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Review

Nitrate contamination of groundwater: An issue for livelihood in Jaffna Peninsula, Sri Lanka

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Groundwater stored in large cavities and channels of Miocene limestone is the only source of portable water in Jaffna Peninsula, Sri Lanka. It is increasingly exploited and polluted by various contaminants that results in less availability of potable water. Nitrate contamination in drinking water is one of the major concerns which causes severe health impacts, such as methemoglobinemia especially in infants and oesophageal and stomach cancers. The current nitrate levels in drinking water in Jaffna peninsula are much higher than the WHO and SLS levels. The nitrate-N content of groundwater in the Jaffna Peninsula ranges from 0.1 to 45 mg/L as per the literature though the permissible nitrate-N level in drinking water is 10 mg/L. Further, the nitrate concentration in groundwater varies seasonally and is found to be higher during the wet season than the dry season. Research studies carried out at different localities in the Peninsula from 1983 to 2018 have shown that nitrate content of groundwater has increased over this period. A recent investigation in the Chunnakam area revealed nitrate-N level of 45 ppm. Hence, nitrate contamination of groundwater in the Jaffna Peninsula is found to be the most challenging issue in the water management system.

Key words: Groundwater, nitrate, Jaffna Peninsula, contamination.

INTRODUCTION

Groundwater is the important natural source with high economic value and social significance for the livelihood in Jaffna peninsula (Torfs, 2015). It is the water under the earth's surface that flows freely through tiny pores and cracks in rock and soil and can be pumped from wells (Hidayathulla and Karunaratna, 2013). Jaffna peninsula has four main limestone aquifers such as Valikamam, Thenmarachi, Vadamarachi and Kayts. Those are unconfined aquifers which mean the aquifers have direct contact with the atmosphere. Except very little rainy season, extracted groundwater is the only source for irrigation, drinking water and other industrial purposes throughout the year. It is necessary to monitor the quantity and quality of water stored and extracted from these aquifers (Mikunthan et al., 2013). Due to intensive domestic usage (250 L/day per capita), higher inorganic fertilizer use, resettlement and urbanization deteriorate water quality (Nanthini et al., 2001). There should be a monitoring system in the water management to assist long term planning of water supply in Jaffna peninsula.

Although nitrogen is essential for all living things, excessive concentration of nitrogen can be hazardous to

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human health. Nitrogen occurs in the soil in organic form by decaying plants and animal residues. Large quantities of nitrogen enter the soil by addition of inorganic fertilizers. Nitrate is easily leachable with water through the soil profile and concentrates the content in groundwater sources.

This review provides the studies of he nitrate contamination in groundwater in Jaffna peninsula. Furthermore, it gives insights of the sources and negative effects of nitrate contamination and ground water system vulnerability in Jaffna peninsula. In addition, the study gives a broad overview of possible scientific and managerial methods that effectively reduces and mitigates the risk of groundwater nitrate contamination.

NITRATE HEALTH HAZARDS

Nitrate contamination in drinking water is a major crisis in Jaffna peninsula. Due to harmful biological impacts of nitrate concentrated water it causes methemoglobinemia (blue baby syndrome), tumours and gastro-intestinal cancers (Foley et al., 2012). Nitrate is converted into nitrite in the digestive system and nitrite oxidizes the iron in the haemoglobin and form methaemoglobin which reduce the oxygen carrying ability of haemoglobin. This condition is called blue baby syndrome. Fortunately, human over the age of one year can convert methaemoglobin back to oxyhaemoglobin. The high nitrate content in water can affect mainly babies under the age of one, elder people and pregnant women. The potential cancer-causing compound, nitrosamine, can be formed by nitrite react with amines, fortunately, there are no any reports of potential birth defects associated with high nitrate content consumption in Jaffna peninsula. Elevated nitrogen levels may be the reason for relatively higher incidence of oesophagus and stomach cancer in Jaffna (Dissanayake, 1988; Panabokke, 1984; Sivarajah, 2003). Level of risk is increased through irrigation for crops as well as addition of inorganic fertilizers and soakage pits (Torfs, 2015).

