SEASONAL VARIATION OF NITRATE-N IN GROUNDWATER: A CASE STUDY FROM CHUNNAKAM AQUIFER, JAFFNA PENINSULA

SEASONAL VARIATION OF NITRATE-N IN GROUNDWATER: A CASE STUDY FROM CHUNNAKAM AQUIFER, JAFFNA PENINSULA

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ABSTRACT

The Jaffna Peninsula has four main aquifer systems. The largest of these is the Chunnakam aquifer in the Valikamam area. Intensive cultivation in this area has led to groundwater pollution, which is due to the excessive use of inorganic and organic nitrogen fertilisers. The situation is aggravated by excessive irrigation applications, which carries the fertiliser applied to the groundwater almost on a daily basis. In addition, the heavy rainfall experienced during the wet season not only carries the nitrogen to groundwater but also brings the groundwater level close to the surface. As a result, the fertiliser residues remain in the upper layers and also get dissolved in the groundwater. The aim of this study was to assess the spatial and temporal variation of nitrate-N contamination in drinking water in the Chunnakam aquifer, which was a sub-objective of a research project carried out by the International Water Management Institute (IWMI). Forty-four wells representing different uses and land-use patterns were monitored on a monthly basis over a period of one year from January to December, 2011. Nitrate-N concentrations in the water samples were determined using a colorimetric spectrophotometer. The spatial variations of water quality were mapped using ArcGIS 10.1.

The Nitrate-N values from domestic, domestic with home garden, and public wells ranged from below 0.1 to 12.1 mg/l. During the rainy season, 38% of the agro-wells exceeded the nitrate-N limit of the World Health Organization (WHO) drinking water guidelines (10 mg/l) and became unsuitable for drinking purposes. However, only 15% of the agro-wells exceeded this limit by the end of the dry season. A decreasing trend in nitrate-N concentrations was observed from January to March. Nitrate-N was found in most of the wells surrounded by areas with highland crops (onions, chilies, tobacco and eggplant), and the concentrations frequently exceeded the acceptable level (10 mg/l). Even though these agro-wells are used for agricultural purposes, people who work in the field also rely on them for their drinking water supplies. The study clearly indicates that the groundwater quality in some areas of the Chunnakam aquifer is becoming unsuitable for drinking purposes during the wet season while groundwater quality in others remain unsafe throughout the year. Therefore, effective management of groundwater quality in the region is vital. Creating awareness among the people about the possible contamination of groundwater would possibly reduce the excessive use of irrigation water and chemical fertilisers in agriculture.

INTRODUCTION

Sri Lanka has an estimated groundwater potential of 780,000 hectare metres per annum (NARESA, 1991). Groundwater is extensively being used for domestic and agricultural purposes in the country. In the absence of perennial rivers, groundwater is the only source of freshwater for sustaining life and the environment in the Jaffna Peninsula, which lies at the northern tip of the dry zone of Sri Lanka. The peninsula is underlain predominantly by Miocene limestone, which is considered to be appropriate geological material for the development of aquifers. Seasonal rainfall is of a short duration and is the only source of groundwater recharge.

Rapid development of agriculture and the economy, and an increase in the population due to resettlement, result in the contamination of groundwater and creates an intensive shortage of water, especially for agricultural purposes. Rajasooriyar et al. (2002) reported that water shortage is a major problem, and groundwater often serves as an important and safe source of water for the Jaffna Peninsula in Sri Lanka. The deteriorating quality of groundwater in the Peninsula has justified the continuous monitoring and investigation of water quality. A major problem was the intrusion of seawater into the groundwater system, which was identified in the 1950s and highlighted in the 1960s (Balendran et al. 1968). Later, concern centred on the problem of high nitrate levels in groundwater related to high inputs of artificial and natural fertilisers, and congested or improperly planned household soak-pit systems.

