Sources of extent of groundwater pollution in shallow aquifer: A case study from Jaffna District in Sri Lanka

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Sources and Extent of groundwater pollution in shallow aquifer: A case study from Jaffna district, Sri Lanka

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Abstract:

Water is expected to be one of the most critical natural resources in the twenty-first century. Twenty six countries including Sri Lanka are now classified as water deficient, and nearly 230 million people are affected with water shortage. And the prediction is that by 2025, one quarter of the world's population will face severe water shortages. Groundwater is the only water source available in Jaffna Peninsula for all the requirements with seasonal rainfall. Two villages namely Thirunelvely and Kondavil from Jaffna district were selected for this study purpose because the areas are receiving much attention due its environmental uniqueness and its significant groundwater resources, which are being utilized for domestic, agriculture and specially used for Jaffna municipal water supply. Pollution comes from both natural and anthropogenic sources. The possible contamination causes such as monthly average abstraction rate in dry months, actual well depth above mean sea level, proximately to latrines, agricultural areas, lagoon and ponds, municipal solid waste site animal raring houses were considered. Water samples were collected at monthly interval and analyzed for electrical conductivity (EC), chloride, nitrate- N, and total hardness based on Sri Lanka standard. Seasonal variation of measured chemical parameters was analyzed statically. A point interpolation was done to interpret the extent of contamination for EC, chloride, nitrate-N and total hardness using Arc view 3.2. The survey conducted in the study areas reveled that the distance between shallow wells of 12.5% and latrine was less than 10 m when considering contamination source. Meanwhile 40% of wells are constructed at a distance between 10 to 15 m. The recommended distance for the red yellow latasol of Jaffna Peninsula is 15 m however 52.5% of wells did not satisfy the requirements. Out of tested wells 32.5% of shallow wells are situated between 5 m or within the agricultural land. Further 17.5% wells are situated within 100 m. Very few wells (5%) were found 100 m away in the lagoon where as (5%) were found 100 m from ponds. EC values in water from 2.5% of wells had high values which were above the permissible level of 3500 μS/cm and 92.5% of the wells were within the limits of desirable to permissible level. Out of selected wells, 35 % of wells were above chloride desirable level of 200 mg/l. In total hardness, 57.5% of wells had above desirable level of 250 mg/L. Based on the nitrate-N concentration 60 % of the wells were above the recommended level of 10 mg/L. Management of groundwater source and protecting its quality from contamination source is therefore essential to preserve existing groundwater in the Peninsula.

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Sources and Extent of Groundwater Pollution in Shallow Aquifer: A Case Study from Jaffna District, Sri Lanka

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Abstract

Twenty six countries including Sri Lanka are now classified as water deficient, and nearly 230 million people are affected with water shortage. And the prediction is that by 2025, one quarter of the world's population will face severe water shortages. Groundwater is the only water source available in Jaffna Peninsula for all the requirements with seasonal rainfall. Two villages namely Thirunelvely and Kondavil from Jaffna district were selected for this study because the areas are receiving much attention due to its significant groundwater resources, which are being utilized for domestic, agriculture and specially used for Jaffna municipal water supply. The possible contamination causes such as abstraction rate, actual well depth, proximately to latrines, agricultural areas, lagoon and ponds, and animal raring houses were considered. Water samples were collected at monthly interval and analyzed for electrical conductivity (EC), chloride, nitrate- N, and total hardness. A point interpolation was done to interpret the extent of contamination for EC, chloride, nitrate-N and total hardness using Arc view 3.2. The survey conducted in the study areas regarding proximately to pit latrines revealed that 52.5% of wells did not satisfy the requirements even though the recommended distance is 15 m. Out of tested wells 32.5% of shallow wells are situated between 5 m or within the agricultural land. Further 17.5% wells are situated within 100 m from agricultural land. Very few wells (2.5%) were found within 500 m from the lagoon where as (2.5%) were found 100 m from the ponds. There was no correlation between actual depths of the wells to contamination sources and correlation was observed between actual abstraction rate to chloride concentration and EC. The distance from agricultural areas, livestock raring areas and pit latrines to contamination source especially nitrate-N were observed. All the contamination sources are influenced by wet season. Hence, management of groundwater source and protecting its quality from contamination source is therefore essential to preserve existing potential groundwater aquifers in the Peninsula.

