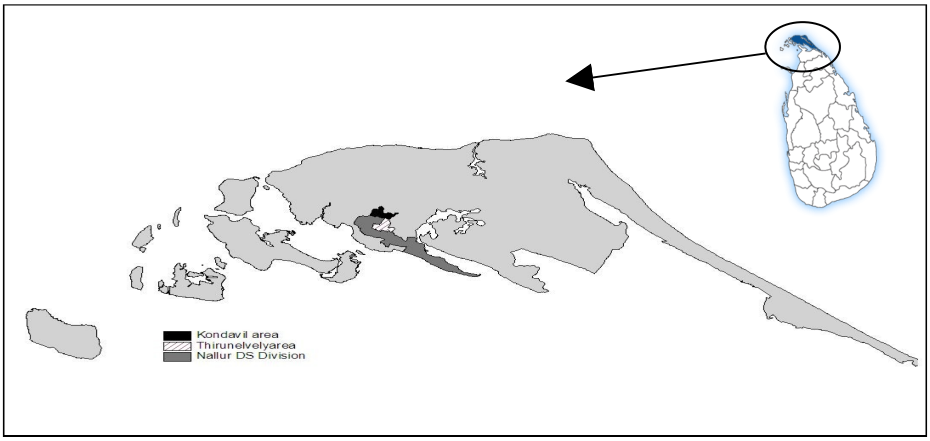

Figure 1. Location of the study area (Not according to scale)

Selection of wells

Kondavil and Thirunelvely areas were selected for the study because the Municipal area in Jaffna is supplied with drinking water pumped from wells located in Kondavil and Thirunelvely, about three miles from Jaffna town. Thirunelvely old, new and Kondavil water supply wells were included in the study. Twenty wells were selected randomly from each study area. The Survey department map of each division was used to locate the wells. These wells were spatially randomly distributed to represent the entire study area. Most of the farm wells are not properly maintained, have improper lining and without extended wall above the soil surface. All randomly selected wells are under multiple usages such as public wells for drinking purpose (10 wells), domestic wells (4 wells), domestic and home gardening (12 wells) and farm wells (14 wells). Though the wells used for agriculture are mentioned as farm wells, they are also used for drinking purposes.

Collection of water sample and chemical analysis

Samples were drawn from the wells approximately at the level of 20 cm depth below the free water surface by using a water sampler, from March 2007 to February 2008 at monthly intervals. Water samples were analyzed for pH, electrical conductivity (EC), chloride, nitrate-N, total alkalinity, total hardness, iron, phosphate, fluoride, manganese and arsenic based on Sri Lanka standard 614: part 1 (1983). The concentration of nitrate-N, phosphate, fluoride, manganese and iron were determined calorimetrically by Spectrphotometer. pH, EC and arsenic were measured by respective meters and arsenator. Mohr's titration, acid-base titration, Ethylene Diamine Tetra Acetic acid (EDTA) titrations were used to estimate chloride, total alkalinity and total hardness, respectively based on the guide line of Sri Lanka Standard 614: part 1 (1983).

RESULTS AND DISCUSSION

Chemical parameters in water supply wells

Thirunelvely old, new and Kondavil water supply wells did not have detectable quality problems. All the measured parameters were well below the safe level except nitrate-N. The average nitrate-N concentration was 9 mg/l, which was closer to the WHO recommended level of 10 mg/l. However, values varied temporally from 6.8 to 15.3 mg/l. The highest value was observed during October and November in all three wells. This may be due to the agricultural activities in the surrounding area.

Chemical parameters in randomly selected wells

pH

The pH values of water samples were within the range of 6.7 to 7.7 indicating a slight alkalinity. Puvaneswaran (1986) reported that pH of the water in Jaffna Peninsula region is greater than 7.0. However, Nagarajah *et al*. (1988) reported that the pH values of well water in the Peninsula were around 7.0. Ileperuma (2000) stated that certain locations such as Anuradhapura and Maha Illuppallama had acid rainfall during the months of November to

December due to the North East monsoon carrying acid precursors from the coal power plants in India. This phenomenon also could influence the pH of the groundwater in Jaffna. pH did not differ significantly with the usage of the wells. According to SLS guideline, pH of drinking water could vary from 6.5 to 9.0. Thus, groundwater in investigated area could be considered as acceptable in this respect.