Pollution of groundwater through nitrate contamination has been receiving attention in the Peninsula since the early 1980s (Mageswaran and Mahalingam 1983; Dissanayake and Weerasooriya 1985; Nagarajah et al. 1988; Rajasooriyar et al. 2002; Mageswaran 2003). The high nitrate levels recorded in the water in the wells of the agricultural areas in the Peninsula are very likely related to the intensive cultivation that is practiced in that region. Farmers apply large amounts of animal waste, green manure and crop residue in addition to the heavy application of inorganic fertilisers. Additionally, irrigation from well water is provided at a higher rate than required to meet crop demand through flood irrigation. Groundwater within the intensively cultivated area had nitrate-N concentrations ranging from 10 to 15 mg/l (Mikunthan and De Silva 2008). Out of the 68 wells studied, the water in 81% of the wells was not recommended for drinking purposes in intensively cultivated agricultural areas (Jeyaruba and Thushyanthy 2010).

An assessment of the vulnerability of groundwater for irrigation and drinking purposes has become important for the management of present and future groundwater quality in the Jaffna Peninsula. However, the information available thus far has not been systematically compiled and reported for the benefit of the water managers and researchers. It is, therefore, essential to establish the baseline information on water quality and water availability to assist in the long-term planning of groundwater use for various purposes. The aim of this study was to assess the spatial and temporal variation of nitrate-N contamination of drinking water in the Chunnakam aquifer, which is the largest of the four aquifer systems found in the Jaffna Peninsula.

METHODS AND MATERIALS

Description of the study area

The Jaffna Peninsula lies in the northernmost part of Sri Lanka. Agriculture is the main source of livelihoods for 65% of the population, and approximately 34.2% of the land is cultivated intensively with high-value cash crops, such as red onion, chillies, potatoes, tobacco, vegetables, banana and grapes, for commercial purposes (Thadchayini and Thiruchelvam, 2005). The Jaffna Peninsula has four main types of aquifer systems, namely, Chunnakam (Valikamam area), Thenmarachchi, Vadamarachchi and Kayts. The Valikamam area is an intensively cultivated and highly populated area in the Peninsula (Puvaneswaran, 1986). The major rainy season occurs during the Northeast monsoon from October to December and the minor rainy season occurs during the Southwest monsoon in April and May. Figure 1 shows the long-term average rainfall in the Jaffna Peninsula. The major soils in the Peninsula are the calcic red-yellow latosols, which are shallow, fine-textured and welldrained with a very rapid infiltration rate (De Alwis and Panabokke, 1972).

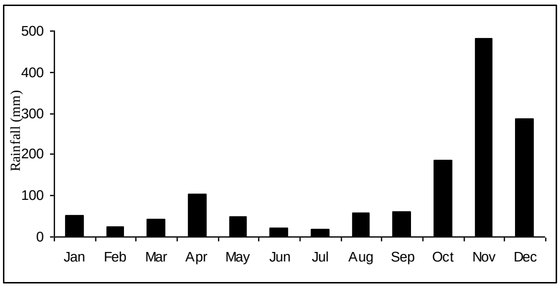

Figure 1: Mean monthly rainfall derived from year 2002 to 2011 (Source: Jaffna district statistical hand book, 2011).

Selection of wells & analytical techniques

Forty-four (44) wells were selected for water quality monitoring in a systematic manner to represent the entire Chunnakam aquifer. All the wells selected were under different uses, such as domestic (well numbers 1 and 2), domestic and home garden (well numbers 3 to 9), public wells (well numbers 10 to 18) for drinking purposes, and farm wells (well numbers 19 to 44). Of the wells selected, 24 were farm wells from different cropping systems, namely, highland crops (chilie, onion, brinjal, and tobacco), mixed crops (highland crops with banana), banana and paddy. Figure 2 shows the locations of the wells selected for monitoring in the Chunnakam aquifer. The sampling covered the period from January to December, 2011, representing all seasons. Concentration of nitrate-N and nitrite-N in sampled water was determined using a colorimetric spectrophotometer. The spatial variations of nitrate-N and nitrite-N were mapped using the Inverse Distance Weighting (IDW) interpolation technique with ArcGIS 10.1. Rainfall data during the study period was obtained from the Meteorological Department, Thirunelveli.

RESULTS AND DISCUSSION

Nitrate-N concentration in groundwater during January 2011 is shown in Figure 3, and ranged from undetermined values to 35 mg/l. Concentration levels from domestic, domestic with home garden, and public wells were acceptable for drinking purposes during the rainy season, as the nitrate-N values were below the limit of WHO drinking water guidelines (10 mg/l) (WHO, 2011). Among the farm wells monitored, nitrate-N concentration in 38% of the wells exceeded the limit of 10 mg/l and the water was not suitable for drinking purposes. Gunasekaram (1983) studied groundwater contamination in the Jaffna Peninsula extensively and found that the nitrate levels exceeded the WHO limits, which he attributed to the mixing of abundant nitrogenous waste matter, and synthetic and animal fertilisers reaching the shallow groundwater table.

