Hydrogeochemical Characterization of Jaffna's Aquifer Systems in Sri Lanka

Dr. Thushyanthy Mikunthan, Dr. Meththika Vithanage, Dr. S. Pathmarajah,
Ms. Sutharsiny Arasalingam, Mr. Ranjith Ariyaratne and Dr. H. Manthrithilake

IWMI
International
Water Management
Institute

Front cover photo: H. Manthrithilake, IWMI

Hydrogeochemical Characterization of Jaffna's Aquifer Systems in Sri Lanka

Mikunthan, T.; Vithanage, M.; Pathmarajah, S.; Arasalingam, S.; Ariyaratne, R.; Manthrithilake, H. 2013. ***Hydrogeochemical characterization of Jaffna's aquifer systems in Sri Lanka***. Colombo, Sri Lanka: International Water Management Institute (IWMI). 69p. doi: 10.5337/2014.001

hydrology/ geochemistry / aquifers / groundwater recharge / groundwater table / water levels / water quality / water levels / heavy metals / inorganic fertilizers / organic fertilizers / nitrogen fertilizers / contamination / chlorides / drinking water / domestic water / irrigation water / evapotranspiration / wells / soils / crop management / land use / rainfall patterns / assessment / spatial distribution / Sri Lanka

978-92-9090-824-1

Acknowledgements

This study was conducted with the financial support of the International Water Management Institute (IWMI), Colombo, Sri Lanka. The authors[1] would like to thank the farmers of the Valikamam area in the Jaffna Peninsula who participated in the questionnaire survey; the staff of the National Water Supply and Drainage Board (NWSDB), Jaffna, for their assistance in the collection of water samples and analysis; and the reviewers who helped to improve the report by providing constructive comments.

[1] Dr. Thushyanthy Mikunthan (Jaffna University), Dr. Meththika Vithanage (Institute of Fundamental Studies, Kandy), Dr. S. Pathmarajah (Peradeniya University), Mr. Ranjith Ariyaratne (International Water Management Institute) and Dr. H. Manthrithilake (International Water Management Institute).

Contents

Summary

The Jaffna Peninsula, falls within the dry zone in Sri Lanka, is underlain by Miocene limestone that is considered to have appropriate aquifer properties for groundwater storage and discharge. The absence of perennial rivers or major water supply schemes to the Peninsula highlights the importance of groundwater as the predominant water resource for domestic, industrial and agricultural use. The seasonal rainfall is of short duration, and is the only source of recharge to the limestone aquifer. The Jaffna Peninsula has four main aquifer systems, namely Chunnakam (Valikamam area), Thenmaratchi, Vadamaratchi and Kayts, of which the Valikamam area is intensively cultivated in the Jaffna Peninsula.

The water available within these limestone aquifers is predominantly used for domestic and irrigation purposes. Intensive irrigation, higher inorganic fertilizer usage along with increases in population growth associated with resettlement has the potential over time for over-extraction of groundwater resources and deterioration in water quality. There is currently a deficit in long-term monitoring of the quantity of water stored and extracted from these aquifers along with changes in the water quality.

An assessment of the vulnerability of groundwater for irrigation and drinking purposes has become a necessary and important task for the management of present and future groundwater quality in the Chunnakam aquifer. The suitability of water for any use is determined not only by the total amount of salt present in the water but also by the type of salt that is present. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. It is, therefore, essential to establish baseline information on water quality and availability to assist in long-term planning whilst ensuring the integrity of supply for the Jaffna Peninsula. Though several studies have been undertaken on groundwater quality in the Peninsula, no systematic studies have been carried out to characterize the chemical quality and recharge potentials of aquifers in the Jaffna Peninsula. The objective of this study was to characterize the hydrogeochemical attributes of the Chunnakam aquifer with the specific objectives of assessing the geochemistry and water quality of the aquifer, mapping groundwater recharge areas and assessing the recharge potentials, identifying nitrate sources and computing the surface loading of nitrate, and making the information easily accessible to future research studies and water/land-use managers.

Spatial variation of net groundwater recharge ranged between 12 to 69% of total rainfall, with an average of 37% at a specific yield of 0.21 during the short rainy season (i.e., October, November and December). This would suggest that approximately 33% of the rainfall is lost as runoff during the rainy season. The spatial variability observed in computed values could not be entirely attributed to the local geohydrology of the area since there isn't enough rain gauges to capture the rainfall variability.

The fall in groundwater levels during January to July was much less than the estimated evapotranspiration (ET), which implies that considerable seawater intrusion takes place to compensate for the drop in groundwater level due to ET. One would assume that for a significant proportion of the growing season that Eta < ETp, it is only when the crop factor (Kc) is ≥ 1 would Eta > ETp. However, this concept needs to be confirmed through further research. This aspect requires a planned study and careful recommendations need to be made to limit groundwater abstraction that brings the required moisture to the surface during the dry season while also considering the crop response to alternate irrigation practices and techniques.

Despite the claim of an imbalance between water withdrawals and recharge made by previous researchers, the difference in groundwater levels over a complete annual cycle indicated a positive

balance in 2011 suggesting no permanent depletion of groundwater levels in the Chunnakam aquifer area during the period of this study. However, it is possible for the mid-season water table to reach as low as 0.5-meters (m) of water in the wells during the dry period. Therefore, not only is water availability reduced but also the freshwater-saltwater interface could reach as close as 20 m below the well bottom depending on the freshwater level above mean sea level. The thickness of the freshwater lens, however, is limited by the flat topography, i.e., the thickness of the soil above mean sea level that holds the freshwater lens. Therefore, the modeling approach supported by adequate field research is proposed to study the dynamics of the saltwater-freshwater interface in relation to groundwater abstraction and recharge. Spatial and temporal distribution maps of various water quality parameters were produced based on a systematic study and is the first of its kind in the Jaffna Peninsula. Wells located in the coastal area exhibited high values of electrical conductivity (EC), sodium, chloride and sulfate. Since, most of the farm wells are located inland; their water quality is generally superior to domestic and public wells. However, farm wells contain nitrate-N levels that are above acceptable levels for drinking purposes. Elevated levels of EC, nitrate-N and low levels of fluoride were identified in comparison with Sri Lankan drinking water standards in the Chunnakam aquifer. The level of nitrate-N concentration in water was influenced by the cropping system, as a high nitrate-N concentration in groundwater was observed in the cultivation of highland crops followed by banana and paddy.

Excessive use of chemical fertilizer together with excessive water application is the cause for the presence of excessive nitrate-N concentration in water. There is a need for awareness raising within farming communities highlighting the hazards associated with excessive use of chemical fertilizers. Furthermore, efficient irrigation water management practices should be introduced to prevent leaching of chemicals to the groundwater.

Seasonal fluctuations in certain water quality parameters were identified which made the water unsuitable for drinking during certain months of the year. Therefore, it is recommended that awareness is created among people living in the Jaffna District on the potential health hazards that can arise due to the use of contaminated water for drinking purposes.

Very low concentrations of toxic heavy metals that include cadmium (Cd), lead (Pb) and arsenic (As) were reported in the Chunnakam aquifer system, but, in some cases, the levels of Cd exceeded the World Health Organization (WHO) limits for drinking water standards. The cause for this could be due to the heavy usage of agrochemicals. The presence of arsenic was less than 10 parts per billion (ppb) (WHO standard). Results from the modified DRASTIC method revealed that the vulnerability of the aquifer specifically to nitrate contamination remains in the 'high' category. The risk of contamination is largely attributed to the heavy fertilizer use for agriculture in the area.

The study provides insights into the potential vulnerability of groundwater resources to increased use associated with population increases and the establishment of intensive irrigated crop production systems that will have long-term implications on water supply and quality. As the Peninsula is currently entirely dependent on groundwater as its sole source of water supply for domestic and agricultural use, the management of this resource is critical in order to avoid compromising this resource through saltwater intrusion. Whilst further research and monitoring of groundwater is required to establish safe and sustainable yields from the aquifers that predominate the Jaffna Peninsula the following tentative recommendations are suggested:

- Assess the potential for rainwater harvesting at the household level through the provision of roof top harvesting systems and associated storage tanks.
- At a community/district level evaluate the potential for managed aquifer recharge (MAR) through the creation of distributed surface storage tanks that harvest runoff and allow

it to recharge the aquifer. Other engineering structures could be assessed to enhance recharge.

- The trialing and promotion of improved irrigation technologies that reduce water requirements for crops will dramatically reduce water withdrawals from aquifers as well as minimize the potential negative impact of nutrient leaching into the aquifer. There are a range of techniques and technologies that can be used to reduce crop water requirements that will need to be assessed for acceptability by farmers.
- The overuse of inorganic fertilizers is assumed to be the source of excessive levels of inorganic nitrate observed in groundwater samples. Change in farmer behavior through extension trainings in the use of fertilizers as well as possibly considering a reduction in subsidies on fertilizers are possible approaches that could be considered.
- An area that was not considered in this study but may need attention is the inclusion of septic tanks as a standard fixture in the current program of resettling displaced persons. The current study did not specifically assess the potential role of septic tanks as point sources of pollutants to groundwater. However, it is plausible that with increases in population on the Peninsula and associated urbanization, septic tanks could become a significant source of pollution. There is a need to assess this potential and to put in place systems that would reduce or eliminate septic tanks as a pollution source.
- Finally, as the Peninsula has a finite water resource there is a need to plan appropriately and to consider other models in water supply and reuse. There are opportunities to learn from other countries such as Singapore in managing finite water resources in a sustainable manner.

CHAPTER I

SETTING THE SCENE

General Introduction to the Jaffna District

The Jaffna Peninsula is situated in the Northern extreme of Sri Lanka. It is geographically confined to the North and East by the Indian Ocean and the West by the Palk Strait, and the Southern areas extend into the mainland of the country. The Jaffna District covers an area of 1,023 square kilometers (km^2) that includes inland waters. The district is predominantly an agricultural area with a high potential for the cultivation of commercial crops that include red onions, chilies, potatoes, tobacco, vegetables, bananas and grapes. Thadchayini and Thiruchelvam (2005) reported that agriculture is the main source of livelihood for 65% of the population, and about 34.2% of the land is cultivated commercially with high-value cash crops. According to the above paper, about 65,400 families and 30,000 farm laborers are involved in agriculture and livestock in the Jaffna District. In addition, a large proportion of the population cultivates their own home gardens. Nagarajah et al. 1988 reported the use of high levels of organic manures from cattle, goats and green manures, and inorganic fertilizers and agrochemicals are applied to these high-value crops. Cultivation of other crops such as paddy, pulses and coconut are at a subsistence level. Palmyrah[2] products yield subsistence income.

The Jaffna Peninsula, lies within the dry zone of Sri Lanka, is underlain predominantly by Miocene limestone that is considered to be appropriate geological material for the development of aquifers. However, the region is prone to groundwater problems, as the resource is limited and its quality has deteriorated over time (Arumugam 1969; Nandakumar 1983). Groundwater is the only source of water for the entire Peninsula and there are currently no major water supply schemes in place to augment current supply. Seasonal rainfall is of a short duration and is the only source of recharge. High evapotranspiration loss during the dry season and high runoff losses during the wet season play a major role in determining the supply of groundwater in the Peninsula.

The deteriorating quality of groundwater in the Jaffna Peninsula has justified continued water quality monitoring and investigation. A major water quality problem, identified in the 1950s and highlighted in the 1960s, is seawater intrusion into the groundwater system (Balendran et al. 1968). Later, concern centered on the high nitrate problems related to high inputs of artificial and natural fertilizers, and congested or improperly planned household soak-pit systems.

Pollution of groundwater by nitrate was investigated by Mageswaran and Mahalingam (1983), Dissanayake and Weerasooriya (1985), Nagarajah et al. (1988), Rajasooriyar et al. (2002) and Mageswaran (2003). Few of these studies have indicated that 80% of the wells in the Peninsula are affected by high nitrate concentrations. The source of nitrate was identified as nitrogenous fertilizers and household soak-pits (Gunasekaram 1983).

Prior to 1960, water was drawn from wells using traditional water-lifting devices (well sweeps). However, with electrification and the importation of inexpensive lift systems, most wells are equipped with small electric or lift pumps. Consequently, there is a tendency to use more water for crops than required. These changes in technology and excess withdrawals of water are also reported by Navaratnarajah (1994).

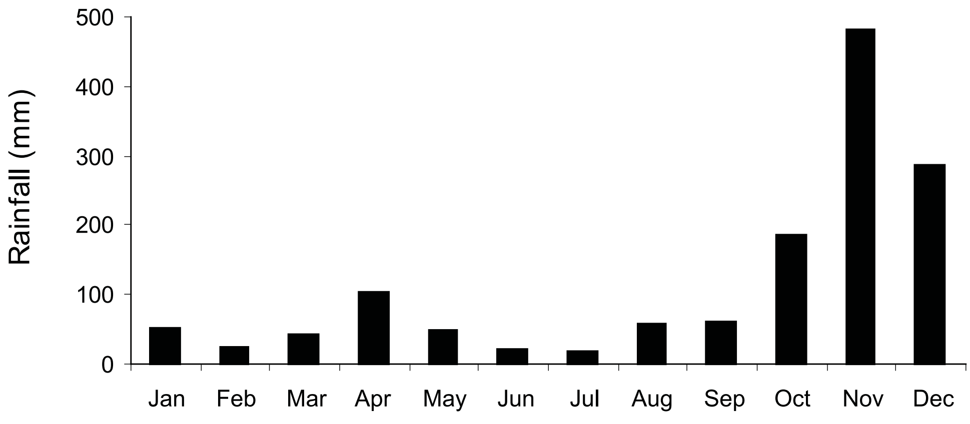
[2] A type of palm tree growing in the area.

There are three non-perennial rivers in the region, namely Thondaman Aru (9.48 kilometers (km), Uppu Aru (19.31 km) and Valuki Aru (9.66 km) which have water only during the rainy season. The bulk of water supply comes from 19,241 agro-wells and 2,433 ditches, most of which are used for agricultural purposes. In addition, over 631 small ponds are available in the Jaffna District. Punthakey and Gamage (2006) estimated the total agricultural well usage in the Jaffna Peninsula as 147,000 million liters per year (MLPY), with well usage during the dry season at 88,000 MLPY and wet-season usage at 59,000 MLPY.

Climate

The Jaffna Peninsula experiences the typical dry zone climate of Sri Lanka, characterized by a wet and a dry season. Rainfall acts as a major source of groundwater recharge, and its seasonality (i.e., bimodal distribution) and uncertainty greatly affects the quantity and quality of groundwater. The major wet season occurs during October to December and is associated with the northeast monsoon. The minor wet season occurs during April to May due to the southwest monsoon. The period between the southwest and northeast monsoons is dry and this dryness extends from June to September. The months of September/October to January/February and February/March to August/September are referred to as *Maha* (wet season) and *Yala* (dry season), respectively. The bulk of the rainfall is received during the months from October to January, with little or no rainfall thereafter. Of the total annual average rainfall, 80% of the rainfall occurs during the northeast monsoon. The remaining rainfall occurs largely as isolated showers during the dry months. Since more than 50% of the northeast monsoonal rainfall is received within a short period, this has resulted in large losses due to surface runoff. The estimated 75% probability of rainfall in the Jaffna District is 510 millimeters (mm) in *Maha* and 102 mm in *Yala*. The mean monthly rainfall from 2002 to 2011 is presented in Figure 1.1.