Electrical conductivity (EC)

The average EC values ranged from 0.56 to 4.0 dS/m (Figure 2). Based on Sri Lankan drinking water standard, 95% of the wells were within the limits of SLS ‘desirable to permissible’. Few domestic wells had relatively high EC values of 4.0 dS/m which was above the Sri Lankan standards for drinking water of 3.5 dS/m. It is an indication of the presence of abundant dissolved ionic species. It could be due to the contribution from weathering of basic rocks. The temporal behavior of EC shows that there was an increase immediately after heavy rainfall in October and November (Figure 2). This may be due to the leaching of salts from nearest fields. Similar seasonal variation of EC was reported by Pathmarajah (2002).

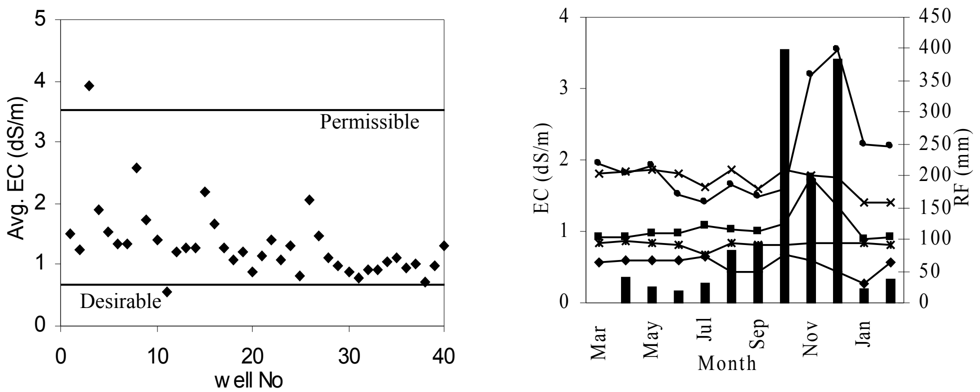

Figure 2. Average EC of groundwater and its temporal variation in some selected wells

Chloride

The chloride concentrations of water samples of all wells were between 32 and 1100 mg/l and the average values are shown in Figure 3. All values of measured wells were below the permissible level of SLS. The high chloride concentration of 1100 mg/l was observed in a public well due to the effect of the lagoon. The concentration of chloride was 252 mg/l and 112 mg/l at Kondavil and Thirunelvely, respectively (Maheswaran and Mahalingam, 1983). The temporal variation of chloride showed slightly high concentration that correlated with most of the dry periods due to evaporation and over extraction. High chloride concentration in the wet season may be due to washing out of salts by rainfall (Figure 3). Although there is no health hazard, people are not willing to drink this water due to taste and cooking problems.

Desirable

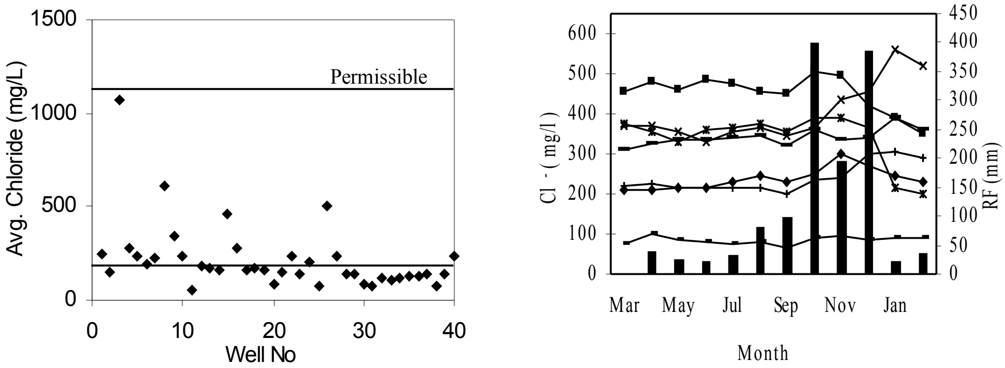

Figure 3. Average chloride concentration of groundwater and its temporal variation in some selected wells

Total hardness

The value of hardness varied from 150 to 600 mg/l and 62.5% of wells studied hardness above SLS desirable level of 250 mg/l to SLS permissible level of 600 mg/l (Figure 4). Most probably the high value of hardness indicates the richness in calcium and magnesium. High amounts of calcium and phosphate in the drinking water may accelerate stone formation in the bladder (Sivarajah, 2003). In addition to heath effects, calcium may precipitate as calcium carbonate within the plumbing and clog pipes. Detergents and soaps do not readily dissolve in hard water. Calcium and magnesium are primarily found in groundwater due to dissolving of limestone and substantial contribution from weathering of rocks.