Introduction

Water is expected to be one of the most critical natural resources in the twenty-first century. Twenty six countries including Sri Lanka are now classified as water deficient, and nearly 230 million people are affected with water shortage. And the prediction is that by 2025, one quarter of the world's population will face severe water shortages (Seckler *et al.*, 1999). Groundwater constitutes 97% of global freshwater and is an important source of drinking water in many regions of the world. The groundwater is a dynamic, replenishable and dependable earth resource which acts as a viable substitute to the surface water supply in many countries (Sharma *et al.*, 2007). As the standard of living of a large section of the world population continues to increase, the strategic importance of fresh water resources also rises. The discriminate extraction of groundwater is developing into drought conditions in several regions of the country which can be controlled by implementing schemes of effective management of groundwater resource. Even in those countries where fresh water is currently available over exploitation is leading to damaging long lasting environmental effects, such as lowering of water tables, depletion of river flows and intrusion of sea water. Adding to these effects, the problem of contamination effectively reduces the problem of sufficiently clean water.

Groundwater passing through the soil dissolves various salts and minerals causing a direct threat to the life of human beings and other organisms. These substances may be either beneficial or toxic depending on their concentrations. The mobilization of various toxics in an environment may be hazardous to human health. Construction of wells with proper distance from toilet pits and latrines, animal raring houses are advisable to eliminate the contamination problem.

Good quality water is one of the primary importance for human health and well being. An increase in land development and projected population growth has raised concerns for the quantity of groundwater available for drinking. Declines in water levels due to increased groundwater withdrawals could have a detrimental impact on the environment and natural resources of the Peninsula. Pollution comes from both natural and anthropogenic sources. The sources of toxic substances that can potentially contaminate groundwater include industrial and municipal landfills, septic tanks, mining and agricultural practices. So it is essential to seek ways of achieving the most efficient and equitable use of these resources at the same time as making their use sustainable. Hence the study was focused on identifying the course of contaminants and its extent by analysis the chemical components; electrical conductivity, chloride, nitrate-N, and total hardness with contamination sources.

Materials and Methods

Location of the study area

The Jaffna peninsula is situated in the Northern most part of Sri Lanka. The project area is within latitudes 9° 25' and 9° 50' and longitudes 70° 50' – 80° 20'. Jaffna district is bounded on the North and East by the Indian Ocean, on the west by Palk Strait and to the South by the Sri Lankan mainland. The project area is flat with a surface gradient not exceeding 2 %. Groundwater is the only water source available in Jaffna Peninsula for all requirements. Two villages namely Thirunelvely and Kondavil from Jaffna district were selected for this study purpose because the areas are receiving much attention due its environmental uniqueness and its significant groundwater resources, which are being utilized for domestic, agriculture and specially used for Jaffna municipal water supply. Figure 1 shows the location of the study area.

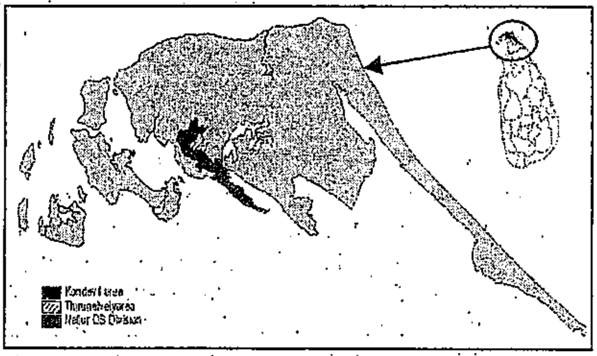

Fig. 1 Location of the study area

Location of wells

Altogether forty wells, twenty wells from each study area were selected. The survey department maps of each division were used to locate the well spatially. The locations of selected wells were point marked in satellite images of the study area by using Arc view 3.2. These wells were spatially randomly distributed to represent the entire study area. The selected wells were geo referenced with counter map of Jaffna peninsula by using Arc view 3.2. The actual depths of the wells above mean sea level were taken from the geo referenced map.