There is a great deal for finding effective treatment processes to reduce nitrate level to safe levels. Reducing the amount of fertilizers used in agriculture, proper management of soakage pits and slurry stores came from manure are supposed to reduce nitrate in groundwater in future.

SOURCES FOR NITRATE CONTAMINATION

In general, nitrate pollution sources are divided into non-point (diffuse) and point-source pollution. Agricultural fertilizers (mainly synthetic fertilizers) application is the largest non-point source (Chern et al., 1999).

Point sources may result in extremely high nitrate concentration in localized areas. Areas of concentrated livestock confinement, leaky sewerage systems and areas of chemical or manure storage are contributed as point sources. Point source pollution occurs from accidental spills of nitrogen rich compounds, absence of slurry storage tanks (Chern et al., 1999). Household waste water contains nitrogen release into the septic system.

Organic nitrogen cannot be used by plants directly. It should be converted into inorganic nitrogen. Plants do not necessarily use the entire nitrate from used fertilizers or organic matter decomposing. In the aerobic zone of soil organic forms of nitrogen is converted into nitrate and leached to the groundwater.

Nearly 80% of nitrate originates from agricultural sources of legumes, manure and inorganic fertilizer. Another 18% comes from atmospheric sources such as automobile gasoline and lightening. The remaining part of 2% comes from sludge disposal sources (Melvani and Pathmarajah, 2013).

SEASONAL VARIATION OF NITRATE CONCENTRATION

The efficiency of nitrogen usage may reduce the potential of nitrate leaching to the groundwater. The nitrate leaching potential depends on used nitrogen rate, type of nitrogen source, application time (large amount of nitrate is needed at growing plants so more leaching happens at this stage) and irrigation practices. Soil texture also affects the leaching of nitrogen to the groundwater. The major soils in the Peninsula are the calcic red-yellow latosols, which are shallow, fine-textured and well drained soils (Sutharsiny et al., 2014). This may contribute rapid infiltration of dissoluble nitrate into the groundwater.

GROUNDWATER USAGE IN JAFFNA PENINSULA

Nearly half of the population (Nanthini et al., 2001) in Jaffna peninsula depends with tube well water or dug well water for their drinking purposes. The average annual groundwater recharge was 569,624 m^3 from April 2007 to March 2008 and the average annual groundwater withdrawal was 661,635 m^3 resulting a negative water balance of 92,011 m^3 (Nanthini et al., 2001). There is an imbalance between extraction and recharge of groundwater. Sustainability of limestone aquifer was threatened due to the over exploitation of groundwater from well or pumping.

NITRATE CONTAMINATION IN GROUNDWATER - STATISTICS VIEW

65% of the population are involve in agricultural activities and 34.2% of land is used for cultivating high land crops

