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In depth analysis of groundwater quality and use of *Moringa oleifera* leaf powder treatment to improve physico-chemical properties and drinkability of contaminated groundwater

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ABSTRACT

Groundwater is the major source for domestic, and other uses in the Jaffna Peninsula, Sri Lanka. This study assessed the spatial and seasonal variation of physical and chemical parameters of water collected from domestic wells in Chunnakam and Vadamaradchi aquifers. The measured physicochemical parameters were compared with the drinking water standards established by Sri Lanka Standards Institution.

Significant spatial variations in the water quality parameters were identified in both areas. Significantly elevated levels of nitrate and oil & grease were identified in Chunnakam, whereas significantly elevated levels of DO and pH were recorded in Vadamaradchi. Nitrate concentration of the wells ranged between 0.021–40.1 mg/L. Oil & grease of these wells ranged from 0.011 to 0.373 mg/L. In Chunnakam, 60% of sampled wells had nitrate level above the permitted nitrate standard level, and all the wells had elevated oil and grease concentration above the permitted standard limit. Filtration of water through *Moringa oleifera* leaf powder could significantly reduce the nitrate an oil and grease concentrations, thereby improving the quality of water.

1. Introduction

In Sri Lanka, the groundwater resources are considered to be lesser in extent than surface water resources. However, the available groundwater resources are widely concentrated in the Jaffna peninsula, which is located in the northernmost region of the country. The Jaffna Peninsula has four main types of aquifer systems, namely Chunnakam (Valikamam area), Thenmaradchi, Vadamaradchi and Kayts (Puvaneswaran, 1986). These groundwater aquifers are very important in providing domestic, irrigation, industrial water supplies.

Although all the human settlements in other parts of the country were near to rivers and wetlands for easy access to water, the shallow aquifers and easy access to groundwater favored the human settlements in the Jaffna Peninsula. The extent of the Jaffna Peninsula is 1025 km^2 and is considered as one of the most densely populated districts in Sri Lanka (Department of census and statistics 2015). In the past decade, intensive rehabilitation and development activities were conducted in Jaffna and agricultural activities are expanding throughout the peninsula.

The excessive usage of ground water resources have caused many water scarcity problems in this area. The groundwater resources are recharged by the rainwater and the seasonality and uncertainty of rainfall greatly affects the quantity and quality of groundwater (Vigneswaran et al., 2015). Also the non-sustainable ground water extraction methods and contamination due to non point source pollution have severely degraded the ground water quality in the aquifers of Jaffna Peninsula (Arumugam, 1970; Nandakumar, 1983). However, recent studies have not been conducted to assess the quality of the groundwater resources in this part of the country. Therefore, the present study as aimed at in depth analysis of physical and chemical parameters in the well water collected from two major aquifer systems, namely, Chunnakam and Vadamaradchi in Jaffna peninsula.

Plant based water treatment procedures for treatment of contaminated water is widely practiced in many parts of the world. These water treatment methods include treatment of contaminated water with extracts and powdered material of seeds, leaves and roots of different species of plants. Among the plant material tested, the seeds of *Moringa oleifera* is considered as one of the most effective primary coagulant for water treatment and its coagulant ability is considered to be similar to the most widely used conventional chemical coagulant, alum (Amagloh and Benang, 2009). Also, The *Moringa oleifera* leaf extract have effectively reduced water hardness, total dissolved solids, sulphate and nitrate concentration in the water (Jahn, 1989). *Moringa oleifera* is recommended as a suitable green water treatment source to be used in

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developing countries due to its common availability, low cost and effective coagulant ability (Amagloh and Benang, 2009). *Moringa oleifera* is a commonly grown plant in the Jaffna peninsula of Sri Lanka as the leaves and fruits of the plant are consumed as a vegetable and many other parts of the tree is used for medicinal purposes. However, the possibility of using *Moringa oleifera* as a plant based water treatment method is not currently practiced or researched in Sri Lanka. The present study conducted to assess the spatial and temporal variation of water quality parameters in Chunnakam and Vadamaradchi, also assessed the effectiveness of filtration through powdered leaves of *Moringa oleifera* to improve drinking water quality in domestic well water.

2. Methodology

This study focused Vadamaradchi and Chunnakam aquifers in the Jaffna peninsula, Sri Lanka. The Vadamarachchi area is fed by the Vadamarachchi aquifer, and is recorded as the most uncontaminated aquifer in Jaffna Peninsula. Chunnakam area is fed by the Chunnakam aquifer which is contaminated with high nitrate and suspected to be contaminated with crude oil. From each area, 10 domestic wells were randomly selected and ten replicate water samples were collected from each well and preserved in accordance with APHA, 1998. The map of the sampling sites are given in Fig. 1.

The temperature, salinity, pH, electrical conductivity, dissolved oxygen concentration, total dissolved solids of each water sample were measured in-situ using pre-calibrated multi parameter water quality checker (HACH model : H940). The water samples were preserved in accordance with APHA, 1998 and were transported to the laboratory of the Department of Zoology and Environmental Management, University of Kelaniya, Sri Lanka. In the laboratory, chemical oxygen demand (COD), nitrate concentration, total phosphorus concentration, total hardness, total solids and oil and grease concentration were measured following the methodologies described in APHA, 1998. In order to assess the spatial variation of water quality parameters during dry and rainy seasons, sampling of each well (Fig. 1) was done at monthly intervals covering both rainy and dry seasons in 2016.