Source of contamination

The study areas do not have industrial land fills and mining activities. Hence other parameters such as actual depth to groundwater, average abstraction rate, proximity to latrines, animal raring house, lagoon and ponds were considered as possible causes. The other possible causes; sea water intrusion and upcorning of salt water have been assigned with EC and chloride concentration. Saline water has been reported to be the most common pollutant in the fresh water (Navaratnajah, 1994). Table 1 and 2 shows the identified source of pollutant, measuring unit and Sri Lankan standard.

Table 1: Identified source of pollutant with measuring unit.

Pollutant	Source of the pollutant	Measuring Unit
Salinity	Sea water intrusion / sea water up corning	As chloride and EC
Nitrate as N	Agro Fertilizers, Human waste, Animal raring sheds.	As Nitrate-N
Hardness	Limestone dolomite	Total carbonate

Table 2: Sri Lankan standard value

Measuring Unit	*SLS DES	**SLS PER
chloride and EC	200 mg/l 750 µS/cm	1200 mg/l 3500 µS/cm
As Nitrate-N	10 mg/l	10 mg/l
Total carbonate	250 mg/l	600 mg/l

*SLS DES- Sri Lankan Standard Desirable
**SLS PER - Sri Lankan Standard Permissible

Sample collection and chemical analysis

Water samples were analyzed for electrical conductivity (EC), chloride, nitrate N, and total hardness based on Sri Lanka standard 614: part 1 (1983) at monthly interval from March 2007 to February 2008. The concentration of nitrate-N was determined calorimetrically by Spectrometer. EC was measured by Electrical conductivity meter. Mohr's titration and Ethylene Diamine Tetra Acetic acid (EDTA) titrations were used to estimate chloride and total hardness, respectively. All the data were compared with Sri Lankan drinking water standards. Bacteriological and chemical safety is the prime importance in the use of groundwater for domestic use. But unfortunately the bacteriological count was unable to measure because of unavailability of facilities. Statistical analysis was done to see the variation of measured parameters between the wells and monthly values. The spatial distribution of contamination was explained separately for dry (average value from March to August) and wet (average value from September to February) season.

A point interpolation was done to interpret the extent of contamination for EC, chloride, nitrate-N and total hardness. A point interpolation performs an interpolation on randomly distributed point values and returns regularly distributed point values. Then above mentioned chemical parameters were measured in some potential areas for validation of interpolation and cross checked with interpreted data for the confirmation.

Results and Discussion

Sea water intrusion and up corning

Saline water may be derived from seawater intrusion into an aquifer, up corning of seawater, water concentrated by evaporation and in situ mineralization. Saline intrusion occurs when seawater displaces or mixes with freshwater within an aquifer. The Jaffna Peninsula has principally an over burden of soil of varying thickness depths, underlain by a massive limestone base. This limestone is porous, full of cavities and interconnected by solution canals and caverns. Hence as the groundwater table rises above mean sea level, the positive head caused drives part of the fresh groundwater via the solution canals into the sea. As a result there is always a saltwater – fresh water interface which moves more and more inland and upwards as the groundwater aquifers is depleted by extraction.

The EC of the water samples is an indicator of salinity. The degree of salinity is positively correlated with the EC of water. This behavioral response was used to determine the nature of salinity for the selected wells. The EC values were ranged from 531 to 3,839 µS/cm. Based on Sri Lankan drinking water standard, 92.50 % of the wells were within the limits of SLS desirable to permissible. Only 2.5% of the wells were below the desirable level of 750 µS/cm. Out of tested wells, 2.5% of wells had relatively high EC values which were above the Sri Lankan standards for drinking water of 3500 µS/cm. It is an indication of the presence of abundant dissolve ionic species. It could be due to the contribution from salt water lagoon (Table 3). The wells within the distance of 1000 m from lagoon had high EC.