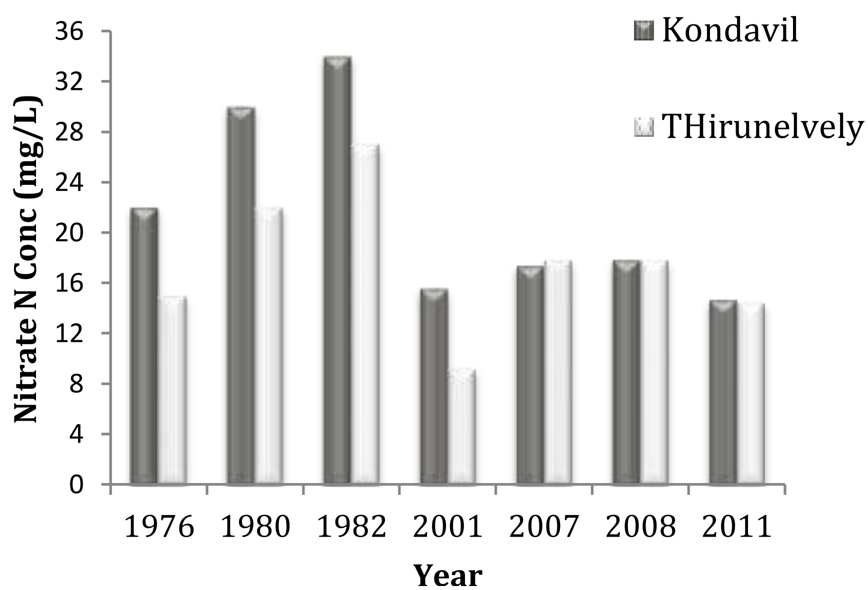

Figure 1. Nitrate-N concentration pattern in Kondavil and Thirunelvely.

such as onion, potato, chilies, tobacco and grapes (Mikunthan et al., 2013). The nitrate content exceeds greater than 10 ppm (WHO recommended level) in 60% of localized agricultural areas. In recent phenomenon, nitrate pollution is increasing and is correlated with the increasing use of nitrogen fertilizers over the last 30 to 40 years (Rajasooriyar et al., 2002; Melvani and Pathmarajah, 2013).

As an example, Figure 1 indicates nitrate concentration pattern from 1976 to 2011 in Thirunelvely and Kondavil areas. Thirunelvely is highly urbanized area and Kondavil is highly cultivated area. Therefore, soakage pit leakage and high fertilizer usage may be the reasons for high nitrate content. And also, those are nearby villages. Dissoluble nitrate can be distributed easily in the ground water.

In 2009, research findings contributes that the monthly average nitrate-N concentration ranged from 7.81 to 19.3 mg/l and 95% of the wells exceeded the drinking water standard of WHO in Jaffna peninsula (Jeyaruba and Thushyanthy, 2009). The Central Environmental Authority has adapted 10 mg/L nitrate-nitrogen as the maximum contaminant level and 1 mg/L for regulated public water systems. In the fields with intensified agriculture nitrate are excessively applied and leached into groundwater bodies (Jeyaruba and Thushyanthy, 2010).

The nitrate-N was ranging from 0.1 to 17.83 mg/l in Valikamam East and the agriculture intense village of Kondavil had the highest value of 17.83 mg/l in nitrate-N (Jeyaruba and Thushyanthy, 2009). In 2010, measured nitrate content in groundwater in Valikamam East within agricultural areas showed that 20% of well water was with nitrate-N content of less than 8 mg/l and 12% were within the critical range of 8 to 10 mg/l and 68% were with value of above 10 mg/l bodies (Jeyaruba and Thushyanthy, 2010). Dimuthu and Suvendran (2017) stated that nitrate-N content in many wells in Valikamam, was found below 8 mg/L. In most of information regarding nitrate content from Chunnakam and Valikamam areas, there are little data available for Thenmarachi and Vadamarachchi aquifers (Table 1).

Figure 2 shows that the places of Kodikamam and Madduvil where the tobacco, vegetables cultivation, indicated high nitrate content than the recommended level. Commonly farmers use 10 to 15 times higher than required amount of fertilizers to tobacco crop to get thick and high number of leaves. However, the tobacco cultivation will be banned in 2020 in Sri Lanka.

Figure 3 indicates some variation in nitrate content in Vadamarachi aquifer. Most of harmful fertilizers were banned during the war time in Jaffna peninsula and this may be the reason in low levels of nitrate in 2001.

The research on the impact of agriculture practices on quality of groundwater found that there was a good correlation between cropping and groundwater nitrate-N content. High nitrate content was observed at high land crops such as carrot than at mixed crops (Jeyaruba and Thushyanthy, 2009).

Figure 4 shows that nearly 75% of the wells exceed 10 ppm of nitrate-nitrogen compared to Sri Lankan standard in Chunnakam area. Similar study done by Dimuthu and Suvendran (2017) also indicated that 30% of wells exceeded the nitrate-nitrogen content. Those wells are used for agriculture as well as drinking purposes. There is a continuing cultivation done in Chunnakam with paddy, vegetables and tobacco.