2.1. Filtration through Moringa oleifera leaf powder

The *Moringa oleifera* leaf powder was prepared as described by Saduzaman et al., 2013. The fresh mature *Moringa oleifera* leaves were rinsed with distilled water and was shade dried. The shade dried leaves were grinded into powder form using grinder (Bright elegant- 240V6A). The resulted powder was stored in a desiccator at a cool dry place until used in the filtration experiment. In the filtration experiment, 1 g leaf powder was added to a glass filtration column and 1 L of raw water were filtered through the leaf powder column. The nitrate n and oil and grease concentrations of the samples before and after filtration were measured following the methodologies described in APHA, 1998.

2.2. Statistical analysis

After confirming the normality using Anderson Darling test, the data were analyzed using ANOVA followed by Tukey's pairwise comparison test to study the spatial and temporal variation of water quality parameters. Principal component Analysis (PCA) was performed to study the categorization of sampled domestic wells based on the water quality parameters. Paired *t*-test was used to analyze the significance of differences in nitrate N and oil and grease concentration in water before and after the filtration through *Moringa oleifera* leaf powder. MINITAB 14 statistical software package was used in the statistical analysis.

2.3. Comparison with drinking water quality standards and classification of the groundwater

The measured physico-chemical parameters in domestic wells were compared with the drinking water quality standards established by Sri Lanka Standards Institution (SLSI - SLSI 614, 2013).

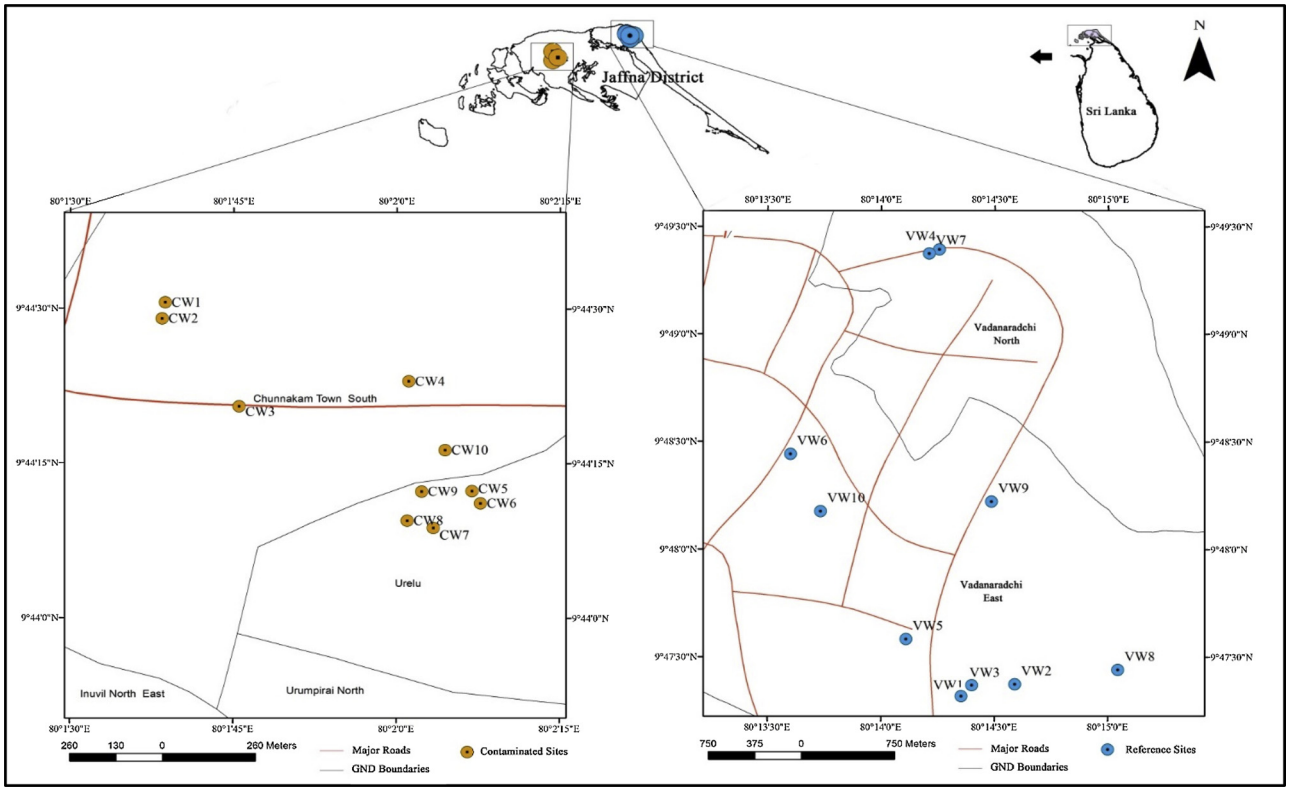

Fig. 1. Map of the study area showing the sampled wells. (CW – wells in the Chunnakam area; VW – wells in the Vadamaradchi area).

Table 1
The spatial variation of mean ± standard deviation(SD) of physico – chemical parameters of wells at Chunakkam. For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (ANOVA, Tukey's pairwise comparison, n = 10).