The chloride concentration was varied from 51 to 1067 mg/L. From selected water samples, 35% of wells were above desirable level (200 mg/L) but below the permissible level (1200 mg/L). Other water samples (65%) had safe for human consumption based on the chloride concentration. Figure 2 and 3 show the spatial distribution of chloride concentration during dry and wet season respectively in Thirunelvely. The large extent of high chloride concentration area was observed during wet season than dry season in both places due to leaching of ions from the soil profile. High concentration of chloride was observed near to the lagoon side and decreases towards inland (Figure 3).

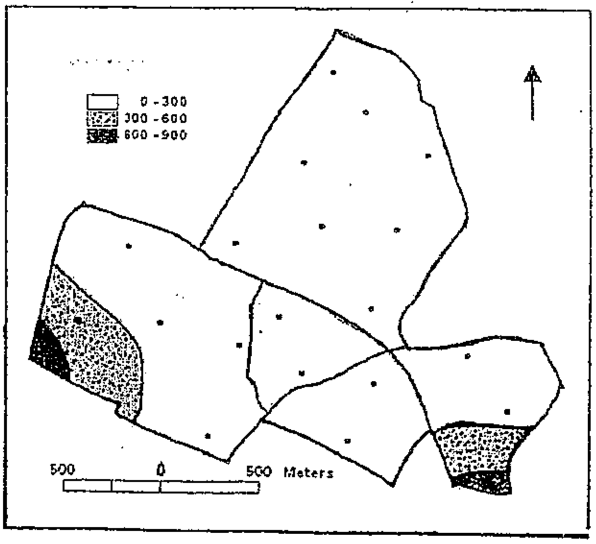

Fig. 2: Spatial distribution of chloride ions during dry season in Thirunelvely

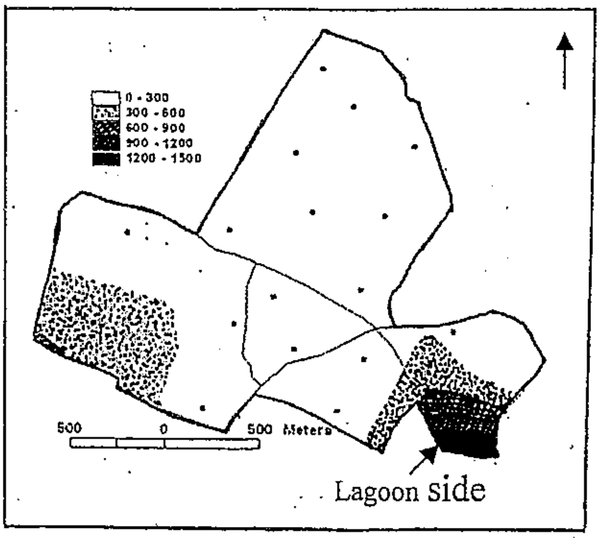

Fig. 3: Spatial distribution of chloride ions during wet season in Thirunelvely

Table 3 Proximity to Lagoon

Distance to Lagoon (m)	% of the wells
0 – 1000	2.5
More than 1000	97.5

Table 4 Proximity to Ponds

Distance to Lagoon (m)	% of the wells
0 – 100	5
More than 100	95

Table 3 and 4 indicate the distances of the wells from lagoon and ponds respectively. Very few wells (2.5%) were found within 1000 m from the lagoon where as 5% was found 100 m from ponds. In aquifers near to the lagoon and ponds excess pumping will reduce groundwater gradients, which reduces outflow of freshwater which may result in denser saline water displaying the fresh water within the aquifer. Groundwater abstraction above the interface causes up corning. Depending on aquifer characteristics, well penetration and pumping rate, a stable situation may be attained where salt water does not reach the well. The localized up corning due to over abstraction was observed in two wells in main aquifer. The problem of saline intrusion and up corning requires the careful and specific management of the costal aquifers to ensure their long term viability and sustainability.

Nitrate contamination

Nitrate contamination 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 itself is relatively non-toxic to humans and animals. However, it can be reduced to toxic nitrate under favorable conditions or by denitrifying bacteria in the upper digestive tract of some infants. Therefore, WHO and national governments set the drinking water standards as 10 mg/L nitrate as N.