Higher fertilizer usage may be the reason for the increase in nitrate content (Prabagar, 2015).

Table 1. Nitrate-N Concentration in different areas in Jaffna Peninsula from 1976 to 2019.

Study period	Nitrate-N conc (mg/L)	Study areas	Reference
1976	15	Thirunelvely	
	22	Kondavil	
1980	22	Thirunelvely	Mageswaran and Mahalingam (1983)
	30	Kondavil	
1982	27	Thirunelvely	
	34	Kondavil	
1988	6.1 - 13	Point pedtro	Kumuthini and Nadarajah (1988)
	16 - 10.5	Siththankerny	
	24 -17.5	Maviddapuram	
1992	4.97 - 6.77	Kokuvil	Baskaran and Mageswaran (1992)
	16.94 -33.9	Fort	
	22.58	Pointpedro	
	1.29 - 44.71	Velvettithurai	
	3.61 - 9.71	Vaddukkodai	
	4.51 - 36.12	Gurunagar	
2001	6.32 - 12.41	Velanai	Velauthamurthy and Mageswaran (2001)
	2.25 - 3.95	Kayts	
	2.03 - 4.11	Ponnalai	
	4.96 - 6.54	Araly	
	5.42 - 7.20	Koddady	
	7.90 - 9.39	Navatkuli	
	6.32 - 7.90	Kokouvil	
	13.77- 15.58	Kondavil	
	14.90- 18.39	Urumpirai	
	8.13 - 11.47	Chunnakam	
	9.94 - 21.75	Valvetithurai	
	1.94 - 4.44	Point pedtro	
	1.35- 2.86	Sarasalai	
	7.67 - 11.56	Madduvil	
	8.58 - 10.17	Kodikamam	
	4.06 - 6.18	Kachchai	
	2.71- 4.27	Mirusuvil	
	6.32 - 9.21	Thirunelvely	
2007	0.16 - 17.41	Kondavil	Jeyaruba and Thushyanthy (2009)
Jul 07 – Feb 2008	0.1 - 17.83	Kopay	Jeyaruba and Thushyanthy (2010)
	0.1- 17.83	Irupalai	
	0.1- 17.83	Thirunelvely	
	0.1 - 17.83	Neervely	
	17.83	Kondavil	
Jan 2011 to Dec 2011	0.1 -12.1	Chunnakam	Sutharsiny et al. (2014)
2011 Aug	1.73 - 26	Chavakachcheri	Kumara et al. (2013)
	1.73 - 26	Jaffna	
	1.73 - 26	Nallur	
	1.73 - 26	Pachchilaipallai	

Table 1. Contd.

2011	14.45 14.67 13.09 12.65 12.42	Thirunelvely Kondavil Nallur Kalviyankadu Kaithadi	Aravinthan and Jasotha (2011)
2012	0 -15.5 15-10 15 -10 1-2.5 5 -10 2.5- 5 10 -15 5 - 10 5 - 10 5 - 10	Kondavil Chunnakam Thellipallai Sandilipay Point pedtro Maruthankerny Kopay Uduvil Chankanai Karaveddy	Hidayathulla and Karunaratna (2013)
2015	7-11	Neervely	Tharshana et al. (2015)
2016	8.2 - 29.8	Valikamam	Jeevaratnam et al., 2018)
2017	3.11 ± 40.1 0.021 - 7.87	Chunnakam Valikamam	Dimuth et al. (2017)
2018	0.61 - 45.04	North east Valikamam	Navaranjan et al. (2018)
2019	10.0 11.8 15.8	Annaikoddai Kalviyankadu Palai	Mahagamage et al. (2019)