FIGURE 1.1. Mean monthly rainfall derived from year 2002 to 2011.



Source: 2002 to 2010 – Jaffna district statistical hand book and 2011 – Meteorological station.

Table 1.1 presents the mean monthly meteorological parameters for Thirunelvely. Average temperature does not vary significantly over the year and ranges from 25 to 30 °C, with significant fluctuation between daytime and nighttime temperatures (Table 1.1.). The relative humidity increases from a low of 67% in March to a high of 80% in November. High wind speeds are experienced

TABLE 1.1. Mean monthly meteorological parameters of Thirunelvely (derived from 2002-2011).

Month	Rainfall (mm)	Air temperature (°C)	Relative humidity (%)	Wind speed (km/hour)	ETo* (mm/day)
January	52	25.7	73.2	5.91	3.8
February	25	28.4	68.8	5.94	4.4
March	44	28.2	67.4	6.94	5.1
April	103	29.8	71.0	12.00	5.4
May	49	30.2	75.0	11.96	5.6
June	21	29.9	73.5	10.64	5.3
July	18	29.7	73.2	10.66	5.4
August	59	29.4	73.1	10.89	5.4
September	60	29.2	75.3	10.89	5.4
October	187	28.2	78.4	6.38	4.1
November	480	26.5	82.8	4.51	3.1
December	287	26.2	79.4	5.83	3.3

Source: 2002 to 2010 – Jaffna district statistical hand book and 2011 – Meteorological station.
Notes: * Penman-Monteith method using CROPWAT.

in July and August, which are characterized by high evaporation and drought conditions. The highest sunshine hours per day is observed during June to July and the lowest in December. Further, uniformly high temperatures prevail in the study area all year-round and contributes to an evaporation level of 45-48% of the annual rainfall. In addition, due to the karstic formation in the limestone in the western and northern coast of the study area, freshwater seepage is observed and 5-8% of recharge is lost to the sea (Navaratnarajah 1994).

Geology

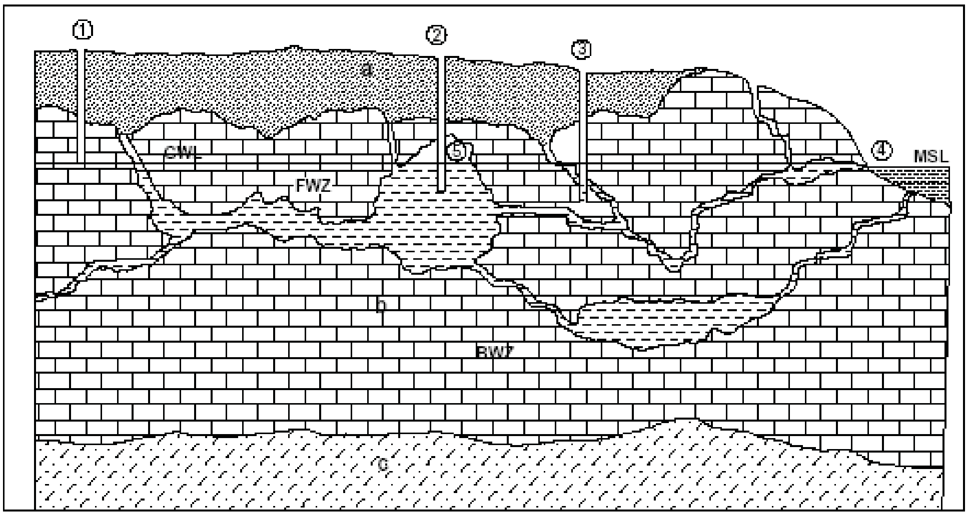
The Jaffna Peninsula is unique in geology and aquifer conditions. The limestone is an important aquifer, and together with thin sand layers form an extensive cover providing a source of drinking water and irrigation across the Jaffna Peninsula. It is almost flat-bedded with a slight dip to the west, and is a creamy colored hard compact, indistinctly bedded and partly crystallized rock. It is massive in parts but some layers are richly fossiliferous into a honeycombed mass. Easily soluble limestone gives rise to a number of underground solution caverns. According to Arumugam (1969), during the Miocene and prior periods thick layers of sands, clays and limestone were deposited from Puttalam to the Jaffna Peninsula in the major sedimentary basin found in the northwest coastal belt of Sri Lanka. In general, this Miocene formation overlies high-grade Precambrian metamorphic rocks, but in some places is underlain by sedimentary layers of upper Jurassic age (Cooray 1984).

Geological units exposed in the Jaffna District are part of a sequence of tertiary aged rocks, which rest on a basement of Precambrian crystalline rocks. The total thickness is approximately 250 m which is made up of three main units, the Mannar sandstone at the base, the Jaffna limestone in the middle and a thin discontinuous surface cover.

The 50-90 m-thick Jaffna limestone overlies the Mannar sandstone, and is extensively exposed in the western part of the Peninsula in the Chunnakam area and in a small area to the west of

Point Pedro (Feasibility Report 2006). However, Cooray (1984) claimed that the vertical thickness of the Miocene limestone exceeds 35 m. According to Cooray (1984), the Miocene limestone of the Jaffna Peninsula is poorly bedded and generally flat, except in some areas where it shows a slight dip to the west. In places the limestone beds are extremely well jointed and have a marked rectangular pattern of closely spaced joints running in northwest to southeast and northeast to southwest directions. These strata hold large quantities of freshwater which is available for extraction. Figure 1.2 schematically represents the geology and groundwater conditions of the Jaffna Peninsula. The formation of the interior of the cavern has not been explored. It extends to an unknown distance beneath the roof and the sides of the well. From the geological conditions of limestone formation it would appear that rainwater enters the cavern through fissures. The entire thickness of the limestone formation is vulnerable to the formation of solution cavities. Freshwater from precipitation percolates into highly karstic and heavily faulted limestone and floats as lens-shaped bodies over the denser water derived from the sea. At the center of the District the thickness of the lens is highest, and is lower in the coastal areas. In coastal areas, freshwater is available at a lesser depth, but at deeper depths it becomes brackish. In the central area, however, freshwater can be obtained due to a higher elevation and the thickness of the freshwater lens.

FIGURE 1.2. Geology and condition of groundwater in the Jaffna Peninsula.



Source: Sirimanne 1952.
Notes: (a) Red earth, (b) Jaffna limestone, (c) Granitic genesis, MSL (mean sea level), GWT (groundwater level), FWZ (zone of freshwater saturation), BWZ (probable zone of brackish water); (1) dry well, (2) bottomless well or tidal well (Nilavarai), (3) ordinary successful well, (4) spring of Keerimalai type, (5) solution cavern.

Immediately after the wet season when water levels are higher, almost all parts of the Peninsula are underlined by freshwater. As the groundwater depletes during the dry season the freshwater lens decreases in size and increases the areas underlined by brackish water. The shallow lens of freshwater remaining at the end of the dry season is extremely sensitive to pumping. Thus, excessive pumping in this area of the Jaffna Peninsula is responsible for several of the water management problems that have emerged. Panabokke and Perera (2005) reported that the limestone aquifer present in Jaffna Peninsula is the richest source of groundwater among the different types of aquifers in Sri Lanka. Table 1.2 presents selected attributes of these aquifers namely the transmissivity, hydraulic conductivity and storage coefficient of different locations.

TABLE 1.2. Estimated transmissivity, hydraulic conductivity and storage coefficient values.

Aquifer type	Transmissivity[3] (m^2/day)	Hydraulic conductivity[4] (m/day)	Storage coefficient[5]
Chundikulum	420	35	0.27
Palai	2-8	0.2-1.8	-
Vadamarachchi	420	35	0.27
Manatkadu	315-525	26-43	0.18-0.32
Kayts	28-35	7-10	-
Chunnakam	-	13.3	-

Source: ADB, Feasibility report 2006.
Notes: m^2 = square meters

Topography and soil type

The soil and water resources of the Jaffna Peninsula are both related to the limestone geology of the land. The soils are formed on marine deposits and sediments under the influence of sea waves and wind. A thin mantle of soils with a thickness of less than 2 m is found above the limestone rock (Rajasooriyar et al. 2002). The soil of the District varies from well-drained and highly productive red yellow latosols in the central area (60,000 hectares (ha); alkaline, saline regasol soils in the coastal area (26,000 ha); and alluvial soils in the Valukki Aru area (10,000 ha). This heterogeneity in soil type gives rise to the cultivation of exotic as well as local crops. The soils are generally characterized as red calcic latosols and within this major soil group there are variations, and brick red loams are found in the center of the study area. These are garden soils cultivated with high-value arable crops. Red yellow latosols are found surrounding the brick red loams and are cultivated with arable crops. The coastal area and saline tracts are cultivated mainly with paddy and crops that are tolerable to salinity.

The soil survey study of Nadarajah (1973) identified two major physiographic types, namely the coastal plain and karst plain. Table 1.3 presents the physical properties of red yellow latosol soils, and Figure 1.3 shows the generalized soil and geology map of the Valikamam region. The soil association of calcic red-yellow latasols is formed from the marine deposits on the older Miocene limestone.

The differences in soil types and soil series have arisen because of the various soil-forming processes that have taken place due to the general land form and differences in macro- and micro-topography in addition to the influence of sea and wind. Figure 1.4 shows the detailed map of different soils mapped at the series level (Nadarajah 1973), and Table 1.4 presents physical and chemical characteristics of these soils.

[3] The **transmissivity** is a measure of how much water can be transmitted horizontally, such as to a pumping well.

[4] **Hydraulic conductivity** is a property of soil or rock that describes the ease with which water/fluid can move through pore spaces or fractures. It depends on the permeability of the material and on the degree of saturation, and on the density and viscosity of the fluid.

[5] **Storage coefficient** or storativity: The amount of water stored or released per unit area of aquifer given unit head change.

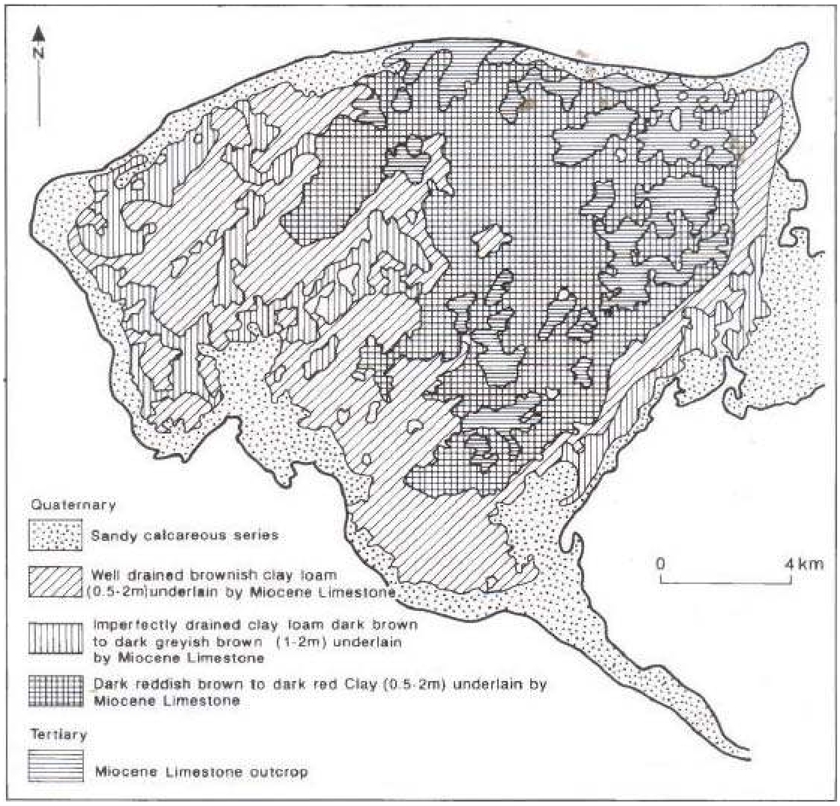
TABLE 1.3. Physical properties of red yellow latosol soil.

Parameters	Value
Infiltration	430 mm/hour
Mechanical analysis	
Coarse sand	39.6%
Fine sand	33.7%
Silt	3.0%
Clay	23.5%
Total porosity	46%
Non-capillary porosity	20%
Bulk density	1.48 g/cm^3
Field capacity	20%
Percentage (%) by volume	(17 – 23)
Permanent wilting	10%
Percentage (%) by volume	(7 – 12)
Available moisture	10%
	(9 – 13)

Source: Joshua 1973

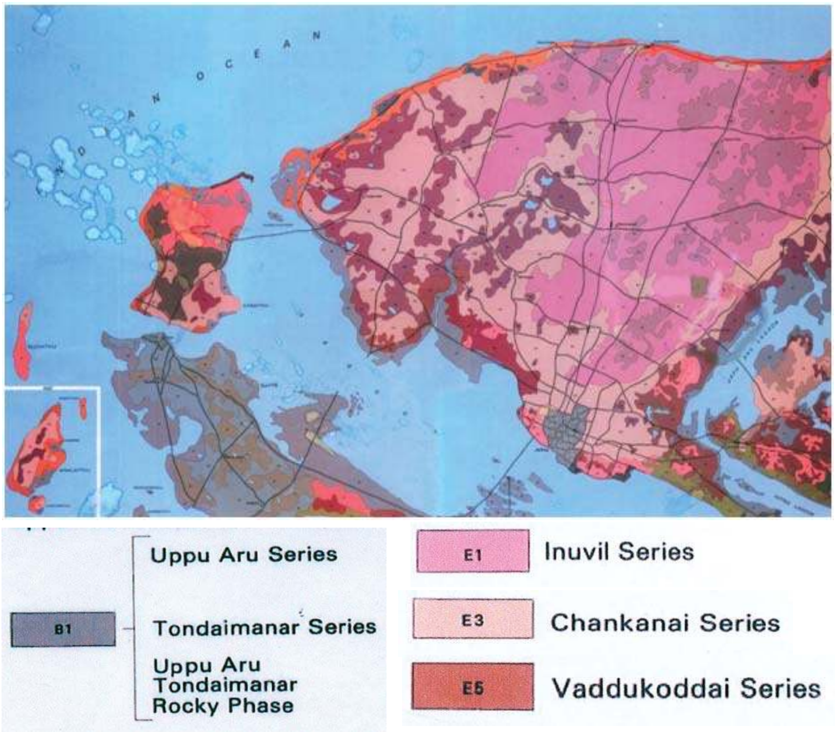
Notes: g/cm^3 = grams per cubic centimeter

FIGURE 1.3. Generalized soils and geology map of the Valikamam region.



Source: Rajasooriyar et al. 2002.

FIGURE 1.4. Description of benchmark soil map of central and western parts of Jaffna.



Source: Nadarajah 1973.

TABLE 1.4. Properties of the soil series found in the Valikamam area.