Parameter	CW1	CW2	CW3	CW4	CW5	CW6	CW7	CW8	CW9	CW10
pH	7.0 ± 0.1^{a}	7.2 ± 0.1^{a}	7.2 ± 0.1^{a}	7.4 ± 0.1^{a}	7.6 ± 0.03^{a}	7.4 ± 0.03^{a}	7.3 ± 0.03^{a}	7.5 ± 0.1^{a}	7.5 ± 0.1^{a}	7.6 ± 0.1^{a}
DO (mg/ L)	4.5 ± 1.6^{a}	5.4 ± 1.2^{a}	4.9 ± 1.4^{a}	5.3 ± 1.3^{a}	8.1 ± 0.5^{b}	6.9 ± 0.6^{b}	5.9 ± 0.9^{a}	6.7 ± 0.8^{b}	6.8 ± 0.7^{b}	4.9 ± 1.5^{a}
COD (mg/L)	7.0 ± 2.0^{a}	6.76 ± 1.4^{a}	7.2 ± 1.8^{a}	7.9 ± 1.1^{a}	5.7 ± 2.5^{a}	5.7 ± 1.3^{a}	6.5 ± 1.8^{a}	6.2 ± 1.5^{a}	5.7 ± 2.7^{a}	4.1 ± 1.6^{a}
EC (μs/cm)	763.1 ± 54.3^{a}	761.1 ± 13.3^{a}	950.3 ± 25.9^{b}	503.0 ± 64.2^{c}	574.1 ± 76.1^{c}	688.0 ± 24.2^{c}	622.7 ± 18.9^{c}	710.7 ± 44.9^{a}	760.2 ± 10.9^{a}	588.2 ± 42.3^{c}
TDS (mg/L)	372.0 ± 25.7^{a}	371.8 ± 6.5^{a}	467.0 ± 13.5^{b}	243.7 ± 32.0^{c}	278.9 ± 37.5^{c}	335.2 ± 12.2^{a}	303.1 ± 9.1^{a}	350.8 ± 24.6^{a}	375.7 ± 5.7^{a}	286.0 ± 20.9^{a}
Salinity (ppt)	0.4 ± 0.03^{a}	0.4 ± 0.01^{a}	0.5 ± 0.01^{a}	0.2 ± 0.03^{b}	0.3 ± 0.04^{b}	0.3 ± 0.01^{b}	0.3 ± 0.01^{b}	0.3 ± 0.02^{b}	0.4 ± 0.01^{a}	0.3 ± 0.02^{b}
Temperature (°C)	30.0 ± 0.2^{a}	30.4 ± 0.4^{a}	29.4 ± 0.1^{a}	29.6 ± 0.2^{a}	30.0 ± 0.2^{a}	30.9 ± 0.6^{a}	30.4 ± 0.5^{a}	30.5 ± 0.6^{a}	29.9 ± 0.1^{a}	29.5 ± 0.7^{a}
Total Solids (mg/L)	488.9 ± 45.9^{a}	460.0 ± 50.0^{a}	622.2 ± 48.4^{a}	468.9 ± 42.9^{a}	540.0 ± 70.7^{a}	517.8 ± 74.8^{a}	557.8 ± 71.2^{a}	575.6 ± 82.3^{a}	571.1 ± 45.9^{a}	528.9 ± 66.9^{a}
Total Hardness (mg/L $CaCO_3$)	223.0 ± 51.1^{a}	237.2 ± 38.8^{a}	241.5 ± 41.5^{a}	197.1 ± 32.1^{a}	198.3 ± 42.4^{a}	250.6 ± 16.4^{a}	241.1 ± 22.5^{a}	252.5 ± 10.0^{a}	216.3 ± 23.3^{a}	193.0 ± 46.7^{a}
Oil and Grease (mg/L)	0.4 ± 0.07^{a}	0.3 ± 0.07^{a}	0.2 ± 0.04^{a}	0.3 ± 0.04^{a}	0.4 ± 0.06^{a}	0.3 ± 0.1^{a}	0.2 ± 0.03^{a}	0.3 ± 0.1^{a}	0.3 ± 0.1^{a}	0.2 ± 0.05^{a}
Nitrate N (mg/L)	6.4 ± 0.4^{a}	3.1 ± 0.8^{b}	3.1 ± 0.5^{b}	9.3 ± 0.1^{c}	37.4 ± 5.2^{d}	40.0 ± 2.9^{d}	21.1 ± 5.5^{d}	18.2 ± 2.4^{c}	12.7 ± 3.4^{c}	11.5 ± 2.6^{c}
Total Phosphorous (mg/L)	0.1 ± 0.02^{a}	0.1 ± 0.03^{a}	0.1 ± 0.02^{a}	0.1 ± 0.01^{a}	0.1 ± 0.02^{a}	0.1 ± 0.02^{a}	0.1 ± 0.02^{a}	0.1 ± 0.01^{a}	0.1 ± 0.01^{a}	0.1 ± 0.01^{a}

3. Results

3.1. Water quality in Chunnakam

The mean ± standard deviation (SD) of spatial variation of the water quality parameters in the Chunnakam area is given in Table 1.

Dissolved oxygen (DO) in the wells of the Chunakam area ranged between 7.0 to 8.6 mg/L and well numbers 5(CW5), 6(CW6), 8(CW8) and 9(CW9) recoded significantly high DO concentrations compared to the other wells in the area. Chemical oxygen demand (COD) of the Chunnakam area ranged from 4.1 to 7.9 mg/L; total hardness (TH) ranged from 192.0 to 252.5($CaCO_3$) mg/L the oil & grease values ranged in between 0.1- 0.4 mg/L and the total phosphorous (TP) values ranged from 0.050 to 0.113 mg/L. However, the mean values for TH, COD, oil &grease and TP did not show significant variations among wells in the Chunnakkam area throughout the study period ($p > 0.05$). The nitrate- N concentration (TN) ranged from 3.11 to 40.1 mg/L. Significantly high mean TN values were recorded in CW4, CW8, CW9 and CW10 (Table 1). The electrical conductivity (EC) values ranged in between 503.0–950.3 μS/cm; the total dissolved solids (TDS) ranged in between 247.3 to 467.0 mg/L and the salinity ranged in between 0.24 to 0.46‰. Well number 4 (CW4) showed the significantly lowest mean EC, TDS and salinity throughout the study period and the well number 3 (CW3) showed the significantly highest value ($p < 0.05$) for these parameters throughout the study period.