Previous studies Gunasekaram, 1983 and Maheswaran, 2003 have shown very high levels of nitrate in the groundwater of the study area. Nitrate is variously associated with diseases like methaemoglobinemia, gastric cancer, thinning of blood vessels, aggressive behavior and hypertension (Sivarajah, 2003). Nitrates which could be converted into carcinogenic substances such as nitrosoamines within the body are of importance in the incidence of esophageal cancer in Sri Lanka. Jeyakumaran (2008) said that contamination of shallow groundwater aquifer or soil in Jaffna Peninsula is a threat to the health of the people who consume it.

The average nitrate-N concentration value ranged from 0.71 to 16 mg/L and 40% of water samples had safe for human consumption and 60% of the wells were above the recommended level of 10 mg/L. De Silva and Hohne, 2005 stated that the poor groundwater quality in most of the boreholes is due to poor well construction and indiscriminate construction of wells close to contamination sources without knowing the hydro geological background of the area. Figure 4 and 5 clearly shows the spatial distribution of nitrate-N in dry and wet season. The low nitrate-N concentration area was altered as high nitrate-N area during wet season due to leaching of nitrate-N from soil to groundwater

Table 5 Proximity to latrines

Proximity to Latrines (m)	% of the wells
< 10	12.5
10 – 15	40
15 – 20	12.5
> 20	35

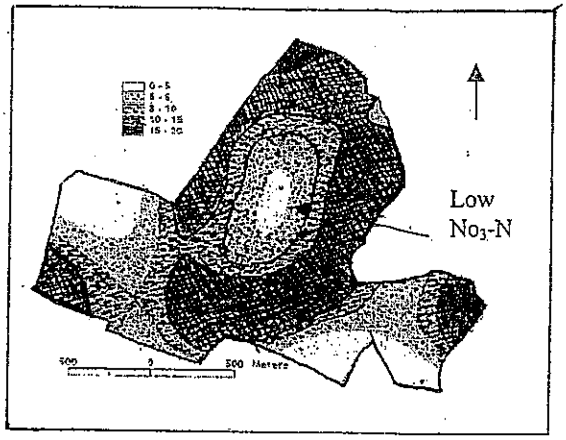

Fig. 4 Spatial distribution of NO_3-N in dry season

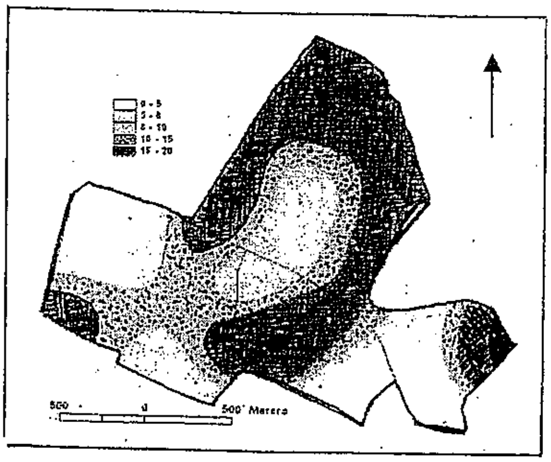

Fig. 5 Spatial distribution of NO_3-N in wet season

Table 6: Proximity to Agricultural lands

Proximity to Agricultural lands (m)	% of the wells
< 5	32.5
5 – 50	7.5
50 – 100	10
> 100	50