Parameter	Inuvil series	Chankanai series	Vaddukkoddai series	Uppu Aru series
Infiltration (cm/h)	19.7 - 24.9	19.2 - 24.9	5.6 - 1.8	0.5 - 27
Bulk density (g/cm^3)	1.58	1.4	1.23	1.27
Porosity (%)	44.93	48.9	47.58	49.78
Field capacity by volume (%)	20.75	25.63	34.74	46.64
PWP by volume (%)	6.2	7.26	13.16	13.14
EC (dS/m)	0.067 - 0.014	0.07 – 0.129	0.9 – 1.074	8.19 -12.8
pH (1st layer)	7.8	7.13	7.8	8.19
Available nitrate (mg/kg) (1st layer)	7.11	10.89	8.43	Not measurable
Available phosphorus (mg/kg) (1st layer)	4.7	12.01	5.52	10
Available potassium (mg/kg) (1st layer)	23.46	60.07	27.61	50.02
Organic matter (%) (1st layer)	5.95	5.95	5.95	5.95

Source: Jegajeevagan 2005.
Notes: cm = centimeters; mg = milligrams; kg = kilograms; EC = electrical conductivity;
PWP = permanent wilting point; h = hour

Land use

The Jaffna District is predominantly an agricultural area with crops such as red onions, chillies, potatoes, tobacco, vegetables, bananas and grapes being cultivated for commercial purposes. Other crops such as paddy, pulse, coconut cultivation at subsistence level, and palmyrah products are also a source of income. About 62,269 families and 30,408 farm laborers are involved in agriculture and livestock keeping in the District. In addition, a large share of the population is involved in home gardens. Paddy is cultivated on 8,948.5 ha and other field crops are also cultivated in the Jaffna District (Jaffna District statistical hand book 2011). Paddy is produced during the *Maha* season under rainfed conditions while vegetables are produced almost all year-round under rainfed or irrigated conditions. Land use of the Chunakam Aquifer area is presented in Figure 1.5, and the land-use extents extracted from the map are shown in Table 1.5.

FIGURE 1.5. Land-use pattern of Chunnakam aquifer area.

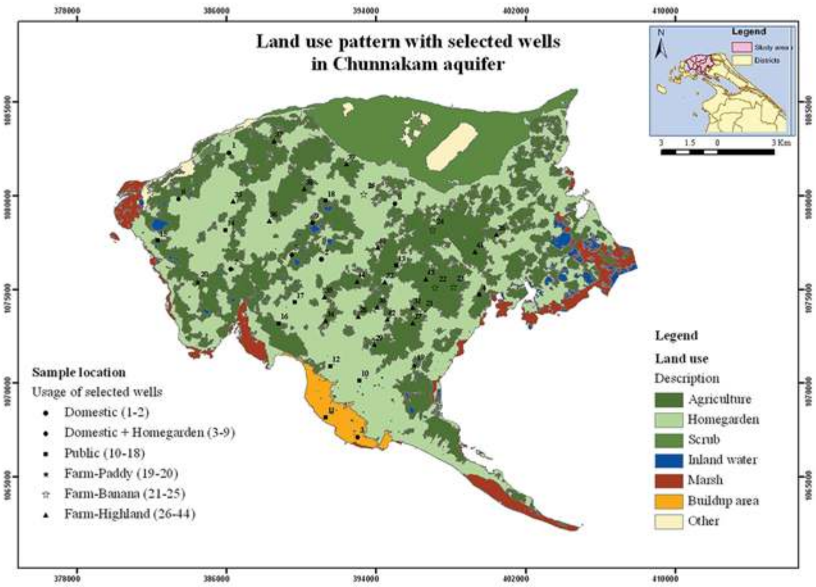


TABLE 1.5. Land-use extents extracted from the land-use map.

Land use	Area (km^2)	%
Agriculture	107.22	31.68
Home garden	156.85	46.35
Scrub	36.26	10.71
Inland water	6.91	2.04
Marsh	16.8	4.96
Builtup area	7.2	2.13
Other	7.19	2.12
Total	338.43	100.00

Source: Sri Lanka Water Audit (http://waterdata.iwmi.org)

Objective

The Jaffna Peninsula has four main types of aquifer systems, namely Chunnakam (Valikamam area), Thenmarachchi, Vadamarachchi and Kayts, of which the Valikamam area is intensively cultivated in the Jaffna Peninsula (Puvaneswaran 1986). An assessment of the vulnerability of groundwater for irrigation and drinking purposes is an essential undertaking in managing current and future demand that also includes water quality. The suitability of water for any use is determined by the total amount and the type of salt present in the water. Water quality or suitability for use is judged on the potential severity of problems expected to develop over the long-term. It is, therefore, essential to establish baseline information on water quality and availability that is required for future water-related studies or project planning in the 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. Consequently, the major objective of this study was the hydrogeochemical characterization of the Chunnakam aquifer, which is an important water body of Jaffna's aquifer systems.

Specific objectives are to:

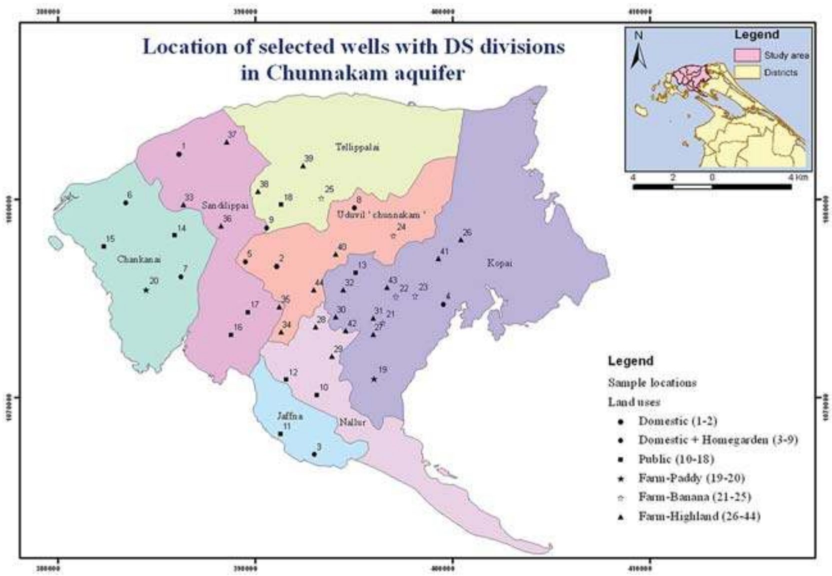
- Map groundwater recharge areas and assess the recharge potentials;
- assess the geochemistry and water quality of the Chunnakam aquifer;
- identify nitrate sources and compute the surface loading of nitrate; and
- make the information easily accessible to future research studies and water/land-use managers.

Scope of the study

Phase I of the study is limited to the area serviced by the Chunnakam aquifer and to a complete annual cropping and groundwater recharge cycle, i.e., from January 2011 to December 2011. Comprehensive geographic information system (GIS)-based hydrogeochemical maps, characterizing the Chunnakam aquifer, has been developed. Information available on groundwater recharge and nutrient-loading has been compiled and compared with the present study.

Forty-four wells were selected for water quality monitoring in a systematic manner to represent the entire Chunnakam aquifer (Figure 1.6). Selected wells fall under different usages that include domestic (D), domestic and home gardening (D+H), public wells for drinking purposes (P), and farm wells (F). Of the selected wells, 26 were farm wells from different cropping systems, namely highland

FIGURE 1.6. Location of selected wells with DS divisions in the Chunnakam aquifer.



crops (chillies, onions, brinjals and tobacco), bananas and paddy fields. Nineteen wells selected were under highland crops. Five wells selected were under banana cultivation. Since it is not very common to find wells in paddy fields in the Peninsula, only two wells were selected for sampling.

References

Arumugam, S. (1969). Development of groundwater and its exploitation in the Jaffna Peninsula. Paper read at the Annual conference, October 1970. The Institution of Engineers, Ceylon.

Balendran, V.S., C.H.I. Sirimanne, and S. Arumugam. (1968). Groundwater resources of Jaffna Peninsula, Water Resource Board, Colombo.

Cooray, P.G. (1984). An introduction to the Geology of Sri lanka. 2nd revised ed. National Museums Sri Lanka, Colombo. Pp. 120-260.

Dissanayake, C.B. and S.V.R. Weerasooriya. (1985). The hydrogeochemical atlas of Sri Lanka. Natural Resources, Energy and Science Authority of Sri Lanka, Colombo.

Feasibility report. (2006). A feasibility study for water supply and sanitation system for the Jaffna Peninsula. ADP project. Project No: 5068020 . National water supply and drainage board. Jaffna. Sri Lanka.

Gunasekaram, T. (1983). Groundwater contamination and case studies in Jaffna Peninsula, Sri Lanka. Global Engineering Technology Services, Jaffna.

Jegajeevagan, K. (2005). Morphological, physical and chemical characterization of selected soil series in Jaffna Peninsula. Unpublished Thesis, B.Sc, Faculty of Agriculture, University of Jaffna.

Joshua, W.D. (1973). Physical properties of soil as related to irrigation and water management. In: proceedings of National seminar on water management and control at the farm level FAO/ Sri Lanka. Colombo, Sri Lanka 18-23. June 1973.

Mageswaran, R. and. S. Mahalingam. (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.

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

Nadarajah, N. (1973). Soils of Jaffna peninsula, Land use division, Irrigation department.

Nagarajah, S., B.N. Emerson, V. Abeykoon and S. Yogalingam (1988). Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution. Tropical Agriculturist. 144: 61-73 pp.

Nandakumar, V. (1983). Natural environment and groundwater in Jaffna peninsula, Sri Lanka. Climatological notes, Tsukuba, Japan. 33:155-164.

Navaratnarajah, V. (1994). Water problems in the Jaffna peninsula, 20th WEDC International Conference in Affordable water supply and sanitation. 1994, Colombo, Sri Lanka. pp.191- 193.

Panabokke, C.R. and A.P.G.R.L. Perera. (2005). Groundwater resources of Sri Lanka. Water Resources Board, Colombo, Sri Lanka.

Punthakey, J.F. and P.D.N. Gamage. (2006). Coupled flow and salinity transport modelling and assessment of groundwater availability in the Jaffna Peninsula, Sri Lanka. 32nd WEDC International Conference 2006, Colombo, Sri Lanka.

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

Rajasooriyar, L., V. Mathavan, H.A. Dharmagunawardhane, and V. Nandakumar. (2002). Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka. In: Sustainable groundwater management. Hiscock, K.M., Rivett, M.O. and Davison, R.M. (Eds). Geological Society, Londan. 193: 181 – 197.

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

Sirimanne, C. H. I. (1952). The geology for water supply. Complied by Arumugam, S. (1974) Studies on groundwater in Sri Lanka. Water resource board, Colombo. pp.31-58

Thadchayini, T. and S.Thiruchelvam. (2005). An economic evaluation of drip irrigation project for banana cultivation in Jaffna district. In Galagedara, L.G. (Ed). Water resources researches in Sri Lanka. Symposium proceedings of the water professionals day - 2005. Pp. 111-126.

CHAPTER II
GROUNDWATER RECHARGE ESTIMATION

Introduction

Groundwater recharge can be defined as 'the downward flow of water reaching the water table, forming an addition to the groundwater reservoir' (Lerner et al. 1990). Rainfall is the principal source for recharge of groundwater. Other sources include recharge from rivers, streams, irrigation water, etc. The amount of moisture that will eventually reach the water table is the natural groundwater recharge, which depends on the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the depth of the water table and soil type. Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of retarding layers. In addition, evapotranspiration, bedrock geology, available groundwater storage, presence of influent rivers and presence of karst features also affect the amount of recharge.

There are two main types of recharge: direct (vertical infiltration of precipitation where it falls on the ground) and indirect (infiltration following runoff). Recharge occurs both naturally through the water cycle and through anthropogenic processes (artificial groundwater recharge), where rainwater and/or reclaimed water is routed to the subsurface. Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate abstracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged. Recharge can help move excess salts that accumulate in the root zone to deeper soil layers or into the groundwater system (Misstear 2000).

The Jaffna Peninsula does not have perennial rivers or any other external recharge sources. Therefore, rainfall is the major source of groundwater recharge for the Chunnakam aquifer[6]. Permeable soil, flat topography and other surface features such as basin irrigation systems and local surface depressions (ponds) facilitate infiltration of rainfall to a great extent. The Jaffna Peninsula has about 2000 small ponds of various sizes including the ponds that belong to temples scattered over the area (M. Patrick Diranjan, Assistant Commissioner, Department of Agrarian Development, Jaffna, personal communication May 02, 2012). General soil and aquifer properties and land use in the Chunnakam area are given in Chapter I (Tables 1.4 and 1.5). Agriculture and home gardens occupy about 78% (264 km^2) of the land area and are the dominant land use.

Groundwater abstraction, recharge and other related issues have been studied in the Jaffna Peninsula since the 1960s. However, as described in the subsequent sections, the observations and conclusions made by various researchers are often contradictory and no consensus has been reached on the aforementioned issues. Moreover, except for the feasibility study carried out for the Asian Development Bank (ADB)-assisted third water supply project of the National Water Supply and Drainage Board (NWSDB) (Feasibility Report 2006), no spatially and temporally descriptive groundwater abstraction, recharge and related information is available for agricultural water management purposes. The modeling approach used in the feasibility study is mostly targeted for use by water supply engineers. Therefore, a systematic study was undertaken to characterize and map the geochemical and recharge dynamics of the Chunnakam aquifer during January to December, 2011, to generate information for agricultural water managers.

[6] Chunnakam is one of the four and major aquifer systems identified in the Jaffna Peninsula.

Assessment of groundwater recharge in the Jaffna Peninsula

Karstic limestone is the main aquifer in the Jaffna Peninsula. The population of the Jaffna Peninsula depends entirely on groundwater resources to meet all of their water requirements. The recharge to groundwater in the Peninsula is almost entirely from rainfall percolation; any significant contribution by lateral percolation from the basement is very unlikely. All the shallow groundwater found within the karstic cavities originates from the infiltration of rainfall, and this shallow groundwater forms mounds or lenses floating over the saline water. The Chunnakam aquifer is fully recharged from the northeast monsoonal rainfall that occurs during November and December. No appreciable rainfall occurs after February, and the volume of stored water within the mounds of the karstic cavities tends to drop rapidly within three months after the cessation of the wet season. This significant loss of groundwater is due to the considerable karstification which intensifies the subsurface flow. This is the main problem in the aquifer in the Jaffna Peninsula, thus limiting water supplies in the dry season which extends up to the period from August to September (Panabokke and Perera 2005).

According to Balendran et al. (1968), of the annual recharge of rainwater in the Peninsula, which is between 10 to 20 x $10^7 m^3$, approximately 50% eventually drains out to the sea and the remainder is used mostly for agriculture and domestic purposes. The aquifer boundary itself expands and contracts through the wet and dry seasons, respectively. Monitoring studies have confirmed a significant imbalance between the withdrawals and recharge rates (Balendran 1969). Navaratnarajah (1994) stated that, groundwater recharge has been viewed as a function of effective rainfall. In the Jaffna Peninsula, this only occurs during the annual monsoonal rainfall from September to January. After losses through direct runoff (about 10-15%), and losses from evaporation (about 40-48%), only 30-32% of the rainfall is potentially available for groundwater recharge.

Rajasooriyar et al. (2002) reported that estimation of the total catchment recharge has rarely been made for the Jaffna limestone due to the absence of relevant data. For a study carried out in 1997, the volume of recharge was calculated for an area of 185.5 km^2 using estimated values of specific yield and an average increase in groundwater levels of 0.61 m for a few selected wells for the period from August to December. This limited approach revealed that assuming a specific yield of 0.18 would furnish an average annual recharge rate of 2.0 x 10^7 m^3 for the selected area. However, this value does not account for the variation in the spatial pattern of recharge in the area.