3.2. Water quality in Vadamaradchi

The mean ± SD of spatial variation of the water quality parameters in the Vadamaradchi area is given in Table 2. The pH value of the wells from Vadamaradchi area ranged from 7.53 to 8.33 and the DO value of the wells ranged from 6.89 to 8.60 mg/L., the water temperature ranged from 29.5 to 30.0 °C. The pH, DO and water temperature of the well water in Vadamaradchi area did not show statistically significant spatial variation throughout the study period (One way ANOVA, $p > 0.05$). The EC, TDS, salinity, TS and TH showed a broader range of variation. The EC values ranged in between 168.8 to 905.0 μS/cm and the TDS values ranged in between 80.1 to 758.2 mg/L.

Well number 8 (VW8) showed the significantly lowest mean values for EC and TDS and the Well number 10 (VW10) showed the significantly highest values for these parameters. The salinity ranged from 0.08 to 0.58‰. Well number 8 (VW8) showed the significantly lowest mean salinity and the well number 5(VW5) and 10 (VW10) showed significantly highest mean salinity. The TS ranged from 95.6 to 957.8 mg/L and the TH values are ranged from 67.5 to 332.3 ($CaCO_3$) mg/L. Well number 8 (VW8) showed the significantly lowest mean value for TS and TH compared to other wells (ANOVA, Tukey's test, $p < 0.05$).

The COD values ranged from 4.65 to 9.97 mg/L; the oil & grease values ranged from 0.011 to 0.033 mg/L and the TP values ranged from 0.070 to 0.113 mg/L. However, the mean values for COD and oil & grease in Vadamaracchi did not show significant spatial variations throughout the study period (ANOVA, Tukey's test, $p > 0.05$). The nitrate- N concentration ranged from 0.021 to 7.87 mg/L. Significantly highest mean nitrate-N value was recorded in Well number 6 (VW6), and significantly lowest nitrate N concentration was recorded in VW8 (Table 2).

3.3. Temporal variation of water quality parameters

Comparison of mean ± standard deviation (SD) of the water quality parameters in the Chunnakam and Vadamaradchi areas during dry and wet seasons are given in Table 3. There was no significant variation in the water quality parameters in the Vadamarachchi area during rainy and dry seasons (Table 3). The mean DO and TH in the Chunnakam area during the rainy season were significantly high

Table 2
The spatial variation of mean ± standard deviation (SD) of physico – chemical parameters of wells at Vadamaracchi, For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (ANOVA, Tukey's pairwise comparison, n = 10).