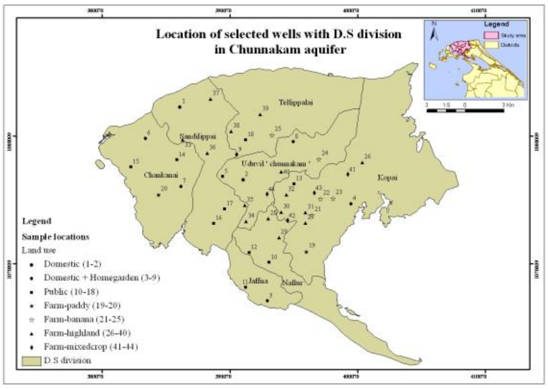

Figure 2: Location of selected wells with Divisional Secretariat (DS) divisions in the Chunnakam aquifer area.

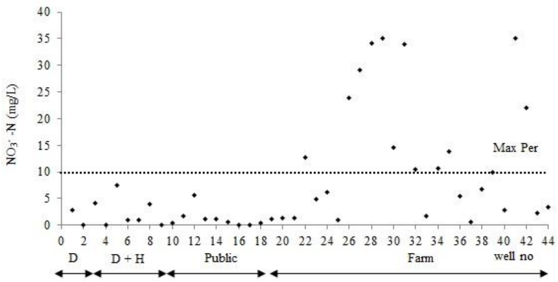

Figure 3: Nitrate-N concentration in groundwater during January 2011.

Nitrate-N concentration in groundwater during July is shown in Figure 4, and ranged from undetermined values to 24 mg/l. All nitrate-N values from domestic, domestic with home garden, and public wells were below the recommended level for drinking purposes during the dry season. Among the selected farm wells, nitrate-N concentration in 15% of the wells exceeded the limit of the WHO drinking water guidelines of 10 mg/l and the water was not suitable for drinking purposes.

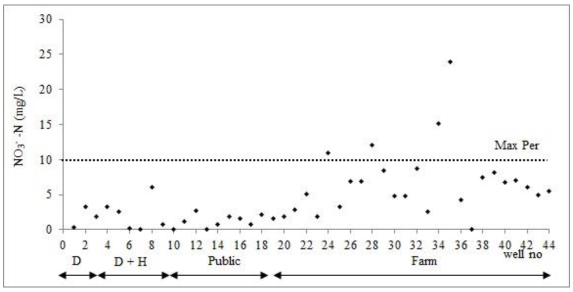

Figure 4: Nitrate-N concentration in groundwater during July 2011.

The spatial variation of nitrate-N in wells under different land uses are presented in Figure 5. A general decreasing trend in nitrate-N concentration was observed from January to March. During the rainy season, the soil is saturated to the water table, facilitating the leaching of nitrate. In addition, the Peninsula experienced heavy rainfall during the Maha season of 2010, which resulted in a high groundwater table in January. This, in turn, would have resulted in the dissolving of nitrate-N that was accumulated in the upper soil layers. Nandasena et al. (2005) reported that rainfall influences the distribution of nitrate-N in the groundwater by raising or lowering the groundwater table.

Well number 5 (domestic and home garden in Sankuvely) and well number 13 (public well in Puttur) had nitrate-N concentrations above the permissible levels for drinking water during March and April, respectively. In all the other domestic and public wells, the temporal variation of nitrate-N was below 10 mg/l throughout the year, and there was no problem of nitrate-N contamination preventing water being used for drinking purposes. Usually, in home gardens, inorganic fertilisers were not used, and the abstraction levels and amount of irrigation were also less than that of farm wells.