A number of methods have been formulated for the estimation of recharge to an aquifer. The soil water balance method is a useful method of estimating recharge provided that necessary information is available for a complete water budget. De Silva (2000) reported that there is a simple, easy-to-use soil moisture balance model which can be used in estimating groundwater recharge in the dry zone of Sri Lanka. The soil moisture balance approach which is based on rainfall, evapotranspiration, runoff, the nature of the soil and growth of crops has proved to be a reliable and flexible technique for estimation of potential recharge. De Silva (2005) discussed shortcomings in the application of soil water budgeting in the dry zone and measures to be adopted are identified for a soil water budgeting method to yield a more meaningful estimate of recharge. De Silva (2004) identified the spatial variability of recharge using the chloride profiling method, and stated that spatial variability in recharge was observed over small areas (1 ha) in the dry zone of Sri Lanka. De Silva and Rushton (2007) applied the technique of Modified Soil Moisture Balance (MSMB) model for an area classified as ‘tropical’ with distinct dry seasons in northwest Sri Lanka.

Punthakey and Gamage (2006) reported that freshwater lenses are recharged by the direct infiltration of rainfall. It has been estimated previously that 80% of rainfall is effective in recharge and the balance 20% is lost as flood runoff. Allowing for evapotranspiration losses, the recharge to groundwater is about 30 to 50% of rainfall, of which between 15 and 50% is lost as subsurface flow to the sea. They further stated that the total agricultural well usage is 147,000 MLPY with dry-season use at 88,000 MLPY and wet season usage at 59,000 MLPY. Of this, an assumed average of 24% returns to the aquifer from excess irrigation. Thus, the net agricultural well usage is 112,000 MLPY.

As determined by the MSMB model, groundwater recharge rates of the limestone aquifer range from 23% to 25% of the annual rainfall in 2007, whereas according to the Water-Table Fluctuation (WTF) method it was 26% and 29% of the annual rainfall in 2008 (Mikunthan and De Silva 2009). Groundwater recharge using the MSMB model for ten years from 1971 to 1980 in five agrarian service centers was estimated by Thiruchelvam (1994), and the results showed that, on average, about 33% of the total rainfall is recharged into the aquifer.

Puvaneswaran (1986) reported that the salinity of water in underground reservoirs increased when the recharge from rainfall was reduced. Hence, steps should be taken to increase the recharge to the underground resources by conserving more of the rainwater. In the early days, a large number of ponds and tanks with interconnected channels were in existence that helped to conserve a large proportion of the rainwater and also to recharge the underground resources by conserving more of the rainwater. However, over a period of time, with increased pressure for housing, several of these ponds and tanks have disappeared with development on these locations taking place after the tanks and ponds were filled.

Methodology

Quantification of the rate of groundwater recharge is essential for sustainable groundwater resource management. It is particularly important in regions with large demands for groundwater supplies such as the Jaffna Peninsula, where natural resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of groundwater resources (Kumar 2003). The following methods are commonly used for estimating natural groundwater recharge:

i. Soil-water balance method

ii. Zero-flux plane method

iii. Groundwater level fluctuation method

iv. Hybrid water fluctuation method

v. Groundwater balance method

vi. Isotope and solute profile techniques

The groundwater level fluctuation method is used in this study as groundwater level observations are available, and the method can also provide information on the temporal and areal recharge variations. This is a simplified form of the groundwater balance equation where inflows from, and outflows to, various external sources are also included. In the absence of perennial rivers and external surface irrigation sources, the groundwater level fluctuation method will yield a reasonable estimate of groundwater recharge.

Groundwater level fluctuation method

This is an indirect method of deducing the recharge from the fluctuation of the water table. The rise in the water table during the rainy season is used to estimate the recharge, provided that there is a distinct rainy season with the remainder of the year being relatively dry. The basic assumption is that the rise in the water table is primarily due to the rainfall recharge. It is recognized that other factors such as pumping or irrigation during the rainy season do not have an influence. Furthermore, the soil is assumed to be at its maximum water-holding capacity during rainy season and any excessive irrigation or rainfall over evapotranspiration will reach the groundwater. If the rise in water table is Δw, the rainfall recharge, Ri, is estimated using Equation (2.1) below:

$$Ri = Sy.\Delta w + T_P - R_T \qquad (2.1)$$

where:

Ri = rainfall recharge (m)

Sy = specific yield

Δw = rise in water table (m)

T_P = abstraction (m)

R_T = irrigation return flow (m)

Fluctuation in groundwater level (Δw) was monitored periodically by taking into consideration the water levels of 44 spatially distributed wells as discussed previously (Figure 1.6). The Thiessen polygon technique was used to estimate the area unit represented by each measuring point and to compute the average storage gain or loss in the aquifer. Due to the flat nature of the topography, it was assumed that all the surface and subsurface inflows are equal to outflows during a relatively short rainy season. Further, due to the absence of irrigation canals, small tanks and perennial rivers in the Chunnakam areas, recharge components associated with secondary sources such as canals and rivers can be safely ignored.

If we consider the period when the water table was shallow and the soil remains highly moist, it could be assumed that any draft from groundwater in excess of evapotranspiration (ET) would return to the groundwater during field irrigation without contributing to soil moisture storage. Thus, Equation (2.1) can be reduced to Equation (2.2) as shown below.

$$C'.Rf = Ri = Sy.\Delta w + ET \qquad (2.2)$$

or

$$C.\ Rf = (Ri - ET) = Sy.\Delta w \qquad (2.3)$$

where:

Rf = total rainfall during the period of study (m)

Ri = rainfall recharge (m)

Sy = specific yield

Δw = rise in water table (m)

C’ & C= fraction of the rainfall that contributes to groundwater recharge.

Here, (Sy.Δw + ET) in Equation (2.2) is considered as gross recharge and Sy.Δw in Equation (2.3) is considered as net recharge. The coefficient C will compound the effect of all the unknown components in the water balance equation including ET whereas C’ will give the fraction of rainfall that contributes to the gain in the groundwater table and evapotranspiration.

The basic limitation of the equation 2.2 is that it neglects the subsurface inflow and outflow, and assumes that every inflow and outflow is uniformly distributed over the area. Therefore, as suggested by Kumar (2003), the use of equation 2.2 should be limited to distinct rainy periods. Moreover, it depends on the value of the specific yield, which is difficult to determine since the water table fluctuation occurs in the partially saturated zone whereas the specific yield values determined by the pumping test is applicable to the aquifer material.

Field data collection

A questionnaire survey was carried out to gather information regarding the cropping pattern and fertilizer usage in the study areas. Recommended rates of fertilizer for each crop were obtained from the fertilizer recommendation for horticultural crops - 2007, Department of Agriculture, Peradeniya. Rainfall data during the study period was obtained from the Meteorological Department, Thirunelveli. A literature survey, direct field observations and key informant interviews were performed as necessary to validate the information gathered and to obtain additional information.

Calculation of crop water requirement

Environmental parameters required for the estimation of reference crop evapotranspiration, i.e., monthly mean temperature, humidity, wind speed velocity and sunshine hours, were obtained from the Meteorological Department, Thirunelveli.

The type of crop, frequency of irrigation, rate of pumping and duration of pumping were obtained through direct observation during the questionnaire survey. Crop coefficients for required crops were taken from Allen et al. 1998. The time required to fill a 50 liter (l) bucket was used to measure the rate of pumping during irrigation.

The CROPWAT (version 8.0) decision support tool, developed by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations (FAO), employing the Penman-Montieth method was used to calculate the reference crop evapotranspiration (ETo) values. Crop evapotranspiration was calculated by multiplying the reference evapotranspiration by the respective crop co-efficient.

Results and Discussion

Groundwater abstraction

Abstraction from public wells was found to be very low (less than 1 cubic meter (m^3)/day (d)) since the method of extraction is purely manual. The average extraction from domestic wells varied within the range of 1 to 1.25 m^3/d. Domestic wells with garden usage varied in the range of 2 to 3 m^3/d and average abstraction from farm wells for agricultural activities varied from 13 to 19 m^3/d (Jeyaruba and Thushyanthi 2009). Punthakey and Gamage (2006) reported that there are 10,263 agricultural wells in the Valikamam area. Therefore, at the above rate, abstraction for agricultural purposes accounts for 164,208 m^3/day. In this study, it was observed that abstraction for irrigation varied from 9.4 to 15.7 mm/day with an average of 11.5 mm/day whereas the daily evapotranspiration (ET)[7] in 2011 varied from 3.4 mm/day in December to 5.6 mm/day in May

[7] Considering the diverse nature of crops cultivated, the non-uniformity in planting dates and presence of perennial crops, crop evapotranspiration (ETc) is assumed to be equal to reference crop evapotranspiration (ETo); in other words, average crop co-efficient (Kc) was assumed to be equal to one. Thus, the notation 'ET' is used in this chapter to denote evapotranspiration.

with an annual average of 4.7 mm/day (Table 2.1). This indicates an excessive amount of irrigation of nearly 51% over the peak demand of 5.6 mm/day; the major portion of which will eventually return to groundwater depending on the soil moisture profile during the dry periods. In addition to the effect on water availability and saltwater intrusion, this excessive water use can have a serious consequence on groundwater pollution as the return flow could carry fertilizer and pesticide residues to groundwater.

Figure 2.1 and 2.2 indicates that monthly potential ET is higher than monthly rainfall except for the months of January, April, October, November and December of 2011. This results in an

TABLE 2.1. Climatic parameters observed and the ETo values estimated for 2011.

Month	Monthly rainfall (mm)	Average temperature	Wind* velocity (km/h)	RH (%)	Average sunshine hours	ETo** (mm/day)	RF-ETo (mm/month)
January	112	25.5	6.92	79	5.80	3.5	5
February	3	26.0	6.16	77	6.60	3.9	-107
March	1	27.7	6.10	65	9.50	5.3	-164
April	211	29.0	7.10	71	8.90	5.4	49
May	12	29.9	13.20	77	9.30	5.6	-163
June	1	30.0	13.40	75	8.56	5.5	-165
July	0	30.1	11.80	75	7.70	5.3	-163
August	15	29.5	12.30	76	7.24	5.2	-145
September	31	29.5	12.00	77	8.50	5.4	-129
October	304	28.3	6.90	81	4.30	3.6	192
November	462	26.7	4.30	83	8.30	3.9	345
December	311	25.9	6.10	81	6.15	3.4	207

Notes:
RH - Relative humidity
ETo - Reference crop evapotranspiration
RF - Rainfall
* Average wind velocity from 1999 to 2008
** Using FAO CROPWAT version 8.0 (Penman-Monteith method) for Thirunelveli (Altitude 4 m, Latitude 9.45 °N, Longitude 79.5 °E)

FIGURE 2.1. Monthly rainfall and reference crop evapotranspiration for 2011.

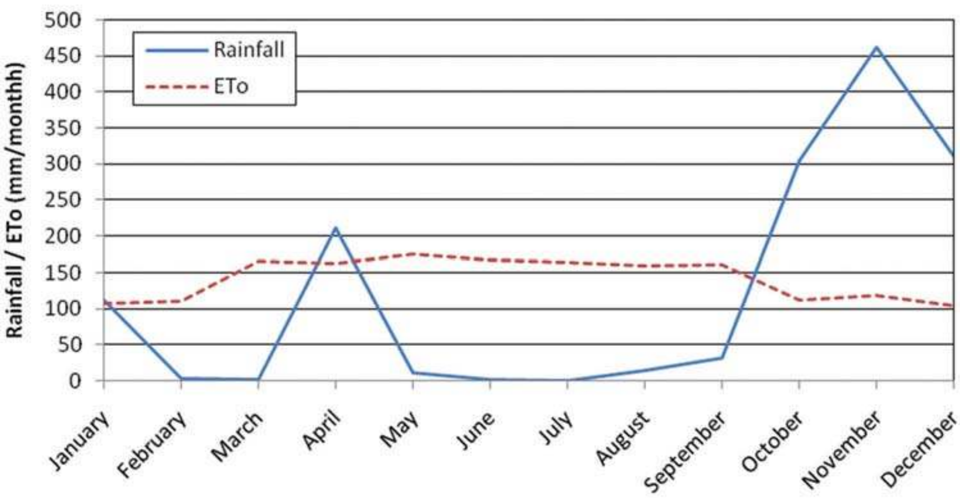
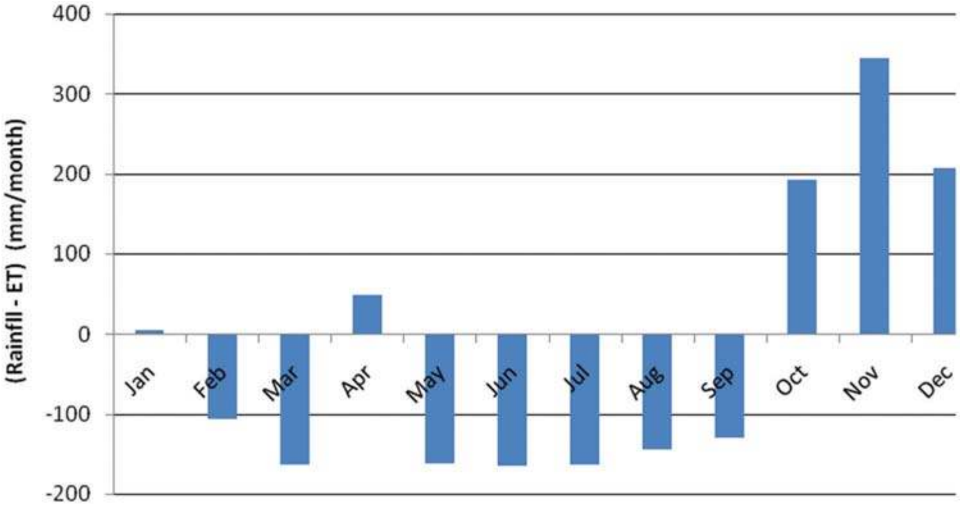


FIGURE 2.2. Monthly deficits (i.e., rainfall - ET) for 2011.



overall deficit of 238 mm in the year 2011, even if 100% of the rainfall is considered effective in recharging the groundwater, there will be an excessive withdrawal of 238 mm from groundwater storage to meet the ET demand unless ET takes place at rates lower than its potential (maximum) values. This aspect requires a planned study and careful recommendations to limit groundwater abstraction that brings the required moisture to the surface during the dry season while considering the crop response to alternate irrigation practices and techniques that could be adopted.

Groundwater recharge

The Groundwater level fluctuation method was used to estimate the groundwater recharge during the wet months from October to December of 2011 (Figures 1.1 and 2.1). The value of specific yield was obtained by calibrating Equation (2.2) to yield a realistic matching, i.e., maximum value of gross recharge, 'Sy.Δw + ET' not to exceed the total rainfall. Thus, a specific yield value of 0.21 was found to yield a reasonable matching of the components. This value falls within the range of values reported by Joshua (1973)[8], Rajasooriyar et al. (2002)[9], Feasibility report (2006)[10] and Thushyanthi and De Silva (2011)[11]. Spatial variation of net groundwater recharge (i.e., Sy.Δw) during the wet season was observed to be from 0.13 to 0.71 m with an average of 0.39 m. This is equivalent to 12.2 to 68.9% with an average of 37.3% of the total rainfall obtained during the same period at a specific yield of 0.21 (Table 2.2; Figure 2.3). These values are slightly higher than the values reported by previous researchers, which may be due to the fact that these values are estimated based on wet-season rainfall whereas other researchers have reported their estimates as the percentage of annual rainfall. However, these values are highly sensitive to specific yield and caution is required in interpreting the values.