Parameter	VW1	VW2	VW3	VW4	VW5	VW6	VW7	VW8	VW9	VW10
pH	7.8 ± 0.2 ^{a}	7.9 ± 0.1 ^{a}	8.0 ± 0.3 ^{a}	7.9 ± 0.4 ^{a}	8.2 ± 0.4 ^{a}	7.5 ± 0.3 ^{a}	7.8 ± 0.3 ^{a}	8.2 ± 0.2 ^{a}	8.1 ± 0.2 ^{a}	7.8 ± 0.3 ^{a}
DO (mg/ L)	6.9 ± 1.1 ^{a}	6.9 ± 1.1 ^{a}	6.9 ± 1.4 ^{a}	7.6 ± 0.6 ^{a}	6.9 ± 1.0 ^{a}	6.9 ± 0.8 ^{a}	7.7 ± 0.6 ^{a}	8.6 ± 0.3 ^{a}	7.0 ± 0.6 ^{a}	7.1 ± 0.5 ^{a}
COD (mg/L)	8.7 ± 1.4 ^{a}	7.4 ± 0.7 ^{a}	9.1 ± 1.0 ^{a}	8.7 ± 2.2 ^{a}	9.9 ± 1.6 ^{a}	6.2 ± 2.6 ^{a}	7.6 ± 0.5 ^{a}	4.6 ± 1.2 ^{a}	6.6 ± 0.7 ^{a}	6.7 ± 2.4 ^{a}
EC (µs/cm)	846.5 ± 84.3 ^{a}	492.1 ± 63.3 ^{b}	671.8 ± 81.7 ^{a}	862.8 ± 31.7 ^{a}	1290.1 ± 56.1 ^{c}	812.3 ± 36.9 ^{a}	857.9 ± 27.7 ^{a}	168.8 ± 6.9 ^{d}	773.0 ± 21.0 ^{a}	1528.1 ± 55.5 ^{c}
TDS (mg/L)	416.1 ± 71.9 ^{a}	237.5 ± 54.0 ^{b}	327.8 ± 4.1 ^{b}	422.1 ± 1.5 ^{b}	616.0 ± 88.2 ^{c}	397.6 ± 8.2 ^{b}	413.3 ± 9.5 ^{b}	80.1 ± 3.3 ^{d}	387.0 ± 6.1 ^{b}	758.2 ± 24.4 ^{c}
Salinity (ppt)	0.4 ± 0.07 ^{a}	0.2 ± 0.05 ^{a}	0.3 ± 0.04 ^{a}	0.4 ± 0.02 ^{a}	0.6 ± 0.05 ^{b}	0.4 ± 0.02 ^{a}	0.4 ± 0.02 ^{a}	0.1 ± 0.01 ^{a}	0.3 ± 0.01 ^{a}	0.5 ± 0.02 ^{b}
Temperature (°C)	29.9 ± 0.1 ^{a}	29.8 ± 0.04 ^{a}	29.8 ± 0.1 ^{a}	29.9 ± 0.07 ^{a}	30.0 ± 0.05 ^{a}	29.6 ± 0.3 ^{a}	29.6 ± 0.2 ^{a}	29.9 ± 0.1 ^{a}	29.5 ± 0.4 ^{a}	30.0 ± 0.04 ^{a}
Total Solids (mg/L)	637.9 ± 85.9 ^{a}	360.0 ± 59.8 ^{b}	473.3 ± 8.8 ^{b}	675.6 ± 52.4 ^{a}	869.4 ± 78.2 ^{a}	455.6 ± 8.8 ^{b}	584.4 ± 9.2 ^{b}	95.6 ± 4.4 ^{c}	571.1 ± 8.9 ^{b}	957.9 ± 74.9 ^{a}
Total Hardness (mg/L $CaCO_3$)	309.8 ± 17.2 ^{a}	206.3 ± 26.3 ^{a}	245.7 ± 23.3 ^{a}	265.1 ± 16.9 ^{a}	332.3 ± 39.4 ^{a}	249.0 ± 12.1 ^{a}	248.6 ± 15.5 ^{a}	67.5 ± 14.3 ^{b}	302.7 ± 21.3 ^{a}	317.4 ± 8.7 ^{a}
Oil and Grease (mg/L)	0.03 ± 0.009 ^{a}	0.02 ± 0.002 ^{a}	0.02 ± 0.009 ^{a}	0.02 ± 0.01 ^{a}	0.02 ± 0.008 ^{a}	0.02 ± 0.005 ^{a}	0.03 ± 0.008 ^{a}	0.02 ± 0.004 ^{a}	0.01 ± 0.005 ^{a}	0.03 ± 0.008 ^{a}
Nitrate N (mg/L)	0.3 ± 0.1 ^{a}	0.3 ± 0.1 ^{a}	0.4 ± 0.3 ^{a}	3.2 ± 0.1 ^{b}	0.3 ± 0.2 ^{a}	7.9 ± 1.9 ^{c}	2.8 ± 0.7 ^{b}	0.2 ± 0.1 ^{a}	0.2 ± 0.1 ^{a}	1.4 ± 0.2 ^{b}
Total Phosphorous (mg/L)	0.09 ± 0.002 ^{a}	0.1 ± 0.01 ^{a}	0.09 ± 0.02 ^{a}	0.1 ± 0.02 ^{a}	0.1 ± 0.02 ^{a}	0.1 ± 0.03 ^{a}	0.1 ± 0.02 ^{a}	0.1 ± 0.02 ^{a}	0.1 ± 0.01 ^{a}	0.1 ± 0.01 ^{a}

compared to that of the dry season and the other water quality parameters did not show significant differences during rainy and dry seasons. The mean pH, TDS, salinity, temperature, TS, COD and TP of the domestic wells in the Chunakkam and Vadamarachchi areas did not show significant differences in both rainy and dry seasons. However, the mean DO and EC of the wells in Chunnakam area was significantly lower than that of the Vadamarachchi in both rainy and dry seasons. The mean Nitrate N and oil and grease concentrations of the wells in Chunnakam area was significantly higher than that of the Vadamarachchi in both rainy and dry seasons.

3.4. Principal component analysis

The results of the principal component analysis based on the physical and chemical parameters of well water of domestic wells in Chunnakam and Vadamaradchi areas are given in Fig. 2.

The eigenvalues of the first two principal components, eigenvectors of the water quality parameters and the principal component scores for the study sites are given in Table 4. Two principal components displaying a cumulative variance of 88.8% were obtained after applying PCA on water quality parameters (Table 4). According to the results of the PCA on water quality parameters, the domestic wells of the Chunnakam and Vadamaradchi areas were clearly categorized into 4 groups (Fig. 2). The wells VW 2 and VW 8 of Vadamaradchi area were categorized into one group and they were characterized by high DO. The VW 10 of Vadamaradchi area and CW 3 of Chunnakam area were categorized together and were characterized by high EC, TDS, TH and salinity, Other wells of the Chunnakam area were categorized into a single group and were categorized by high oil and grease content and high nitrate content. The other wells in the Vadamaradchi area were characterized by high pH and high COD (Fig. 2, Table 4).

3.5. Comparison of water quality parameters with the drinking water standards

The drinking water standards established by the Sri Lanka Standards Institution (SLSI - SLSI 614, 2013) for selected water quality parameters and the percentage of wells exceeding or at the marginal level of these standard levels are given in Table 5.

The pH, COD, TDS and TP of the well water in both Chunnakam and Vadamaradchi areas did not exceed the SLSI drinking water standards. However, 10% of the wells in the Chunnakam area and 60% of the wells in Vadamaradchi area exceeded the SLSI drinking water standards for electrical conductivity (Table 5). The well number 8 (VW8) of the Vadamaradchi area which is used as a service well to provide water to other parts of the Jaffna Pennsula recoded the lowest mean EC during the study period (Table 2). When the total hardness is considered 20% of the wells in the Chunnakam area and 70% of the wells in Vadamaradchi area exceeded the SLSI drinking water quality standards (Table 5). None of the wells in Vadamaradchi area exceeded the SLSI drinking water quality standards for oil and grease and nitrate N. However, in the Chunnakam area, all the wells were above or at the marginal level of the SLSI drinking water quality standards for oil and grease and 60% of the wells exceeded the SLSI drinking water quality standards for nitrate N (Table 5).