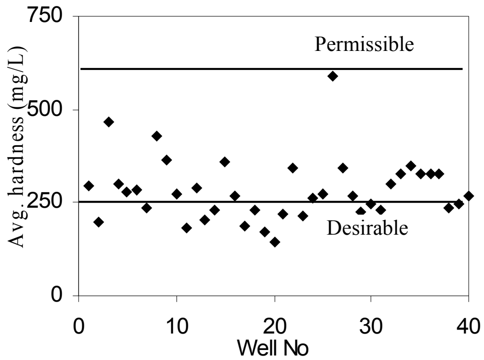

Figure 4. Average hardness of groundwater

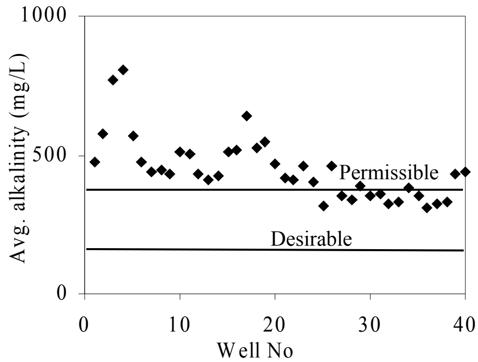

Figure 5. Average alkalinity of groundwater

Total alkalinity

The total alkalinity varied from 300 to 810 mg/l and 68% of the wells were above the recommended SLS permissible level of 400 mg/l (Figure 5). The temporal variation shows high value of alkalinity during rainy season that indicates leaching of ions from surrounding fields to the groundwater. Compared to public wells, farm wells showed low alkalinity. Nearly 70% of the wells cannot be recommended for drinking purposes.

Nitrate–N

The average nitrate-N concentration is shown in Figure 6 and the temporal fluctuation of nitrate–N with rainfall in two different usages of well is shown in Figure 7. Groundwater within the intensively cultivated area had nitrate-N concentrations within the range of 10-15 mg/l compared to 2 mg/l within the non-cultivated domestic area. The buildup of nitrate is significant in agricultural fields and it had been estimated as 1 - 2 mg/l/ year in Kalpittiya (Kuruppuarachchi and Fernando, 1999).