[8] Joshua 1973 - reported non-capillary porosity as 20% for Red-Yellow Latosols.

[9] Rajasooriyar et al. 2002 - assumed this value to be 0.18.

[10] Feasibility report 2006 - reported values ranging from 0.18 to 0.32 for various locations in Jaffna.

[11] Thushyanthi and De Silva 2011 - reported 0.27 for Valikamam.

TABLE 2.2. Net and gross recharge during the wet months (October, November and December, 2011).

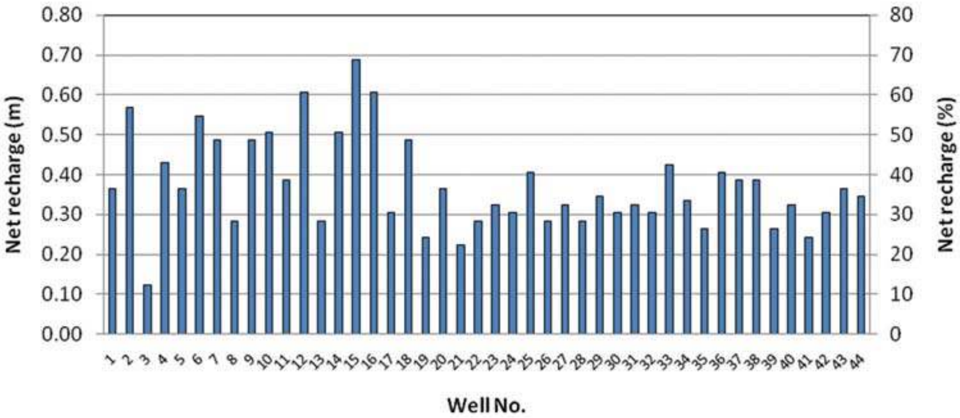
	Location	Land use	Net recharge Sy.Δw (m)	Gross recharge Sy.Δw + ET (m)	Net recharge (%)	Gross recharge (%)
1	Mathakal	D	0.38	0.69	36.49	66.48
2	Uduvil	D	0.59	0.90	56.76	86.75
3	Jaffna	D+H	0.13	0.44	12.16	42.16
4	Neervely	D+H	0.45	0.76	42.97	72.97
5	Sankuvely	D+H	0.38	0.69	36.49	66.48
6	J/173	D+H	0.57	0.88	54.73	84.73
7	Sankarathai	D+H	0.50	0.81	48.65	78.65
8	Elalai	D+H	0.29	0.60	28.38	58.38
9	Kantharodai	D+H	0.50	0.81	48.65	78.65
10	Thirunelveli	P	0.53	0.84	50.68	80.67
11	Jaffna	P	0.40	0.71	38.51	68.51
12	Jaffna	P	0.63	0.94	60.81	90.81
13	Puttur	P	0.29	0.60	28.38	58.38
14	Siththankeni	P	0.53	0.84	50.68	80.67
15	Moolai	P	0.71	1.02	68.92	98.92
16	Navaly	P	0.63	0.94	60.81	90.81
17	Manipay	P	0.32	0.63	30.41	60.40
18	Alaveddy	P	0.50	0.81	48.65	78.65
19	Irupalai	F	0.25	0.56	24.32	54.32
20	Vaddukoddai	F	0.38	0.69	36.49	66.48
21	Kopai	F	0.23	0.54	22.30	52.29
22	Neervely	F	0.29	0.60	28.38	58.38
23	Neervely	F	0.34	0.65	32.43	62.43
24	Punnalaikadduvan	F	0.32	0.63	30.41	60.40
25	Mallakam	F	0.42	0.73	40.54	70.54
26	Puttur	F	0.29	0.60	28.38	58.38
27	Kopai	F	0.34	0.65	32.43	62.43
28	Kondavil	F	0.29	0.60	28.38	58.38
29	Thirunelveli	F	0.36	0.67	34.46	64.46
30	Urumpirai	F	0.32	0.63	30.41	60.40
31	Urumpirai	F	0.34	0.65	32.43	62.43
32	Urumpirai	F	0.32	0.63	30.41	60.40
33	Pandatharippu	F	0.44	0.75	42.57	72.56
34	Kokuvil	F	0.35	0.66	33.45	63.44
35	Inuvil	F	0.27	0.58	26.35	56.35
36	Chankanai	F	0.42	0.73	40.54	70.54
37	Ilavalai	F	0.40	0.71	38.51	68.51
38	Alaveddy	F	0.40	0.71	38.51	68.51
39	Thellipalai	F	0.27	0.58	26.35	56.35
40	Punnalaikadduvan	F	0.34	0.65	32.43	62.43
41	Neervely	F	0.25	0.56	24.32	54.32
42	Urumpirai	F	0.32	0.63	30.41	60.40

(Continued)

TABLE 2.2. Net and gross recharge during the wet months (October, November and December, 2011) (Continued).

	Location	Land use	Net recharge Sy.Δw (m)	Gross recharge Sy.Δw + ET (m)	Net recharge (%)	Gross recharge (%)
43	Neervely	F	0.38	0.69	36.49	66.48
44	Maruthanamadam	F	0.36	0.67	34.46	64.46
	Average		0.39	0.70	37.26	67.25
	Minimum		0.13	0.44	12.16	42.16
	Maximum		0.71	1.02	68.92	98.92

FIGURE 2.3. Net groundwater recharge during the wet period from October to December, 2011.



The rainfall obtained during the period from 1st October to 21st December of 2011 was 1,036 mm, and the ET was 400 mm during the same period. When ET is also compounded, the gross recharge varied from 42.2 to 98.9% with an average of 67.3%. This indicates that about 33% of the total rainfall results in surface runoff during the rainy season (Table 2.2). Rainfall data used in this study was obtained from the Thirunelveli agro-meteorological station. Therefore, the spatial variability as shown in Figure 2.4 could have been a result of local rainfall variability and geohydrology of the area. The average net gain in aquifer storage of 0.39 m by the end of the wet season can be safely used for dry-season cultivation and other consumptive uses sustainably. However, it is stated that about 50% can be lost as dry-season lateral flow through karst features of the limestone (Balendran et al. 1968). According to Thiruchelvam (1994), agricultural water use in the Valikamam region is about 78% of the total recharge, leaving about 22.3% of the total recharge for other uses. Field crops account for about 53% of the recharge and the balance irrigation mainly goes to home gardens and for the cultivation of permanent crops (25% of the total recharge).

Table 2.3 and Figure 2.5 show the theoretical and actual groundwater head loss or gain during the monitoring period. The fall in groundwater levels between January to July was much less than that of the ET irrespective of the dry-season flow to the sea, which implies that considerable seawater intrusion takes place to compensate the loss in head due to ET. It also implies that actual ET takes place at values less than the potential ET during the dry months. However, this concept needs to be clarified through further research. Similarly, the gain during the wet months is less than the rainfall (RF), indicating substantial runoff to the sea during the wet months. A runoff value of 33% is reported in this study.

FIGURE 2.4. Spatial distribution of net groundwater recharge (%).

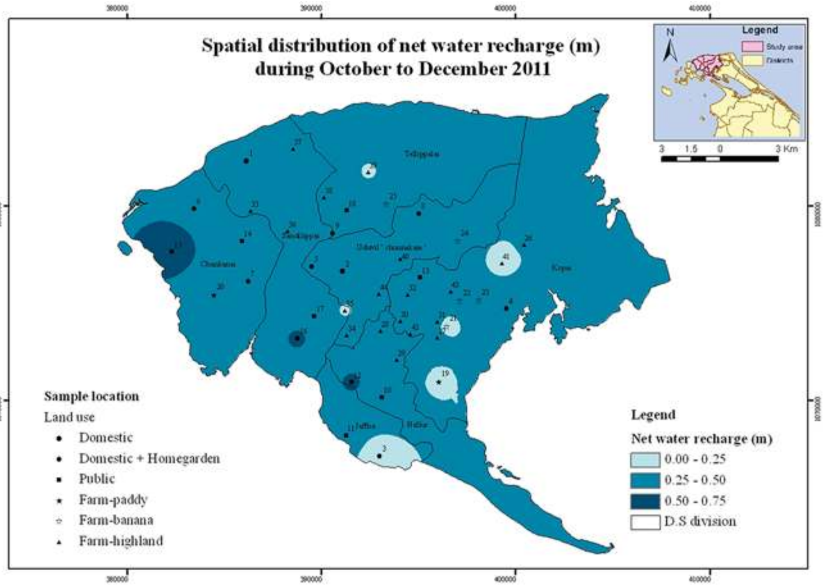


TABLE 2.3. Theoretical* and actual groundwater head loss or gain during the monitoring period.

	Location	Land use	Δw Jan-Apr (m)	Δw Apr-Jul (m)	Δw Jul-Sept (m)	Δw Oct-Dec (m)
	RF		0.10	0.19	0.04	1.04
	ET		0.44	0.52	0.36	0.31
	RF-ET		-0.34	-0.34	-0.32	0.73
	(RF-ET)/Sy*		-1.60	-1.60	-1.53	3.45
1	Mathakal	D	-0.15	-0.15	0.30	1.80
2	Uduvil	D	-0.25	-0.80	0.60	2.80
3	Jaffna	D+H	-0.55	-0.15	0.75	0.60
4	Neervely	D+H	-0.56	-0.76	0.10	2.12
5	Sankuvely	D+H	0.10	-0.30	0.20	1.80
6	J/173	D+H	-0.60	-0.10	0.00	2.70
7	Sankarathai	D+H	-0.35	-0.40	-0.10	2.40
8	Elalai	D+H	0.12	-1.00	0.20	1.40
9	Kantharodai	D+H	-0.08	-1.10	-0.10	2.40
10	Thirunelveli	P	-0.89	-0.70	-0.20	2.50
11	Jaffna	P	-1.06	-0.55	0.35	1.90
12	Jaffna	P	-0.54	-0.80	0.20	3.00
13	Puttur	P		-3.70	0.20	1.40
14	Siththankeni	P	-0.20	-0.30	-0.20	2.50
15	Moolai	P	-1.20	-0.50	0.00	3.40
16	Navaly	P	-1.30	-0.30	-0.20	3.00
17	Manipay	P	-0.20	-0.40	-0.10	1.50
18	Alaveddy	P	-0.35	-0.20	-0.10	2.40
19	Irupalai	F	-0.50	-0.60	0.10	1.20
20	Vaddukoddai	F	-0.95	0.00	-0.30	1.80

(Continued)

TABLE 2.3. Theoretical* and actual groundwater head loss or gain during the monitoring period (Continued).

Location		Land use	Δw Jan-Apr (m)	Δw Apr-Jul (m)	Δw Jul-Sept (m)	Δw Oct-Dec (m)
21	Kopai	F	-0.61	-0.35	0.35	1.10
22	Neervely	F	-0.84	-0.85	0.05	1.40
23	Neervely	F	-0.11	-0.73	-0.25	1.60
24	Punnalaikadduvan	F	-0.69	-0.20	0.00	1.50
25	Mallakam	F	1.20	-1.50	-0.20	2.00
26	Puttur	F	-0.42	-0.58	0.10	1.40
27	Kopai	F	-0.76	-0.10	-0.10	1.60
28	Kondavil	F	-0.62	-0.40	0.20	1.40
29	Thirunelveli	F	-0.10	-0.10	-0.20	1.70
30	Urumpirai	F	-0.10	-0.50	0.10	1.50
31	Urumpirai	F	-0.15	-0.75	0.40	1.60
32	Urumpirai	F	-0.63	-0.30	0.00	1.50
33	Pandatharippu	F	-0.40	-0.30	0.00	2.10
34	Kokuvil	F	-0.10	0.00	-0.05	1.65
35	Inuvil	F	-0.40	0.00	0.20	1.30
36	Chankanai	F	-0.75	-0.40	-0.20	2.00
37	Ilavalai	F	-0.07	-0.25	0.10	1.90
38	Alaveddy	F	-0.09	-0.30	-0.20	1.90
39	Thellipalai	F	0.38	-0.20	0.10	1.30
40	Punnalaikadduvan	F		-5.30	0.30	1.60
41	Neervely	F	-0.04	-1.78	1.10	1.20
42	Urumpirai	F	-0.65	-0.20	0.20	1.50
43	Neervely	F		-4.50	0.00	1.80
44	Maruthanamadam	F	0.30	0.70	-0.10	1.70
	Average		-0.37	-0.72	0.08	1.84
	Minimum		-1.30	-5.30	-0.30	0.60
	Maximum		1.20	0.70	1.10	3.40

* Theoretical groundwater head loss or gain assuming Sy as 0.21.

The depth of wells showed a linear relationship with the depth of the dry-season water table (Figure 2.6) and the average depth of water during the dry season was around 0.5 to 1.5 m irrespective of the depth of the well (Figure 2.7). This implies that there was no tendency among farmers to deepen wells to increase water availability in the dry season. However, personal communication with farmers suggests that they usually dig wells up to the limestone layer, and the average depth of water (0.97 m) available during the dry season (Table 2.4; Figure 2.7) is insufficient to provide the drawdown required to irrigate. Farmers practice different techniques to manage the situation. While some of them carry out intermittent pumping, others tend to install a small diameter vertical borehole (10-15 cm) into the well bottom, which has now been declared as being illegal by the District Secretary, Jaffna, unless approval is obtained from the NWSDB (M. Patrick Diranjan, Assistant Commissioner, Department of Agrarian Development, Jaffna, personal communication May 02, 2012). This aspect merits further investigation.

FIGURE 2.5. Actual and theoretical groundwater head loss or gain in 2011.

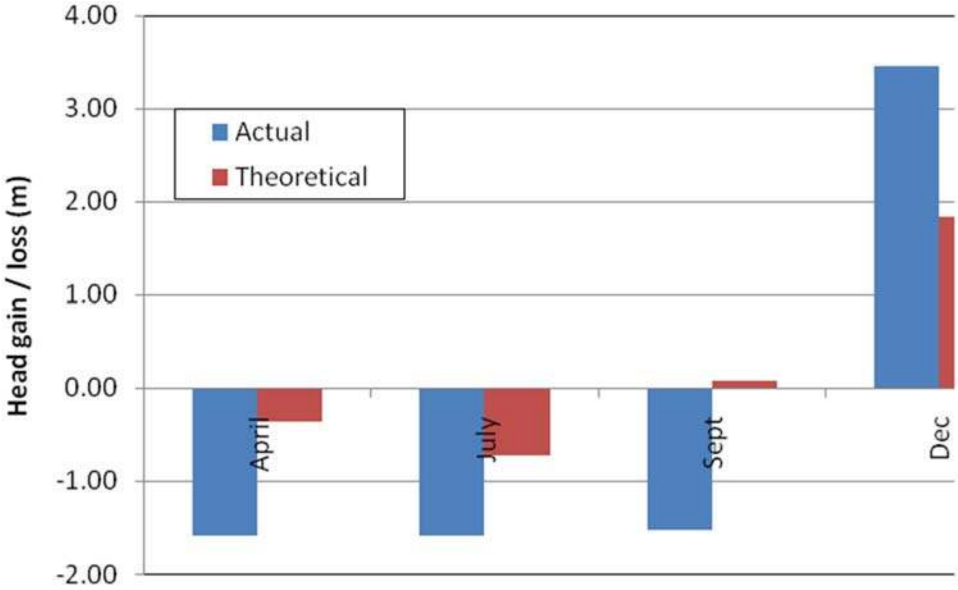


FIGURE 2.6. Relationship between well depth and depth to dry-season water level in 2011.