The groundwater within the intensively cultivated area had high levels of nitrate-N concentrations. Concentration of nitrate-N in land use under paddy and banana cultivation had lower values than in highland crops. Nitrate-N levels found in most of the wells used for the cultivation of highland crops exceeded the limit of the WHO drinking water guidelines. The high nitrate-N values of 35 mg/l were observed at well number 29 (Thirunelveli) and well number 41 (Neervely), which are located in an intensively cultivated area. A recent study also confirmed nitrate-N levels ranging from 0 to 15.5 mg/l in the area under study (Hidayathulla and Karunaratna, 2013). The build-up of nitrate is significant in agricultural fields and is estimated at 1 to 2 mg/l/year in Kalpitiya (Kuruppuarachchi and Fernando, 1999). Even though these wells were being used for agricultural purposes, people who work in the field use the well water for drinking. The most probable cause for the high nitrate-N concentrations in farm wells could be the leaching of excess fertilisers to the shallow groundwater. Nagarajah et al. 1988 reported the use of high levels of organic manure from cattle, goats and green manure, and inorganic fertilisers and agrochemicals being applied to these high-value crops.

In recent years, intensive agricultural practices have increased in response to population growth and have resulted in very high inputs of artificial and natural fertilisers, with excessive amounts of manure being applied to agricultural land in rotation. Inputs are always above crop requirements, resulting in leaching of the excess fertiliser to groundwater. Gunatilake and Iwao (2010) concluded that the application of nitrogenous fertiliser in Sri Lanka has a direct impact on the concentration of nitrates in groundwater in the vicinity. Jeyaruba and Thushyanthy (2009) noted that the level of nitrate-N concentration in groundwater was influenced by the cropping system; high nitrate-N concentration in groundwater was observed in highland crops followed by mixed crops such as banana and paddy. Cultivation of banana is usually under basin irrigation with organic fertilisers. Before planting of banana suckers, farmers bury green manure into the pits and they keep the plants in the field for approximately five years. Most farmers are not using any inorganic fertilisers for the cultivation of banana. Premanandarajah et al. (2003) mentioned that the addition of organic manure increases nitrogen retention capacity and reduces nitrate loss by leaching in sandy soils. Therefore, crops can efficiently utilise the applied fertiliser and the residual nitrogen will remain in the soil for the next crop. Since nitrogen retention