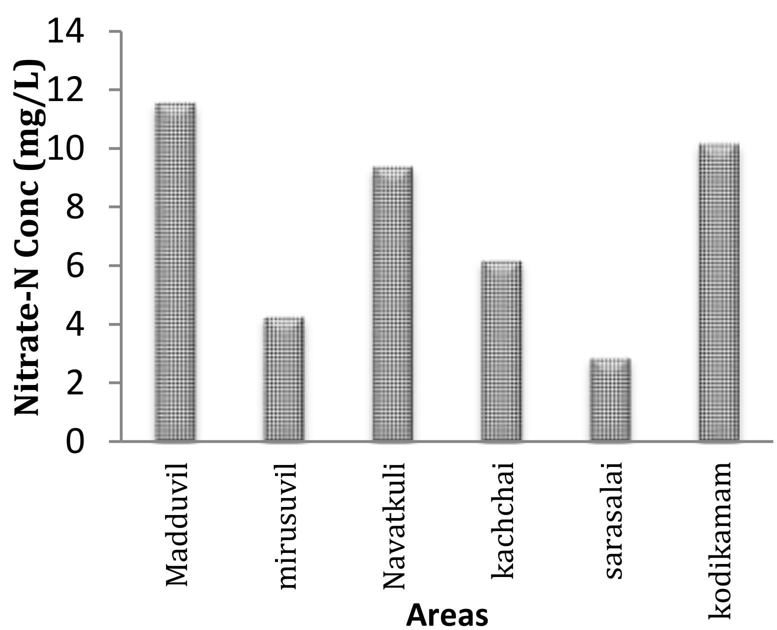

Figure 2. Nitrate-N concentration in Thenmarachchi aquifer in 2001.

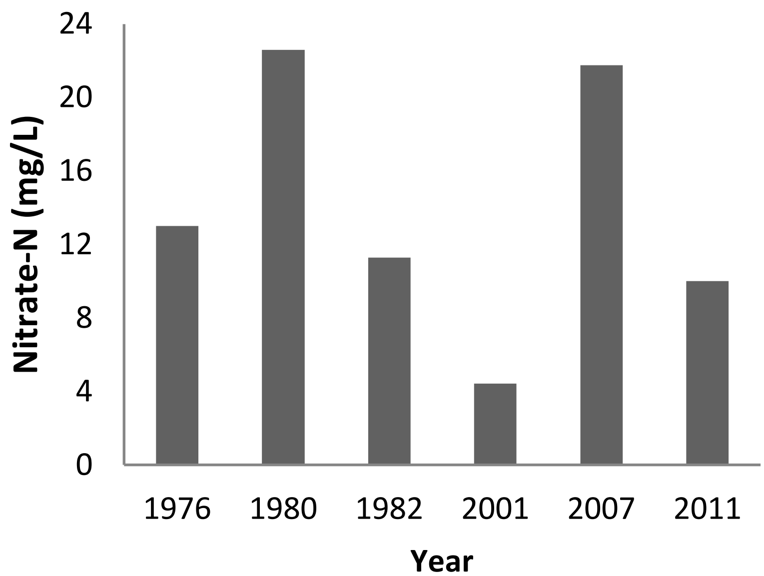

Figure 3. Nitrate-N Concentration pattern in Vadamarachchi aquifer.