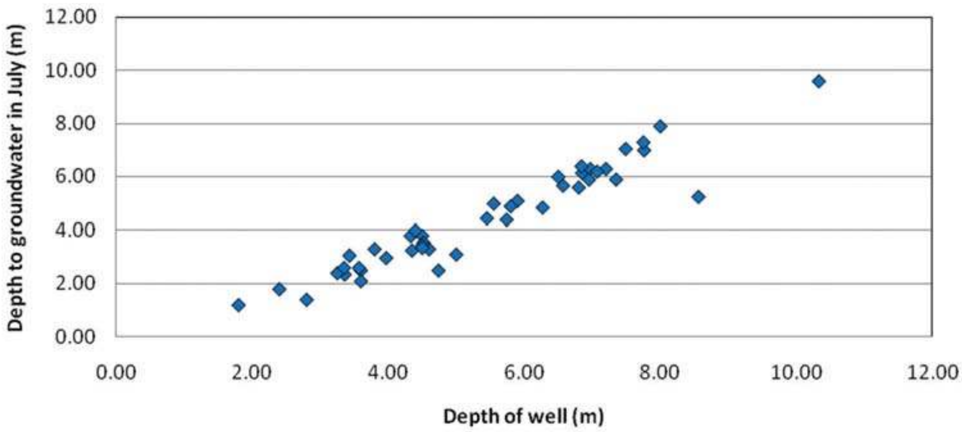


FIGURE 2.7. Relationship between well depth and depth of water in the well during the dry season of 2011.

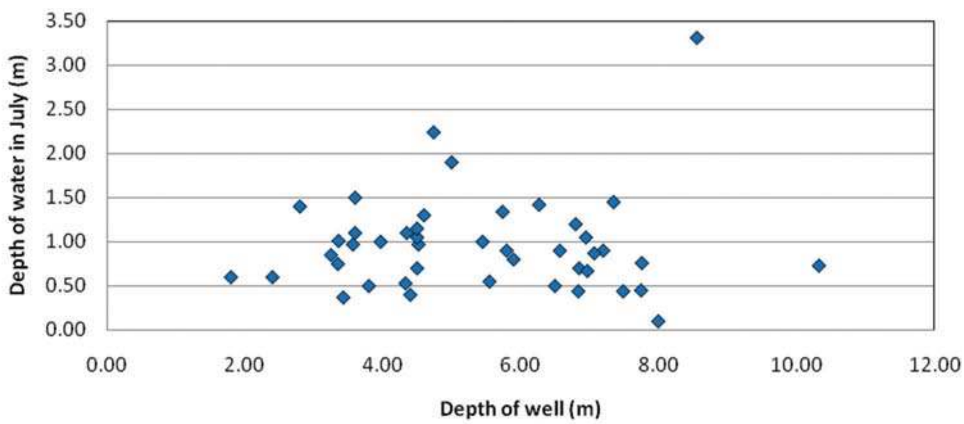


TABLE 2.4. Depth of wells, dry-season water depth, dry-season depth to groundwater, wet-season average depth to groundwater and overall gain in water depth during 2011.

	Location	Land use	Depth of wells (m)	Well water depths - July (m)	Depth to groundwater - July (m)	Average depth to groundwater Oct - Dec (m)	Overall gain in depth Jan - Dec (m)
1	Mathakal	D	4.50	0.70	3.80	2.60	1.80
2	Uduvil	D	4.52	0.97	3.55	1.55	2.35
3	Jaffna	D+H	3.36	1.01	2.35	1.30	0.65
4	Neervely	D+H	2.40	0.60	1.80	0.64	0.90
5	Sankuvely	D+H	3.60	1.10	2.50	1.40	1.80
6	J/173	D+H	3.97	1.00	2.97	1.62	2.00
7	Sankarathai	D+H	3.25	0.85	2.40	1.30	1.55
8	Elalai	D+H	5.45	1.00	4.45	3.55	0.72
9	Kantharodai	D+H	4.74	2.24	2.50	1.40	1.12
10	Thirunelveli	P	4.60	1.30	3.30	2.25	0.71
11	Jaffna	P	4.35	1.10	3.25	1.95	0.64
12	Jaffna	P	3.80	0.50	3.30	1.60	1.86
13	Puttur	P	3.43	0.37	3.06	2.16	0.66
14	Siththankeni	P	3.35	0.75	2.60	1.55	1.80
15	Moolai	P	4.50	1.05	3.45	1.75	1.70
16	Navaly	P	4.50	1.15	3.35	2.05	1.20
17	Manipay	P	6.85	0.70	6.15	5.50	0.80
18	Alaveddy	P	3.57	0.97	2.60	1.50	1.75
19	Irupalai	F	2.80	1.40	1.40	0.70	0.20
20	Vaddukoddai	F	1.80	0.60	1.20	0.60	0.55
21	Kopai	F	7.49	0.44	7.05	6.15	0.49
22	Neervely	F	6.27	1.42	4.85	4.10	-0.24
23	Neervely	F	8.56	3.31	5.25	4.70	0.51
24	Punnalaikadduvan	F	5.74	1.34	4.40	3.65	0.61
25	Mallakam	F	6.97	0.67	6.30	5.50	1.50
26	Puttur	F	6.57	0.90	5.67	4.87	0.50
27	Kopai	F	7.76	0.76	7.00	6.30	0.64
28	Kondavil	F	7.75	0.45	7.30	6.40	0.58
29	Thirunelveli	F	10.33	0.73	9.60	8.95	1.30
30	Urumpirai	F	6.95	1.05	5.90	5.05	1.00
31	Urumpirai	F	5.90	0.80	5.10	3.90	1.10
32	Urumpirai	F	5.55	0.55	5.00	4.25	0.57
33	Pandatharippu	F	3.60	1.50	2.10	1.05	1.40
34	Kokuvil	F	8.00	0.10	7.90	7.13	1.50
35	Inuvil	F	7.20	0.90	6.30	5.45	1.10
36	Chankanai	F	7.35	1.45	5.90	5.10	0.65
37	Ilavalai	F	4.33	0.53	3.80	2.75	1.68
38	Alaveddy	F	6.84	0.44	6.40	5.65	1.31
39	Thellipalai	F	5.00	1.90	3.10	2.35	1.58
40	Punnalaikadduvan	F	5.80	0.90	4.90	3.80	1.08

(Continued)

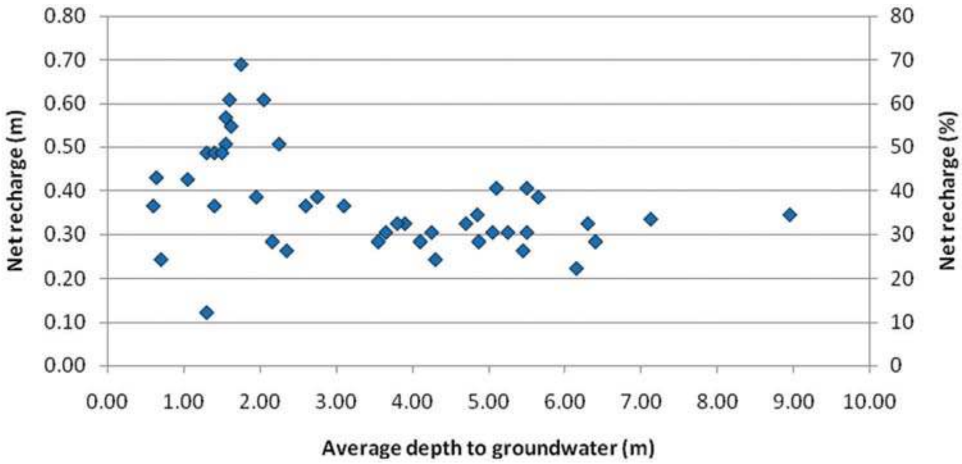
TABLE 2.4. Depth of wells, dry-season water depth, dry-season depth to groundwater, wet-season average depth to groundwater and overall gain in water depth during 2011 (Continued).

	Location	Land use	Depth of wells (m)	Well water depths - July (m)	Depth to groundwater - July (m)	Average depth to groundwater Oct - Dec (m)	Overall gain in depth Jan - Dec (m)
41	Neervely	F	6.50	0.50	6.00	4.30	0.48
42	Urumpirai	F	7.07	0.87	6.20	5.25	0.85
43	Neervely	F	4.40	0.40	4.00	3.10	0.70
44	Maruthanamadam	F	6.80	1.20	5.60	4.85	2.60
	Average		5.41	0.97	4.45	3.44	1.10
	Minimum		1.80	0.10	1.20	0.60	-0.24
	Maximum		10.33	3.31	9.60	8.95	2.60

When the wet season average depth to the water table is shallow (i.e., less than 2 m), the recharge rate is observed to be higher than that of deeper depths (Figure 2.8). Beyond that level, net recharge remains nearly constant at around 30% irrespective of the average depth to the water table. This indicates that the profile soil moisture has an influence on groundwater recharge to a certain extent even during the wet season.

Despite the claim of an imbalance between withdrawals and recharge made by previous researchers (Balendran 1969; Rajasooriyar et al. 2002; Thushyanthi and De Silva 2011), difference in groundwater levels over a complete annual cycle of cultivation and recharge, i.e., between January 2011 and December 2011, showed a positive balance indicating no permanent depletion of groundwater in the Chunnakam aquifer area during the study period. A similar remark was made by Panabokke and Perera (2005) as well. However, it is possible for the midseason water level in the wells to reach a depth as low as 0.5 m during the dry periods as observed in this study (Figure 2.5). Therefore, a regional management plan is essential to manage water demand during the dry season.

FIGURE 2.8. Relationship between average depth to groundwater and net recharge during wet months.



Potential for saltwater intrusion

The presence of a freshwater lens above saltwater in the Jaffna Peninsula has been reported by Punthakey and Gamage (2006). Assuming an average freshwater head of 1 m above mean sea level (amsl) during the dry period, according to the principle of Ghyben-Herzberg lens, it can be inferred that a saltwater interface will be present at 40 m below mean sea level (bmsl). Furthermore, the danger is that the reduction in freshwater volume cannot be visually judged as the reduction will be compensated by seawater intrusion. A detailed study is required to verify the dynamics of this interface with the pattern of dry-season groundwater extraction.

Conclusions

Spatial variation of net groundwater recharge was observed to be from 12 to 69% of the total rainfall, with an average of 37% at a specific yield of 0.21. When ET is also added to effective recharge, the net recharge varied from 42 to 99% with an average of 67%. This indicates that about 33% of the rainfall results in runoff during the rainy season. The spatial variability observed in computed values could be attributed to local rainfall variability and partly to the geohydrology of the area.

The fall in groundwater level during January to July was much less than the estimated ET, which implies that considerable seawater intrusion takes place to compensate the loss in head due to ET. It also implies that actual ET takes place at values less than the potential ET during the dry months. However, this concept needs to be clarified through further research. This aspect requires a planned study and careful recommendations need to be made to limit groundwater abstraction that brings the required moisture to the surface during the dry season while considering the crop response to alternate irrigation practices and techniques.

Despite the claim of imbalance between withdrawals and recharge made by previous researchers, the difference in groundwater levels over a complete annual cycle showed a positive balance indicating no permanent depletion of groundwater in the Chunnakam aquifer area during the study period. However, it is possible for the midseason water table to reach a depth as low as 0.5 m of water in the wells during the dry period. Therefore, not only is water availability reduced but also the freshwater-saltwater interface could reach as close as 20 to 40 m below the well bottom depending on the freshwater head above mean sea level. In addition, the thickness of the freshwater lens is limited by the flat topography; that is the thickness of the soil above mean sea level which is a limiting factor in the Jaffna Peninsula.

Recommendations

A detailed study is required to determine the total number of wells and pumps, abstraction pattern for various uses and total volume of abstraction on a yearly basis.

Introduction of water-saving irrigation practices and techniques are essential to manage the dry-season water demand and availability.

Estimation of dry-season subsurface runoff and actual ET is essential to model their implications on seawater intrusion, and a detailed study is required to verify the dynamics of this freshwater-seawater interface with the pattern of dry-season groundwater extraction.

Establishment of spatially distributed rainfall recording stations is essential if any meaningful estimation of spatial variation of groundwater recharge is to be made and development of a regional agricultural water management plan is to be designed.

The effect of delayed recharge from surface ponds and the effect of newly constructed saltwater exclusion bunds, such as Arali Bund, built across the seasonal river, Valukai Aru, need to be studied.

References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and drainage. Paper 56. FAO, Rome, Italy. Pp 110-113.

Balendran, V. S. (1969). Salt water fresh water interface studies in the Jaffna Peninsula, Report III. Geological Survey Department, Colombo, Sri Lanka. pp 36.

Balendran, V. S., Srimanne, C. H. L. and S. A.Arumugam. (1968). Groundwater investigation in Jaffna Peninsula. Water resources board, Colombo, Sri Lanka. pp 1-16.

De Silva, C. S. and K. R. Rushton. (2007). Groundwater recharge estimating using improved soil moisture balance methodology for a tropical climate with distinct dry season. Hydrological Sciences Journal. 52(5): 1051-1067.

De Silva, R.P. (2005). Limitations of a soil water budgeting method in estimating groundwater recharge with particular reference to the dry zone of Sri Lanka. Journal of National Science Foundation, Sri Lanka. 33(2):99-113.

De Silva, R.P. (2004). Spatial variability of groundwater recharge- Is it really variable?. Journal of Spatial Hydrology. 4(1):1-18.

De Silva, R.P. (2000). A simple soil water balance model to estimate groundwater recharge in the dry zone of Sri Lanka. Tropical agricultural research and extension. 3(2):120-126.

Feasibility report. (2006). A feasibility study for water supply and sanitation system for the Jaffna Peninsula. ADP project. Project No: 5068020 . National water supply and drainage board. Jaffna. Sri Lanka.

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

Joshua, W.D. (1973). Physical properties of soil as related to irrigation and water management. In: proceedings of National seminar on water management and control at the farm level FAO/ Sri Lanka. Colombo, Sri Lanka 18 -23. June 1973.

Kumar. C. P. 2003. Estimation of groundwater recharges using soil moisture balance approach. Journal of Soil and Water Conservation, Soil Conservation Society of India. 2(1-2): 53-58.

Lerner, D. N., Issar, A. S. and Simmers, I. (1990) Groundwater Recharge. A Guide to Understanding and Estimating Natural Recharge. International Contributions to Hydrogeology no. 8, Verlag Heinz Heise, Hanover, Germany.