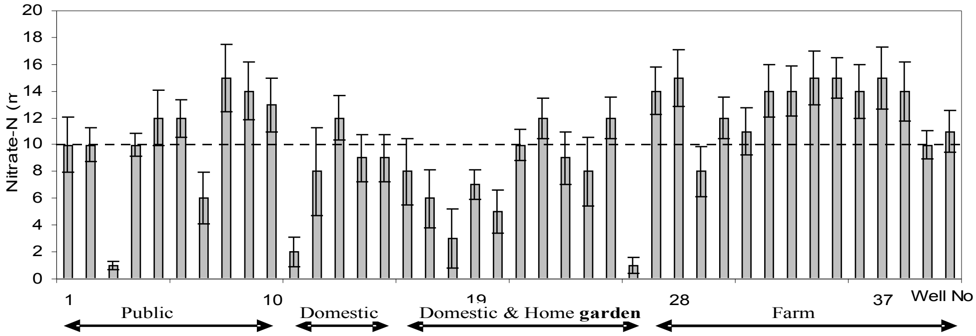

Figure 6. Average concentration of NO_3- N with deviation

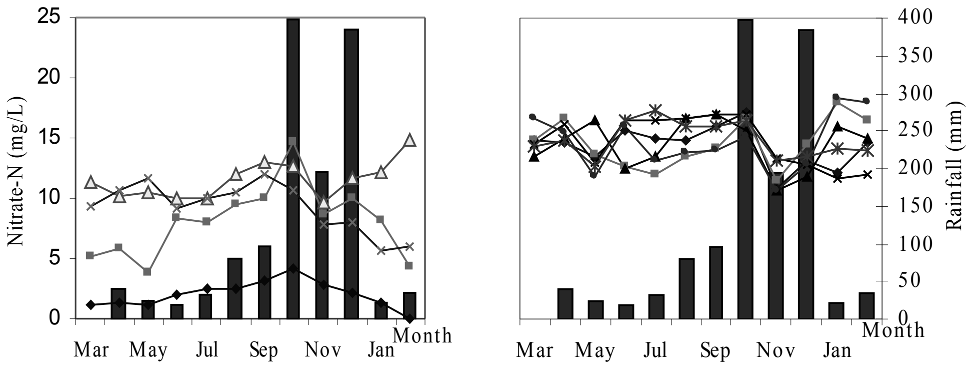

Figure 7. Temporal fluctuation of NO_3-N in domestic and selected farm wells

After the onset of rainfall in October, the concentration of nitrate was reduced in November due to dilution and it again increased during December in most of the wells following heavy rainfall (Figure 7). This increment is most probably due to leaching from the adjoining cultivated fields with high application of fertilizers shown through a survey conducted among farmers and by direct observations. During rainy season, the soil will be wetted enough, upto the water table facilitating the leaching of nitrate. Nitrate ions do not come into contact with soil surfaces and move freely through the soil environment (Allred, 2007). Hence, the mobility of the nitrate iron in the soil environment is high during the wet season and nitrate leaching is also high in wet season. In domestic land use, because of high recharge and low pumping rate of the wells, the concentration of nitrate was reduced during the rainy season. The statistical analysis showed that there was no significant difference between domestic (7.70 mg/l ^{c}) and domestic wells with home gardening (7.76 mg/l ^{c}). But these two usages of wells were significantly differed from farm (12.44 mg/l ^{a}) and public wells (10.63 mg/l ^{b}). At the same time, farm wells and public wells were significantly different from each other.

The nitrate-N content was higher than the permissible level of WHO (10 mg/l) for drinking water in most of the public wells and farm wells making it unsuitable for human consumption. This result was supported by Nagarajah *et al*. (1988) and Maheswaran (2003) in Jaffna and Kuruppuarachchi *et al.* (1990) and Vaheesar (2001) at various places in Sri Lanka. The public wells showed higher levels of nitrate-N. This is probably due to the wells in densely populated areas, being closely situated to the soakage pits of toilets.

Higher nitrate concentration of groundwater is a common occurrence in many areas of the world and has become a major problem in some shallow aquifers (Li *et al*., 2007). Nitrate is variously associated with diseases like methaemoglobinemia, gastric cancer, thinning of blood vessels, aggressive behavior and hypertension (Sivarajah, 2003). None of these have been conclusively established from scientific studies in Sri Lanka, although some suggestions have been made that the high nitrate in drinking water in Jaffna peninsula is responsible for abnormally high incidence of gastric cancer (Ileperuma, 2000; Sivarajah, 2003).

Fluoride

The concentration of fluoride changed from 0.0 to 0.56 mg/l. Results revealed that 98% of the wells including water supply wells had water with less than 0.5 mg/l which leads to deficiency of fluoride. The recommended level of fluoride in drinking water is 0.5 to 1.5 mg/l (Sri Lanka standard 614: part 1, 1983). Since fluoride enters the body mainly through drinking water, people in these areas may have the risk of dental caries.

Other parameters

The values of arsenic and manganese were not determined. There was no possibility of getting these ions into the groundwater because the effluents from the industries do not discharge into the ground (Maheswaran, 2003). The iron and phosphate concentrations were relatively low in all samples and did not reach harmful levels.