3.6. Filtration through Moringa oleifera leaf powder

The nitrate concentration and oil and grease concentration of the water samples collected from domestic wells in the Chunnakam and Vadamaradchi before and after filtration through *Moringa oleifera* leaf powder is given in Table 6.

The filtration through Moringa oleifera leaf powder significantly reduced nitrate N and oil and grease concentrations in both Chunnakam and Vadamaradchi areas (Table 6). The percentage reduction of nitrate N in Chunnakam and Vadamaradchi were 17.6% and 11.6%

Table 3
The temporal variation of mean ± standard deviation (SD) of physico − chemical parameters of wells at Chunnakam and Vadamaracchi during rainy and dry periods. For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (ANOVA, Tukey's pairwise comparison, n = 10).

	Chunnakam		Vadamaracchi	
Parameters	Rainy	Dry	Rainy	Dry
pH	7.39 ± 0.04[a]	7.36 ± 0.07[a]	7.92 ± 0.01[a]	7.93 ± 0.01[a]
DO (mg/L)	5.35 ± 0.52[a]	6.2 ± 0.03[b]	7.15 ± 0.15[c]	8.61 ± 0.14[c]
Conductivity (μS/cm)	731.2 ± 31.9[a]	672.7 ± 51.9[a]	798.0 ± 115.0[b]	871.0 ± 115.0[b]
TDS (mg/L)	356.9 ± 16.0[a]	329.3 ± 25.8[a]	392.2 ± 57.4[a]	412.3 ± 57.6[a]
Salinity (‰)	0.35 ± 0.02[a]	0.033 ± 0.03[a]	0.39 ± 0.06[a]	0.38 ± 0.06[a]
Temperature (∘C)	30.22 ± 0.32[a]	30.73 ± 0.09[a]	29.90 ± 0.03[a]	29.91 ± 0.05[a]
TS (mg/L)	500.0 ± 24.3[a]	545.9 ± 21.4[a]	650.0 ± 113.0[a]	527.0 ± 67.7[a]
TH (ppm,$CaCO_3$)	173.3 ± 14.0[a]	250.8 ± 14.6[b]	235.4 ± 23.30[b]	263.8 ± 31.1[b]
COD (mg/L)	6.36 ± 1.23[a]	6.24 ± 0.72[a]	7.91 ± 1.33[a]	7.06 ± 0.45[a]
Oil & grease (mg/L)	0.244 ± 0.079[a]	0.249 ± 0.035[a]	0.027 ± 0.005[b]	0.021 ± 0.003[b]
Nitrate- N (mg/L)	16.03 ± 5.33[a]	16.80 ± 4.07[a]	1.31 ± 0.44[b]	1.88 ± 0.85[b]
Total phosphate (mg/L)	0.061 ± 0.005[a]	0.086 ± 0.008[a]	0.091 ± 0.008[a]	0.108 ± 0.010[a]

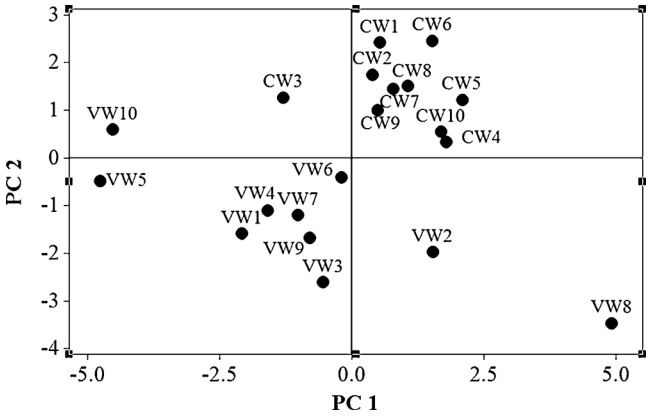

Fig. 2. Ordination of the study sites based on PC1 and PC2 scores of PCA of the physico-chemical parameters of water sampled from the domestic wells in Chunnakam and Vadamaradchi areas. (CW – wells in the Chunnakam area; VW – wells in the Vadamaradchi area).

Table 5
The drinking water standards established by the Sri Lanka Standards Institution (SLSI - SLSI 614, 2013) for selected water quality parameters and the percentage of wells exceeding or at the marginal level of these standard levels.

Parameter	SLSI drinking water standards	Percentage of wells exceeding or at the margin of the SLSI drinking water standards (%)	
		Chunnakam	Vadamaradchi
pH	6.5 – 8.5	0	0
EC (μS/cm)	800	10	60
TDS (mg/L)	500	0	0
Total Hardness (mg/L, $CaCO_3$)	100	20	70
COD (mg/L)	10	0	0
Oil & grease (mg/L)	0.2	100	0
Nitrate- N (mg/L)	10	60	0
Total phosphate (mg/L)	2.0	0	0

Table 4
Summary of the PCA of physico-chemical parameters of water sampled from the domestic wells in Chunnakam and Vadamaradchi areas. Cumulative % variation of only the PC1 and PC2 are shown. A high cumulative percentage as high as 66.2% of the total variation among physico-chemical parameters are explained by PC1 and PC2 axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.02	41.8	41.8
2	2.90	47.0	88.8