Mikunthan, T. and C. Shanthi De Silva. (2009). Estimation of groundwater recharge in limestone aquifer using an improved soil moisture balance method: A case study in Jaffna district. Journal of Tropical Agricultural Research. 21 (1):51-61

Misstear, B.D.R. (2000). Groundwater recharge assessment: a key component of river basin management. National Hydrology Seminar 2000. Dublin. Pp 51-58.

Navaratnarajah, V. (1994). Water problems in the Jaffna Peninsula. 20th WEDC International Conference in Affordable water supply and sanitation. 1994, Colombo, Sri Lanka. pp.191- 193.

Panabokke, C.R. and A.P.G.R.L. Perera. (2005). Groundwater resources of Sri Lanka. Water Resources Board, Colombo, Sri Lanka.

Punthakey, J. F. and N. P. D. Gamage. (2006). Coupled flow and salinity transport modelling and assessment of groundwater availability in the Jaffna Peninsula, Sri Lanka. 32nd WEDC International conference. 2006. Colombo, Sri Lanka. pp 326-327.

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, H.A. and V. Nandakumar. (2002). Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka. In: Sustainable groundwater management. Hiscock, K.M., Rivett, M.O. and Davison, R.M. (Eds). Geological Society, Londan. 193: 181 – 197.

Rushton, K.R., Eilers, V.H.M. and R.C. Carter. 2006. Improved soil moisture balance methodology for recharge estimation. Journal of Hydrology, 318: 379-399.

Sophocleous, M.A. (1991). Combining the soil water balance and water-level fluctuation methods to estimate natural groundwater recharge - practical aspects. Journal of hydrology. 124: 229-241.

Thiruchelvam, S. (1994). An economic analysis of groundwater use in the Jaffna district for agriculture. Thesis submitted in fulfillment of the requirement for the degree of Doctor of Philosophy. Post Graduate Institute of Agriculture, University of Peradaniya, Sri lanka.

Thushyanthy, M and C.S.De Silva (2011). Assessment of Groundwater Resources in Jaffna Limestone Aquifer and Suggestions for a Groundwater Regulatory Framework. Tropical Agriculture Research.

CHAPTER III
GROUNDWATER QUALITY

Introduction

There are over 100,000 dug wells in the Peninsula, of which 17,860 are agricultural wells and the remainder are used to meet the demand for domestic and home garden purposes in urban and rural areas (Kraft 2002). The large density of wells would indicate heavy extraction of freshwater, and the increasing problems of water quality and quantity available for consumption. Over-extraction of groundwater could lead to an increase in salinity in the Jaffna Peninsula, where the aquifer is surrounded by the sea. Thus, it has been the main focus of groundwater research in the past few years.

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; Mageswaran 2003). The high nitrate levels recorded in the well waters of the Peninsula's agricultural areas is very likely related to the intensive cultivation that is practiced in that region. Farmers apply large amounts of animal wastes, green manures and crop residues in addition to the heavy application of inorganic fertilizers. 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 10-15 mg/l (Mikunthan and Silva 2008). Out of the 68 wells studied, 81% of the wells were not recommended for drinking in intensified agricultural areas (Jeyaruba and Thushyanthy 2009).

Since the cessation of the civil war in 2009, considerable interest has been shown in groundwater studies in the Jaffna Peninsula. It is speculated that after the lifting of fuel and fertilizer restrictions, the issue of groundwater quality and availability will emerge as a significant constraint to the development of the region. It is, therefore, essential to establish baseline information on water quality and availability to inform future water-related studies and other activities in the Peninsula. A study was undertaken to characterize the chemical quality of Chunnakam aquifer with special reference to its suitability for domestic and agricultural uses.

Objectives

The specific objectives of this study were to:

- characterize the chemical attributes of the Chunnakam aquifer;
- map the spatial distribution of water quality of the aquifer; and
- determine the effect of land use on the chemical quality of groundwater under different cropping systems that include highland crops, banana and paddy.

Methodology

Collection of water samples

Water samples were collected for chemical analysis on five occasions during the period January to December 2011 to represent various climatic regimes within a year. Samples were collected from the surface of the wells, as no stratification in water quality was anticipated due to the continuous use of the wells. Each sample was poured into one liter plastic bottles after rinsing with the same water. The bottles were then tightly sealed, labeled and transported to the laboratory of the NWSDB, Jaffna, for analysis within 48 hours of collection.

Analytical techniques

Samples were analyzed for pH, electrical conductivity (EC), chloride, nitrate-N, nitrite-N, fluoride, calcium, magnesium, carbonate, bicarbonate, sodium, potassium, sulfate, total phosphate, iron and manganese concentration. The pH meter and EC meter were used to measure the pH and EC, respectively. Chloride concentration was measured by silver nitrate titration. Nitrate-N, nitrite-N, fluoride, total phosphate, iron and manganese concentrations were estimated using colorimetric spectrophotometer. Calcium and magnesium content were determined by ethylenediaminetetraacetic acid (EDTA) titration using Eriochrome Black T as an indicator. Carbonate and bicarbonate content were measured by acid-base titration. Sodium and potassium content were determined using a flame photometer at the Institute of Fundamental Studies (IFS), Hantana, Kandy. Sulfate content was estimated by the turbidimetric method using the turbidity meter. The procedures of the analysis were based on the quality standard SLS 614 of the Sri Lanka Standards Institution (SLSI).

Spatial distribution maps

Spatial distribution maps for different parameters were developed using the Inverse Distance Weighting (IDW) interpolation technique with ArcGIS 10.

Questionnaire survey and data collection

Apart from literature survey, a questionnaire survey was carried out to gather information regarding the type of crops, cropping pattern, fertilizer usage and farming practices in the study areas. A direct field observation during the questionnaire survey was performed as necessary to validate the information gathered and to obtain additional information.

Results and discussion

General

Observation of the survey on physical characteristics of selected wells indicated that most of the farm wells were not properly maintained, improperly lined and devoid of an extended wall above the soil surface. Apart from domestic and public wells, agricultural wells are also being used for drinking purposes.

A typical farm area covers 0.1 to 1.5 ha. General land uses are coconut, banana and gardens comprising jackfruit, mango, citrus, papaya, pomegranate and other trees. Farmers perform intensive cultivation during both the wet and dry seasons. They select their crops according to market demand and decide their own cropping calendar and irrigation schedule. Timing of crop, sequence of crop, irrigation and all the cultivation practices are decided by the farmer who cultivates the field with their own experience. Most of the farmers keep the land fallow for two months (August and September). After the onset of rainfall, the land is prepared and cattle manure and organic matter are incorporated into the soil, harrowed and then tilled by two-wheel tractors.

These farmers are practicing either mono-cropping or mixed cropping. Onion, beetroot, brinjal and tobacco are cultivated as mono-crops. In case of mixed crops, for example, onion, sweet yam and even carrot are planted at the same time in the border of the basin. After the harvesting of onion and carrot, sweet yam is left in the field. In addition, they are practicing multiple cropping; planting two or more crops consecutively or at the same time on the same field, for example, *Amaranthus* (15-20 days), raddish (45 days) and onion (90 days) for maximum land utilization. Hence, high amounts of fertilizer are used to satisfy the requirements for all stages of the crops. In some areas, farmers practice year-round cultivation without fallowing the land. High income generated through short-term cash crops such as onion and tobacco attracts more farmers to follow this cultivation practice. Table 3.1 shows the cropping pattern of some of the fields in the study area.

TABLE 3.1. Cropping calendar of a few selected fields.

Month	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8
September October November December January February March April May June July August	Banana (September–August)	Banana (September–August); Tobacco (October–January); Okra (October–December); Onion (April–July)	Banana (September–August); Onion (December–February); Onion (May–July)	Onion (December–February); Beetroot (March–July); Carrot (April–July)	(September–December); String bean (December–March); Onion (December–March); Tomato (December–May); Sweet yam (May–August)	Cassava (September–August); (September–October); (September–October); Snake gourd (March–August); String bean (March–August)	Tobacco (December–March); Onion (May–July)	Tobacco (December–March)

Drinking water quality of selected wells

pH

The pH value of drinking water is an important index of acidity or alkalinity. A number of minerals and organic matter interact with one another to give the resultant pH value of the sample. The average pH values of water samples were within the range of 7.20 to 8.26, indicating slight alkalinity (Figure 3.1). Puvaneswaran (1986) and Rajasooriyar et al. (2002) reported that the pH value of water in the Jaffna Peninsula region is greater than 7.0 while Nagarajah et al. (1988) reported that the pH values of well water in the Peninsula were around 7.0.

The spatial variation of average pH values in the Chunnakam aquifer is presented in Figure 3.2. The figure also shows the temporal variation of pH values under different land use scenarios.

According to SLSI guidelines, the desirable level of pH for drinking water could vary from 7.0 to 8.5. Thus, groundwater in the study area could be considered as being acceptable for drinking in this respect.

FIGURE 3.1. Average pH values in the wells studied.

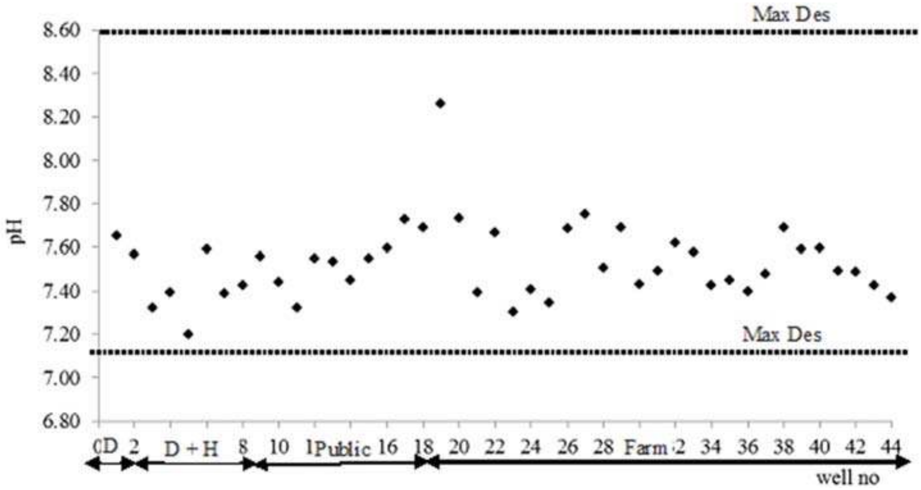
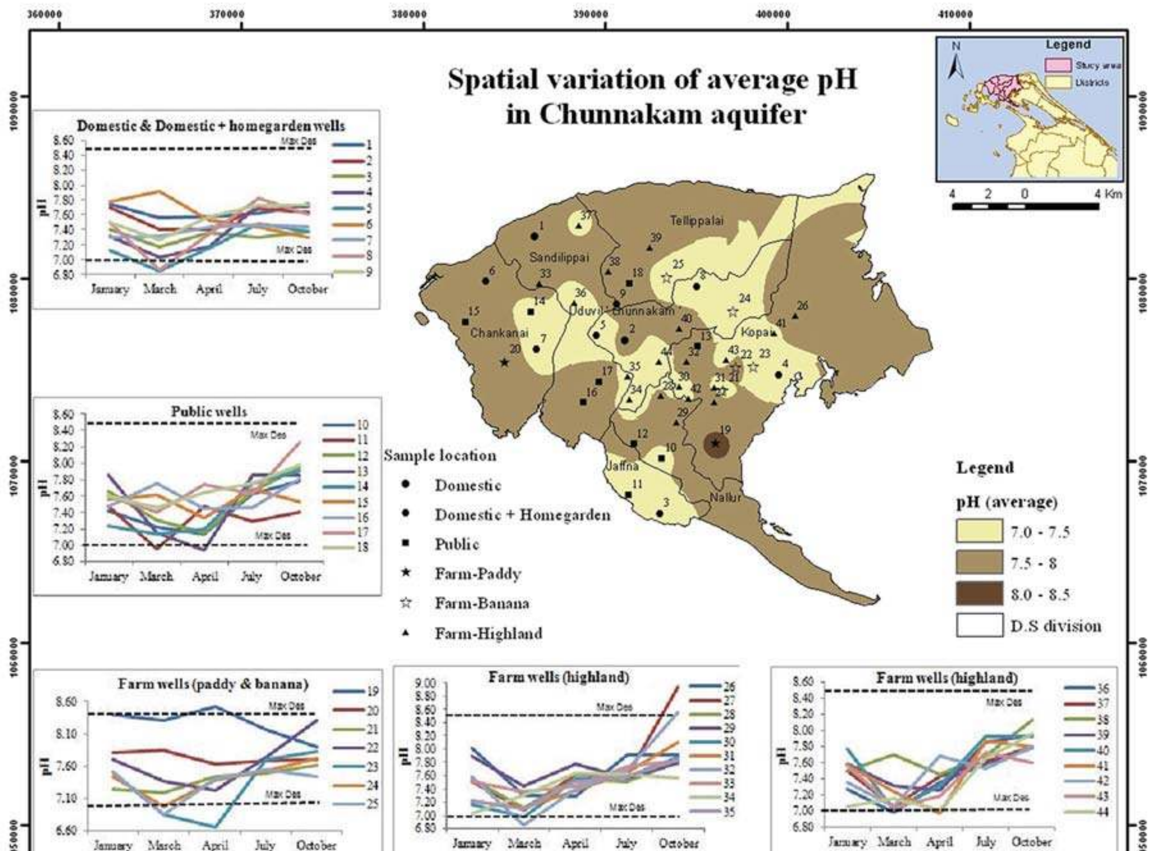


FIGURE 3.2. Spatial variation of average pH values in the wells studied.



Electrical Conductivity (EC)

Conductivity is the measure of the capacity of a material to conduct the electric current. A high EC value is an indication of the presence of abundant dissolved ionic species. It could be due to the contribution of the weathering of basic rocks, materials added as fertilizers and soil amendments, or due to seawater intrusion.

In the Jaffna Peninsula, January is the end of the wet season and July is end of the dry season. EC values of wells monitored during January are shown in Figure 3.3. The EC values during January ranged from 320 µS/cm to 4,320 µS/cm. Based on SLSI guidelines for drinking water, 95% of the wells were within the limits of SLSI permissible levels. Well numbers 5 and 15 had relatively high EC values of 3,500 µS/cm, which were above the SLSI guidelines for drinking water. Based on SLSI guidelines, the water in all the wells were acceptable for drinking purposes except well numbers 5 and 15.

The EC values during July ranged from 315 µS/cm to 7,050 µS/cm (Figure 3.4). Based on SLSI guidelines for drinking water, 89% of the wells were within the limits of SLSI permissible levels. However, it is visible that well numbers 6, 7, 15 and 20, which are located near the coastal area, had severe salinity problems by the end of the dry season in the Chunnakam aquifer. Other wells also showed an increase in EC values when compared to the values noted in January. The cause for such a drastic increase warrants further investigation.

FIGURE 3.3. Concentration of EC during January 2011.