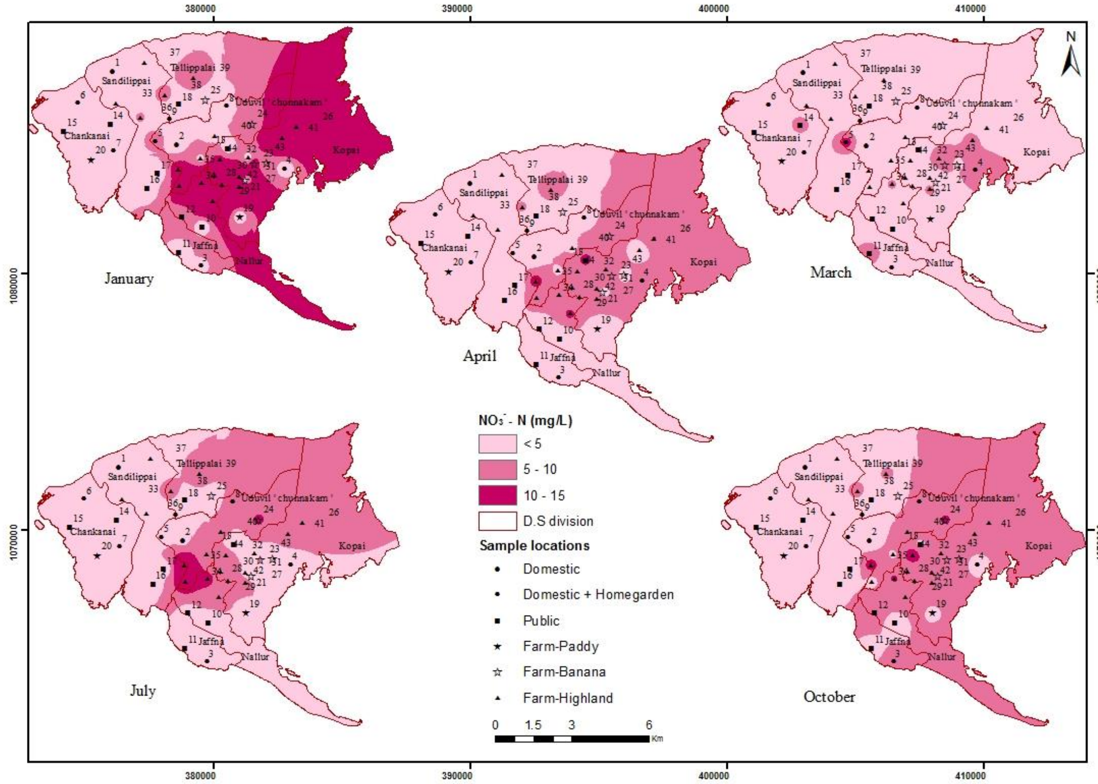

Figure 5: Spatial variation of nitrate-N in the Chunnakam aquifer.

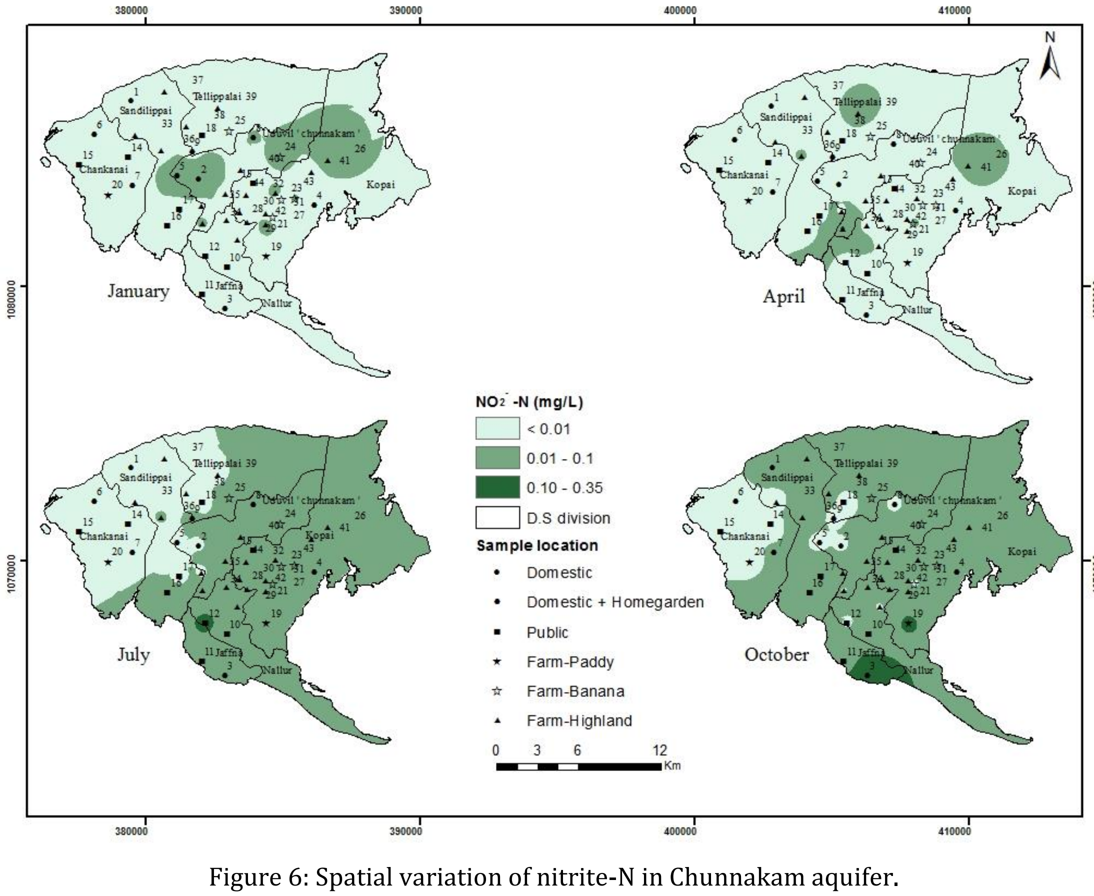

Figure 6: Spatial variation of nitrite-N in Chunnakam aquifer.

increases with organic fertilisers, this may be the reason for low nitrate-N concentrations in groundwater in land use under banana cultivation. Hence, one of the ways to reduce nitrate contamination of groundwater is by using organic manures.