Eigenvectors

(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Water pH	-0.094	-0.497	0.297	0.138	0.022
DO	0.011	−0.339	0.613	0.139	0.100
COD	-0.295	−0.164	−0.095	−0.444	-0.442
EC	−0.423	0.127	0.058	0.151	0.026
TDS	−0.421	0.128	0.057	0.154	0.046
Salinity	−0.389	0.184	−0.067	0.086	0.029
Temperature	0.057	0.286	0.530	−0.327	−0.564
Total solids	−0.400	0.171	0.128	0.077	0.212
Total hardness	−0.400	0.089	0.102	−0.170	0.049
Oil and Grease	0.185	0.485	−0.043	−0.133	0.110
Nitrate N	0.178	0.360	0.452	−0.096	0.409
Total Phosphorus	0.089	0.247	0.052	0.736	−0.496

Table 6
The mean ± SD concentration of nitrate N and oil and grease, before and after filtration through *Moringa oleifera* leaf powder. For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (Paired *t*-test, n = 5).

Parameters	Site	Before	After	Percentage reduction (%)
Nitrate-N (mg/L)	Chunnakam	16.80 ± 4.07[a]	13.84 ± 3.37[b]	17.6
	Vadamaradchi	1.80 ± 0.85[a]	1.59 ± 0.77[b]	11.6
Oil & grease (mg/L)	Chunnakam	0.285 ± 0.04[a]	0.183 ± 0.006[b]	35.8
	Vadamaradchi	0.016 ± 0.003[a]	0.012 ± 0.003[b]	25

respectively. The percentage reduction of oil and grease in Chunnakam and Vadamaradchi were 35.8% and 25% respectively.

4. Discussion

The drinking water quality of groundwater can be measured by a combination of physicochemical parameters along with microbial parameters (Nanthini et al., 2010). Thus it is important to ensure that the water is safe for consumption as certain constituents in very low or high concentrations have the potential of causing chronic health problems. High nitrate concentration in drinking water in the Chunnakam area is considered as a nationally important water quality problem in Sri Lanka. In the recent years, the requirements for intensification of agricultural activities in Jaffna peninsula have resulted in excessive use of artificial fertilizer, thus resulting in leaching of excess fertilizer to groundwater (Sutharsiny et al., 2014).

The classification scheme for selected water quality parameters proposed by Kempster et al. (1997) for classification of drinking water sources is given in Table 7. According to this classification system, the physical and chemical water quality parameters are used to categorize drinking water sources in to 4 categories as follows:

Category 0: This is ideal water quality, suitable for lifetime use, with no adverse health eff ;ects on the user;

Category I: Water is safe for lifetime use, but is not of ideal water quality as the resources in this category may result in mild adverse health eff ;ects in some occasions.

Category II: water is suitable for short-term or emergency use only, but not necessarily suitable for continuous use over a lifetime. There is no adverse health effects caused if the water in this class is used for a short term, however, adverse health eff ;ects may become more common particularly with prolonged use over many years, or with lifetime use.

Category III: Water is not suitable for use as drinking water without adequate treatment to shift the water into a lower and safer category The water in this category has constituents in a concentration range where serious health eff ;ects might be anticipated, particularly in infants or elderly people with short-term use, and even more so with longer term use.

Based on mean pH of the water collected from Chunnakam and Vadamaradchi areas, all the samples wells are classified into category 0,

Table 7
The classification system of drinking water sources based on the concentration of physico-chemical parameters (Source: Kempster et al., 1997).

Parameter	Category 0	Category I	Category II	Category III
Total dissolved solids (mg/ L)	0-450	450-1000	1000-2450	> 2450
Electrical conductivity (μS/cm)	0-700	700-1500	1500-3700	> 3700
Nitrate- N (mg/L)	0-6	6-10	10-20	> 20
pH	6-9	5-6 or 9-9.5	4-5 0r 9.5 - 10	< 4 or > 10

where in terms of pH the water is safe for lifetime use (Tables 1, 2 and 7). However, in terms of total dissolved solids, the well number 5 (VW 5) and 10 (VW 10) in Vadamaradchi area and well number 3 (CW3) in Chunnakam area are classified into category I. All the other sampled wells in both areas are in category 0. When the mean EC is considered, 55% of the sampled wells from both areas are classified into category I and 40% of the wells are in category 0. In terms of EC, well number 10 (VW 10) of Vadamaradchi area is categorized to category II and well numbers 1,4,5,6,7,and 9 of Vadamaradchi area and well numbers 1,2,3,8,and 9 of Chunnakam area is categorized to category I. All the other sampled wells are in category 0. When the nitrate concentration is considered, well number 6 (VW 6) in the Vadamaradchi area and well numbers 1 (CW 1) and 4 (CW 4) of Chunnakam area is categorized to category I. all the other wells in the Vadamaradchi area except well number 6 are in category 0 in terms of nitrate concentration. In Chunnakam area, well numbers 8, 9 and 10 are categorized into category II in terms of mean nitrate concentration and well numbers 5,6, and 7 are categorized into category III indicating that the water in those wells are not suitable for use as drinking water without adequate treatment. Only 20% of the wells in the Chunnakam area (Well numbers 2 and 3) are in category 0 in terms of nitrate concentration. In the Vadamaradchi area in terms of all the water quality parameters VW 8 was categorized into category 0. VW 8 is used as a service well to provide water to the areas with poor water quality. Therefore, the results of this study an be used to confirm that this service well has ideal water quality, suitable for lifetime use, with no adverse health eff ;ects on the user.