The soak away pits of latrines / septic tanks constructed in limestone areas are often close to domestic wells. The soils have high percolation capacity and promote flow of effluent into the groundwater body. The survey conducted in the study areas reveled that the distance between shallow wells of 12.5% and latrine was less than 10 m. Meanwhile 40% of wells are constructed at a distance between 10 to 15 m (Table 5). The recommended distance for the soil type of red yellow latasol of Jaffna Peninsula should be above 15 m however 52.5% of wells did not satisfy the requirements. The limestone provides almost no purification capacity and with a very high permeability (430 - 500 m/d). Pollution that reaches the ground water can quickly spread very far. It was observed that for the average household of six persons, septic tank pit desludging had not been carried out in over 10 years and there was no overflow which demonstrates the high abstraction capacity of the ground. Out of tested wells 32.5% of shallow wells are situated between 5 m or within the agricultural land. Further 17.5% wells are situated within 100 m (Table 6). The distance of animal raring houses to shallow wells were within 100 m for 20% of tested wells. Good correlation ($R^2 = 82$) was observed in distance to agricultural land, animal raring areas to nitrate-N concentration. There was no correlation ($R^2 = 20$) between actual depths of the well to nitrate-N concentration. Which means even deep wells contain very high nitrate-N concentration than shallow wells Hence indiscriminate placement of wells closer to contamination sources such as agricultural areas, livestock raring areas and pit latrines should be controlled or these wells should not be used for drinking purposes.

Hardness of water

The value of hardness varied from 150 to 1100 mg/L and 8.3% of the wells were above the recommended SLS permissible level of 600 mg/L and 83.3 % of wells had above SLS desirable level of 250 mg/L. Probably 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.

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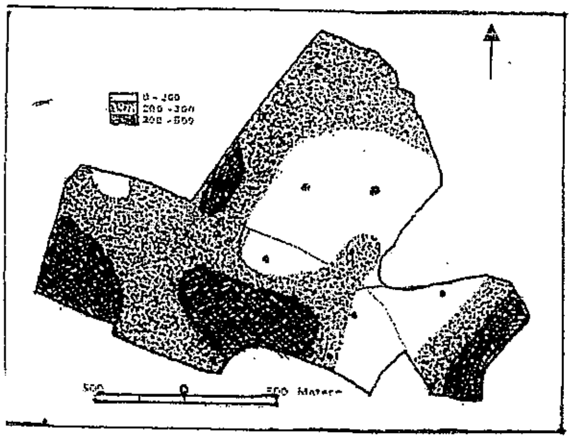

Fig. 6 Spatial distribution of hardness in dry season

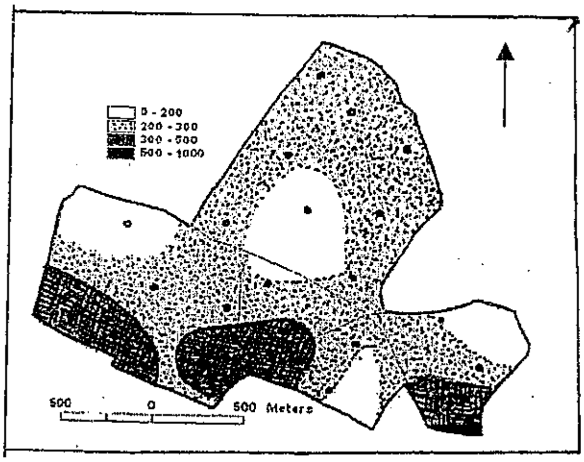

Fig. 7 Spatial distribution of hardness in wet season

Due to the hard water consumption, People in the area suffer from calculi in the urinary tract (Sivarajah, 2003). Seneviratne and Gunatilaka (2005) mentioned hard water is suitable for drinking. Because it is showing low rate of heart diseases when compared to soft water. Total hardness is influenced by rainfall and increased in wet season (Figure 6 & 7). Total hardness of groundwater could be increased due to dissolution of calcium bicarbonate (limestone) aquifer.

Conclusion

Indiscriminate placement of wells closer to contamination sources such as near to lagoons, ponds, agricultural areas, livestock raring areas and pit latrines should be controlled or these wells should not be used for drinking purposes. There was no correlation between actual depths of the wells to contamination sources and positive correlation was observed between actual abstraction rate to chloride concentration and EC. The spatial distribution area or extent of high concentration of EC, chloride, nitrate-N and hardness were increased during wet season than the dry season. Development of a groundwater management strategy is essential for the sustainable management of groundwater resources in terms quality by establishment of groundwater protection zones. The proper separation distances should be maintained between wells and any potential contamination sources. Proper well construction, cement lining and maintenance are necessary. Also the care must be taken when using agro wells for drinking purpose. Wells close to the agricultural fields must not use for drinking purpose.

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