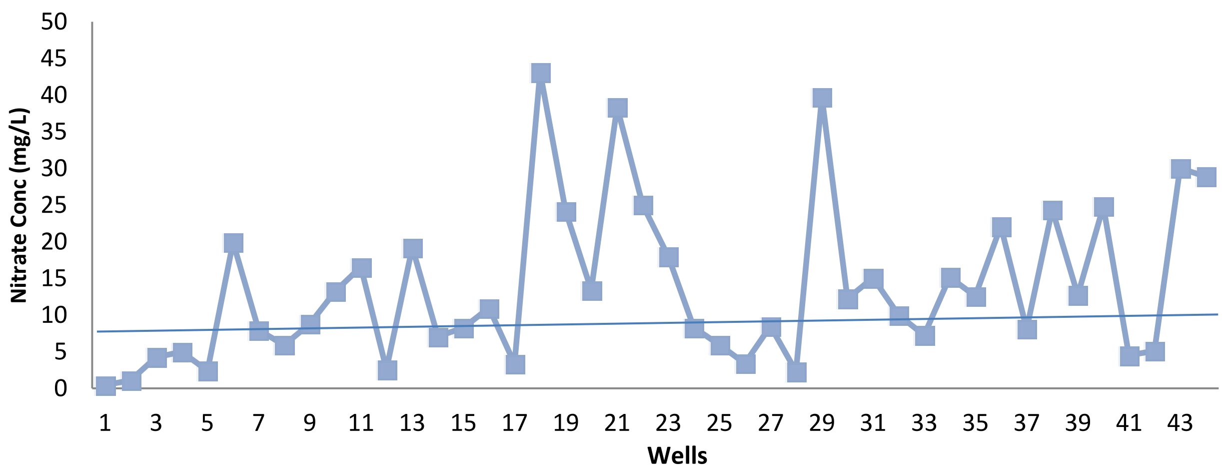

Figure 4. Nitrate-N concentration pattern in Chunnakam aquifer in 2015.

RECOMMENDATION/SUGGESTION

University and other research institutions can provide research findings and educational program on groundwater management on nitrate pollution. Soil fertility, soil type and crop type are considered for reducing nitrate in ground water. Best management practices have to be done to protect water quality by reducing nitrate content from urban and rural areas water sources. Restoring and protecting land and water resources can preserve environment.

Waste water management regulation, discharge of municipal and industrial waste to treatment system and municipal sludges, and biosolids liquids removal in proper way can reduce the nitrate content in the environment. Impacts of leakage should be avoided. Removal of manure, animal waste management practices and feed technology should be implemented. Septic tank design, placement, standards and maintenance should be controlled by the suitable authority.

Nitrate intensified places in Jaffna peninsula within the four aquifers should be identified properly. Mapping need to be done according to the agriculture and non-agriculture areas. With the help of municipal council and water board, household well intensity and agricultural wells will be monitored to reduce the nitrate content in Jaffna peninsula. Management of household waste, industries and buildings sludge disposals need to be done immediately with assurance.

Awareness program for peoples living in Jaffna especially for farmers could be conducted to educate them on the consequences of over application of fertilizers and its impact on groundwater quantity and quality.

Removal of nitrate

Water treatment processes for reducing nitrate concentrations in ground water could be commenced. However, the feasibility of non-treatment alternatives should always be considered first. Possible non-treatment options include drilling a new well, connecting to an adjacent system, removing sources of nitrate contamination, and blending with a low nitrate source. Blending is typically more cost-effective than installing treatment plant. In some cases, it will not be feasible to implement a non-treatment alternative, so treatment process must be considered. There are number of methods to remove nitrate from the contaminated water such as ion exchange, reverse osmosis, and electrodialysis while biological denitrification and chemical denitrification transform nitrate to other nitrogen species through reduction.

Ion exchange

The most commonly used nitrate treatment method is anion exchange and nitrate removed from the treatment stream by displacing chloride on an anion exchange resin. Subsequently, regeneration of the resin is necessary to remove the nitrate from the resin. Regeneration is done by using a highly concentrated salt solution resulting in the displacement of nitrate by chloride. Concentrated waste brine solution contains high in nitrate content and that requires disposal which is very costly.

Reverse osmosis

It is the common nitrate treatment alternative. Most of the nitrate is removed, along with other dissolved ions (desalination).

Electrodialysis

It is an electrochemical process in which ions migrate through ion selective membranes due to their attraction to oppositely charged electrodes.

CONCLUSION

The quality of water for any use is determined by the total amount and the type of contaminants present in the water. Water quality is judged on the potential severity of problems expected to develop over the long term. It is, therefore, essential to establish easily accessible information on water quality and availability that is required for future studies or project planning in Jaffna peninsula. Although several studies have been undertaken on groundwater quality in the Peninsula, no systematic studies have been carried out to characterize the water quality and recharge potentials of aquifers in the Jaffna peninsula. Without any consideration on nitrate reduction from groundwater in Jaffna peninsula, nitrate pollution will affect larger areas and water scarcity occurs for the livelihood in Jaffna.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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