Another factor responsible for high nitrate concentrations in groundwater is the improper planning of soakaway pits and dug wells (Gunasekaram 1983). Distances between latrine pits and dug wells are not maintained based on the site geology and soil type (as recommended), particularly in highly populated urban areas (Rajasooriyar et al. 2002).

The spatial variation of nitrite-N for the selected wells is shown in Figure 6. The concentration of nitrite-N values ranged from below 0.001 to 0.330 mg/l. Generally, nitrite gets oxidised to nitrate in open dug wells. Levels of nitrite-N tend to increase towards the dry season. Most of the farm wells, and some domestic and public wells, had nitrite-N values above the maximum permissible level of 0.01 mg/l during October.

Health effects of nitrate-N

Nitrate is potentially hazardous when present at sufficiently high levels in drinking water. WHO reported that this was linked to methemoglobinemia (blue baby syndrome), especially in infants. However, no such cases have been recorded at the Teaching Hospital of Jaffna. Anyway, there is a high risk of nitrate toxicity related to blue babies in the Peninsula.

Nitrate, which could be converted into carcinogenic substances such as nitrosamines within the body, are of importance in the carcinogenesis of oesophageal and stomach cancers (Dissanayake, 1988). The five-year study on the geographical pathology of malignant tumours in Sri Lanka from 1973 to 1977 has confirmed that the incidence of cancer is relatively higher in the Jaffna District, and one of the reasons for incidence of esophagus cancer could be the elevated levels of nitrate-N in groundwater (Panabokke, 1984). In Jaffna, oropharynx, oesophagus, stomach, breast and liver cancers are common. A national consultant to the WHO (Sivarajah, 2003) reported that the high nitrate content in water could be related to the high prevalence of cancer of the gastrointestinal tract in the people of Jaffna.

Table 1: Distribution of oesophagus and stomach cancer patients within the study area from 2000 to 2009 (after Gunalan et al., 2011).

DS division	Number of cancer patients	Percentage of patients (%)
Sandilipai	17	16
Uduvil	20	19
Thellipalai	6	6
Chanakani	7	7
Kopai	20	19
Nallur	17	16
Jaffna	20	19

A recently study carried out in the Chunnakam aquifer area concluded that there is a risk of cancer due to the consumption of well water with nitrate-N concentrations higher than the recommended level by WHO drinking water guidelines (Gunalan et al., 2011). As shown in Table 1, Uduvil, Kopai, Jaffna, Sandilipai and Nallur are reported as having a high number of oesophagus and stomach cancer patients, as well as the most number of areas with nitrate concentrations in wells among other study areas in this region (Figure 5). Therefore, a detailed study of epidemiology for oesophagus and stomach cancer in these areas is of importance.

CONCLUSION

Groundwater is the only source of freshwater for various uses, including drinking water, in the Jaffna Peninsula. Pollution of this valuable resource due to nitrate leaching from intensively cultivated areas has been reported extensively in the Peninsula. This study observed that nitrate-N contamination in farm wells was higher in the rainy season than in the dry season, indicating that the groundwater is unsuitable for drinking purposes during certain periods of the year. Therefore, awareness should be created among the people on the effects of the excessive use of chemical fertilisers in agriculture on groundwater quality. Wells that are safe for drinking purposes should be identified based on continuous monitoring.

REFERENCES

Balendran VS, Srimanne CHL, Arumugam SA (1968) Groundwater investigation in Jaffna Peninsula. Water resources board, Colombo, Sri Lanka. pp 1-16.

De Alwis KA, Panabokke CR (1972) Handbook of soils of Sri Lanka (Ceylon). Soil science society, Ceylon 2; 1-97.

Dissanayake CB (1988) Nitrate in the groundwater in Sri Lanka- Implication for community health. Journal of the Geological society of Sri Lanka 1; 80-84.

Dissanayake CB, Weerasooriya SVR (1985) The hydrogeochemical atlas of Sri Lanka. Natural resources, energy and science authority of Sri Lanka, Colombo. XXX pp.

Gunalan K, Asanthi HB, Gamage TPD, Thushyanthy M, Saravanan S, Jayakumaran N (2011) Incidence of Oesophageal and stomach cancer related to nitrate-N concentration in groundwater in Jaffna Peninsula. The Water resources research in Sri Lanka. In: Dayawansa NDK, Ranjith Premalal De Silva (Ed.) Symposium proceeding of the water professionals' Day-2011. pp 91-103.