Delineation of aquifer vulnerability zones

The limestone aquifer of the Jaffna Peninsula is not only highly vulnerable to pollution but also subject to land use activities likely to generate pollutants (Lawrence *et al*., 1988). Aquifer vulnerability is the probability of groundwater pollution in the event of a pollutant released at the ground surface. Out of measured parameters, nitrate-N significantly varied with different usages of wells. Hence, nitrate-N was used to delineate the vulnerability zones in a similar study (Amarasinghe and De Silva, 2006).
Aquifer vulnerability area (AVA1)

All the farm wells (except one well), most of the public wells and some of the domestic home garden wells had greater than 10 mg/l in nitrate-N concentration throughout the year and hence classified as AVA1 class. Nearly 65% of the wells have been classified as AVA1 class. There were 10 wells categorized from Thirunelvely and 16 wells from Kondavil under AVA1. Most of the public wells were located in highly populated areas and closer to the pit latrines and some were closer to agricultural fields. Well 13 was in close proximity to livestock raring area. There was no correlation between the actual depths of wells to average nitrate-N which means deeper layers of nearly 10 m are also highly contaminated by nitrate–N compared to shallow depths (Figure 8). Therefore, protection measures such as appropriate technologies for agriculture, proper sewage disposal system and proper distance to soakage pits are imperative to reduce the nitrate pollution in AVA 1 class. The recommended solutions are to promote the use of bio fertilizers and slow releasing fertilizers at the recommended rate. It may be necessary to impose strict guidelines on the use of chemical fertilizers by farmers, especially in AVA1 class.

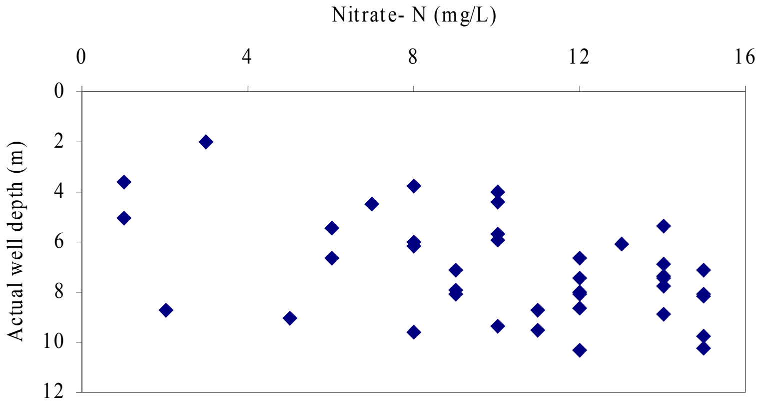

Figure 8. Relationship between actual well depths to average NO_3-N concentration

Aquifer vulnerability area (AVA2)

The wells with concentration of nitrate-N at 8 - 10 mg/l were classified as AVA2. Accordingly, 9 wells (22.5%) were classified into the class of AVA2. Most of the wells which were used for home gardening with domestic use were included in this class. Hence, application of organic matter or organic farming approach or potting culture could be promoted in this area as a protective measure. The proper maintenance of wells such as cement lining of wall, extension of wall above the soil surface to prevent the inflow of surface runoff, removal of vegetation around the well and temporary covering to prevent bird excreta are important.

Aquifer vulnerability area (AVA3)

Five wells (12.5%) were classified into AVA3 class due to presence of less than 8 mg/l of nitrate-N. Thirunelvely has four wells, of which one well has to be prevented for drinking because of high amount of chloride. To maintain and minimize the nitrate pollution in AVA3 class, "best management practices" are recommended. These practices include soil conservation, balanced fertilization, more frequent N-top dressings at smaller rates during rainy season and use of slow release fertilizers. If proper maintenance is practiced in AVA 3 class zones, wells could be used continuously for drinking purposes without health hazards.

CONCLUSIONS AND RECOMMENDATIONS

Continuous monitoring and quality assessment of well water are necessary to avoid quality hazards to the people. High concentrations of nitrate–N, low levels of fluoride, and elevated levels of alkalinity were the identified problems in the study area. Research is urgently required to investigate chemical pollution, the buildup of nitrate especially in more densely populated and intensive agricultural areas belonging to AVA1 class. Among the 40 wells studied, 26 wells were grouped in AVA1 and it is necessary to impose strict control in use of best management practices. Water supply wells and other 9 wells were grouped in AVA2 class. The proper separation distances should be maintained between wells and any other contamination sources**.** Proper well construction, cement lining and maintenance are necessary. Proper maintenance of wells in AVA 3 class zones is essential to use continuously for drinking purpose without health hazards.

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