The ground water of the Jaffna peninsula is recorded to have the highest nitrate content in Sri Lanka. A study in Chunnakam aquifer showed the nitrate-N concentration ranged from 0 to 35 mg/L (Vithanage et al., 2014). During the present study the nitrate-N range from 3.11 to 40.01 mg/L in Chunnakam. The most probable cause for the high concentrations of nitrate in wells could be the excess fertilizers leached to the shallow groundwater. The calcic soil favours the leaching of nitrate-N in to underlying aquifers due to its high permeability in soil layers (Joshua et al., 2013).

In the Chunnakam area, approximately 65% of the population is depending on agriculture as their major livelihood and approximately 34.2% of the land is cultivated intensively with high-value cash crops, such as red onion, chillies, potatoes, tobacco, vegetables, bananas and grapes for commercial purposes (Thadchayini and Thiruchelvam, 2005). The intensive cultivation of cash crops use nitrogenous fertilizers and this is identified as the major reason for increased nitrate concentration in the ground water in Chunnakam area. Nitrate is potentially hazardous when present at sufficiently high levels in drinking water. Methemoglobinemia (blue baby syndrome), especially in infants is due to high nitrate levels in drinking water. The records of the Teaching hospital of Jaffna, also indicates that there is a risk of blue babies in Jaffna (Panabokke, 1984). In addition, in this part of the country, cancers of the oropharynx, oesophagus, stomach, breast and liver are common. Accordance with WHO, the high nitrate content in water could be related to the high prevalence of cancer of the gastrointestinal tract in the people of Jaffna (Sivarajah, 2003). Also, there have been suggestions that nitrate in drinking-water could be associated with congenital malformations and incidences of childhood diabetes mellitus (WHO, 2011).

Contamination of groundwater in Chunnakam area due to nitrate has been studied by many researchers in Sri Lanka (Mageswaran and Mahalingam, 1983; Dissanayake and Weerasooriya, 1985; Nagarajah et al., 1988; Rajasooriyar et al., 2002; Mageswaran, 2003) and these research have recommended to reduce excessive use of nitrogenous fertilizers in agricultural activities. However, due to lack of management and monitoring of fertilizer usage nitrate contamination of ground water has become a continuing water quality problem.

Nowadays, in addition to nitrate contamination, residents complain on crude oil contamination of well water in the Chunakkam area. The

results of the present study also indicated signs of crude oil contamination in the sampled wells in the Chunakkam area. Crude oil contamination of ground water in Jaffna peninsula has been a concern from the year 2008 (Vigneswaran et al., 2015). When the water is contaminated with crude oil, it becomes undrinkable due to the oily smell. Also, the presence of potential toxic hydrocarbon products and heavy metals in crude oil can cause serious health effects. In addition to petroleum hydrocarbons, this contamination may due to hexane-soluble material including soaps, animal fats, waxes, vegetable oil and related substances (Vigneswaran et al., 2015). In the present study, the oil & grease concentration of the wells from Chunnakam area ranged from 0.2 to 0.4 mg/L resulting all the wells exceeding or at the marginal level of SLSI drinking water quality standards (Table 5). However, the exact source of the oil and grease for the oil and grease contamination of the Chunnakam aquifer is unknown and no long term research have been carried out regarding this aspect previously. Therefore, it is essential to continuously monitor the spatial and temporal variation of oil and grease concentration of the ground water in the Chunakam aquifer to maintain healthy water quality.

The filtration through *Moringa oleifera* leaf powder could significantly reduce nitrate N and oil and grease concentrators in water (Table 6). The positively charged proteins in the *Moringa oleifera* leaf powder may have provided adsorbent surfaces to the nitrates and organic component of oil and grease, thereby reducing their concentrations in the solution (Saduzaman et al., 2013). Further reduction in nitrate can be done by allowing the *M. oleifera* leaf filtered water to be settled down. Coagulant capability of *M. oleifera* leaf powder can be used in small scale to reduce nitrate and oil and grease concentration, as the *M. oleifera* tree is commonly distributed in tropical countries including Sri Lanka. However, in terms of mean nitrate N concentration, the filtered water was still categorized into category II of the drinking water source classification scheme proposed by Kempster et al. (1997). Therefore, it is important to further increase the coagulation ability of *M. oleifera* filtrate by supplementing it with another plant based water treatment technique, in order to improve the effectiveness of filtration.

5. Conclusion

This study indicates that there is a significant temporal variation of the water quality parameters in the Chunnakam and Vadamaradchi areas in the Jaffna Penninsula. However, according to the SLSI water quality standards and classification scheme for selected water quality parameters proposed by Kempster et al. (1997), the water quality of the Chunnakam area can be considered as more impaired than that of the Vadamaradchi area. In addition, significantly higher oil and grease level indicates a potential source of crude oil contamination in Chunnakam area. Therefore, it is recommended to continuously monitor the nitrate and oil and grease concentrations in well water and to apply suitable water treatment methods to reduce excess nitrate and oil and grease in drinking water. *Moringa oleifera* leaf powder can be recommended as a suitable home water treatment agent to remove excess nitrates and oil and grease in contaminated water in this area and improvements to the filtration technique may help to overcome the increased nitrate, oil and grease associated water quality problems in the Jaffna peninsula.

Also implementation of regulatory activities to prevent further contamination of groundwater due to the excessive addition of nitrates and oil and grease is of vital importance.

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