Gunasekaram T (1983) Groundwater contamination and studies in limestone aquifer of Jaffna, Sri Lanka. Mimeograph documents.

Gunatilake SK, Iwao Y (2010) A comparison of nitrate distribution in shallow groundwater of two agricultural areas in Sri Lanka and in Japan. Sabaragamuwa University Journal 9(1); 81-95.

Hidayathulla MSM, Karunaratna GRR (2013) Assessment of Groundwater Quality in Shallow Aquifers in Jaffna Peninsula. Proceedings to 29th Technical Sessions of Geological Society of Sri Lanka, 2013. pp 109-113.

Jaffna district statistical hand book (2011) Annual publication, District Secretariat, Jaffna.

Jeyaruba T, Thushyanthy M (2010) Health hazardous: nitrate-N in groundwater and soil in intensified agricultural areas. International Conference on Sustainable Built Environment (ICSBE-2010) Kandy, 13-14 December 2010. pp 71-77.

Jeyaruba T, Thushyanthy M (2009) The effect of agriculture on quality of groundwater: A case study. Middle-East Journal of Scientific Research 4 (2); 110-114.

Kuruppurachchi DSP, Fernando WARN (1999) Impact of agriculture on groundwater quality: leaching of fertilisers to groundwater in Kalpitiya Peninsula. Journal of Soil Science, Sri Lanka11; 9-15.

Mageswaran R (2003) Quality of groundwater in the Jaffna Peninsula. International workshop on environmental management in north- east Sri Lanka. 1st- 4th December, 2003. Thirunelvely, Jaffna, Sri Lanka. pp 75-81.

Mageswaran R, Mahalingam R (1983) Nitrate nitrogen content of well water and soil from selected areas in the Jaffna Peninsula. Journal of National Science Council, Sri Lanka 11(1); 269-275.

Mikunthan T, De Silva CS (2008) Nitrate pollution in groundwater: A case study in Thirunelvely and Kondavil in Jaffna district. The water resources research in Sri Lanka. In: Dayawansa NDK, Ranjith Premalal De Silva (Ed.) Symposium proceedings of the water professionals' Day – 2008. Pp. 27-37.

Nagarajah S, Emerson BN, Abeykoon V, Yogalingam S (1988) Water quality of some wells in Jaffna and Killinochchi with special reference to nitrate pollution. Tropical Agriculture 44; 61-73.

Nandasena KA, Gunawardhana DKSN, Kendaragama KMA (2005) Groundwater quality of three agro-ecological zones of Sri Lanka. Journal of soil science society of Sri Lanka 17; 20-30.

NARESA (1991) Natural Resources of Sri Lanka: conditions and trends, NARESA Colombo. 169 pp.

Panabokke RG (1984) The geographical pathology of malignant tumors in Sri Lanka – a 5- year study. Ceylon Medical Journal 29; 209-224.

Premanandarajah P, Nandasena KA, Thedchanamoorthy K (2003) Effect of organic manure on nitrate pollution of groundwater and soil nitrogen. International Workshop on Environmental Management in North-East Sri Lanka. pp 63-64.

Puvaneswaran P (1986) Geomorphology of the Valukkai aru drainage basin. Sri Lankan Journal of South Asian studies 1; 43-58.

Rajasooriyar L, Mathavan V, Dharmagunawardhane HA, Nandakumar, V (2002) Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka. Sustainable groundwater management. In: Hiscock KM, Rivett MO and Davison RM (Ed.) Geological Society, London 193; 181-197.

Sivarajah N (2003) Health related problems of water pollution in Jaffna. International Workshop on Environmental Management in North-East Sri Lanka. pp 89-94.

Thadchayini T, Thiruchelvam S (2005) An economic evaluation of drip irrigation project for banana cultivation in Jaffna district. Water resources researches in Sri Lanka. In: Galagedara LG (Ed.) Symposium proceedings of the water professionals' day- 2005. pp 111-126.

WHO (2011) Guidelines for drinking water quality. 4th edition. World Health Organization-2011, Geneva pp 307-433.