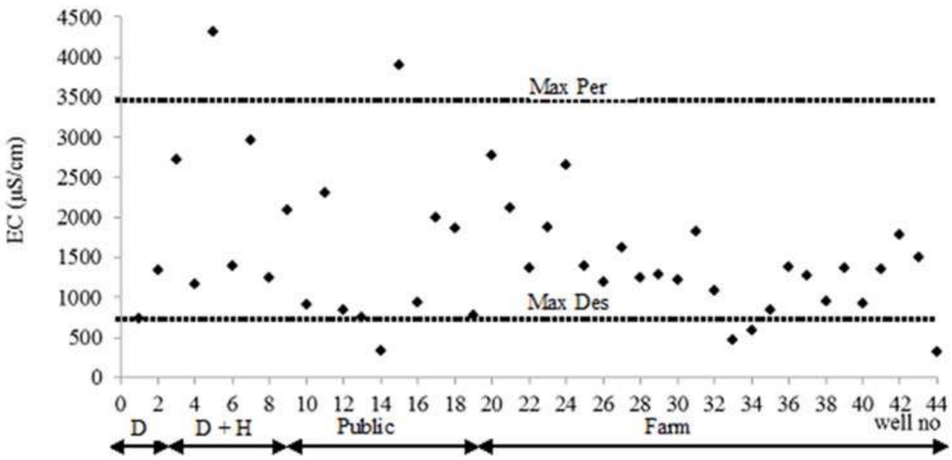
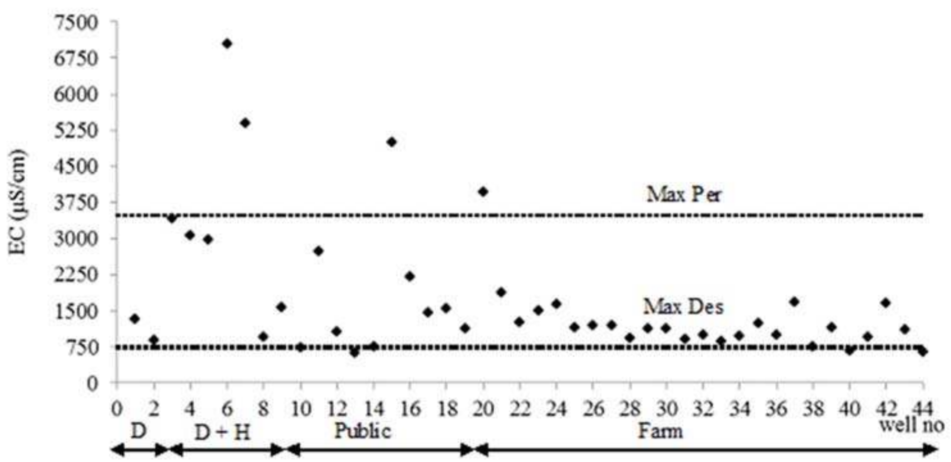
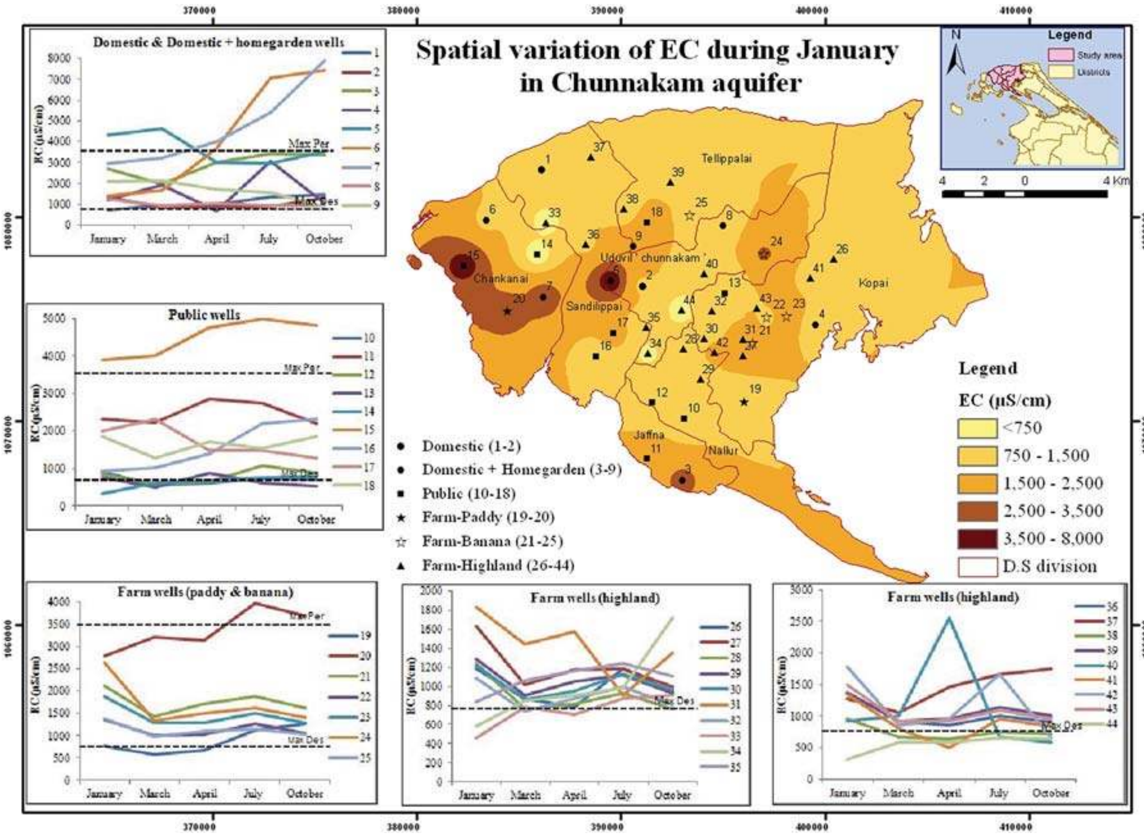


FIGURE 3.4. Concentration of EC during July 2011.



Figures 3.5 and 3.6 show the spatial variation of EC during January and July 2011, respectively. As shown in the figures, groundwater in the Chunnakam aquifer is characterized by the occurrence of moderately high to high EC contents with widely differing concentration among individual wells. High EC values were observed near the coastal areas and values decreased when moving further inland. The above results are in agreement with the spatial distribution of chloride (Figure 3.9 and 3.10). The trend of conductivity generally reflects the chloride concentration in groundwater and is enriched with sodium, calcium and magnesium ions (Jothivenkatachalam et al. 2011).

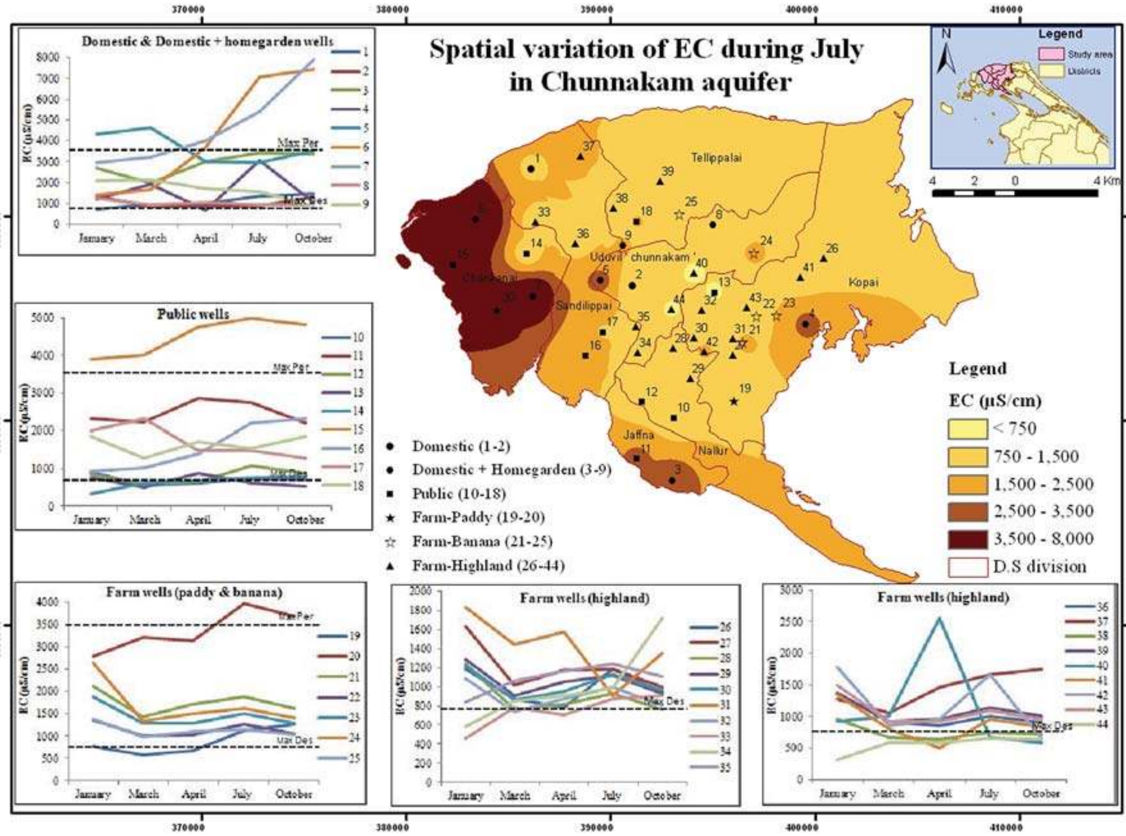
FIGURE 3.5. Spatial variation of EC during January.



In general, farm wells are low in EC when compared to the domestic and public wells even during the dry season. It could be due to the interior nature of the farming areas from the coastline. The water used by some domestic users with home gardens and in public wells was above SLSI guidelines for drinking purposes. Well number 5, which is found at Sankuvely, was above permissible levels during January and March, but after that it was below permissible levels during April, July and October. Well number 7, which is located at Vaddukoddai, also has salinity problems throughout the year except in January. Well number 15, located at Moolai, was above permissible levels during all months of the year. These three wells are located in the coastal area. Among farm wells, well number 20 (Vaddukoddai) was above permissible levels during July and October. It is also located near the coastal area. All other farm wells had an acceptable quality for drinking purposes based on the temporal fluctuation of EC.

Also, a high value for EC generally means a high degree of salinity. Therefore, it was clear that wells that are located near the coastal area had severe salinity problems when compared to other wells.

FIGURE 3.6. Spatial variation of EC during July.



Freshwater in the aquifer floating in the form of a lens of varying thickness above saline water had varying salinity levels depending on its location and distance from the sea. Puvaneswaran (1986) reported that the salinity of groundwater in a location at the Valukaiaru drainage basin in the Valikamam area is inversely related to its distance from the sea. The intensive agricultural pattern adopted in the last three decades also led to the increase in salinity of the water. Several wells once used to supply potable water are not in use now due to the increase in salinity (Nandakumar 1983). This study could not verify the above observations of previous researchers. However, moderate to high salinity levels (EC values) observed suggest that long-term monitoring is essential to make a firm conclusion and devise protective measures.

Chloride

The chloride concentrations of water samples of all wells were between 61 mg/l to 1,115 mg/l during January 2011 (Figure 3.7). All values of measured wells were below the permissible level of SLSI guidelines (1,200 mg/l). High chloride concentration of 1,115 mg/l was observed in a public well (Moolai) located in the coastal area. Of the 44 wells measured, 68% had chloride content less than 200 mg/l and 32% were within the range of 200 to 1,200 mg/l during the end of the wet season in the Chunnakam aquifer.

The chloride concentrations of water samples of all wells were between 70 mg/l to 2,808 mg/l during July 2011. As shown in Figure 3.8, well numbers 6, 7 and 15 had high chloride problems during the end of the dry season in the Chunnakam aquifer. Except for these three wells, the water in all the other wells was suitable for drinking purposes. Of the 44 wells measured, 34% had chloride content less than 200 mg/l during the end of the dry season in the Chunnakam aquifer. Mageswaran (2003) stated that water in the Karaveddy, Ponnalai and Thondamanaru areas had a salty taste and the concentration of chloride varied in the range of 900 mg/l to 1,000 mg/l.

FIGURE 3.7. Concentration of chloride during January 2011.

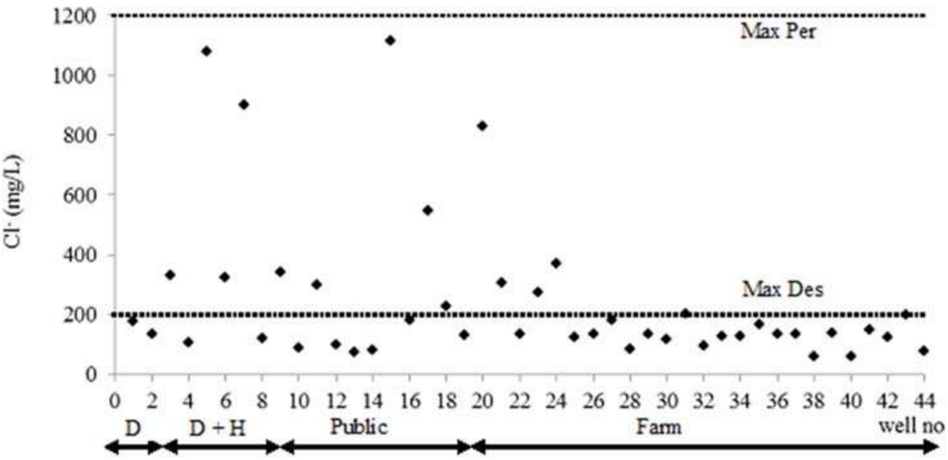
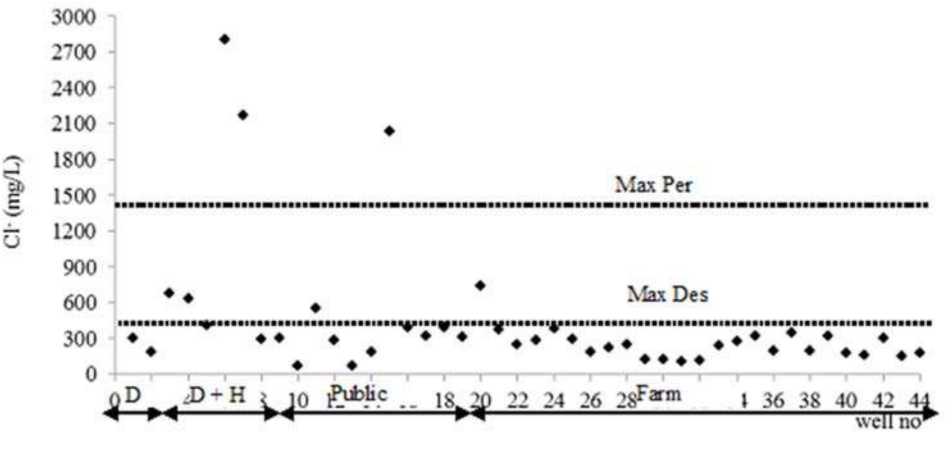


FIGURE 3.8. Concentration of chloride during July 2011.



The spatial distribution and temporal variation of chloride with different land use is presented in Figures 3.9 and 3.10. All farm wells were acceptable for drinking requirements except well number 20. Well number 20, which is located in a paddy field in Vaddukoddai, had above 1,200 mg/l of chloride concentration during October. Based on Figures 3.9 and 3.10, a high concentration of chloride was observed near the coastal areas and decreased when moving further inland. The patterns of EC and chloride concentration are a clear indication of the influence of the sea. Rajasooriyar et al. (2002) mentioned that a high chloride concentration in some selected coastal locations provide evidence for seawater intrusion. A substantial increase in chloride concentration during the month of July, as shown in Figure 3.10, needs further verification.

FIGURE 3.9. Spatial variation of chloride concentration during January.

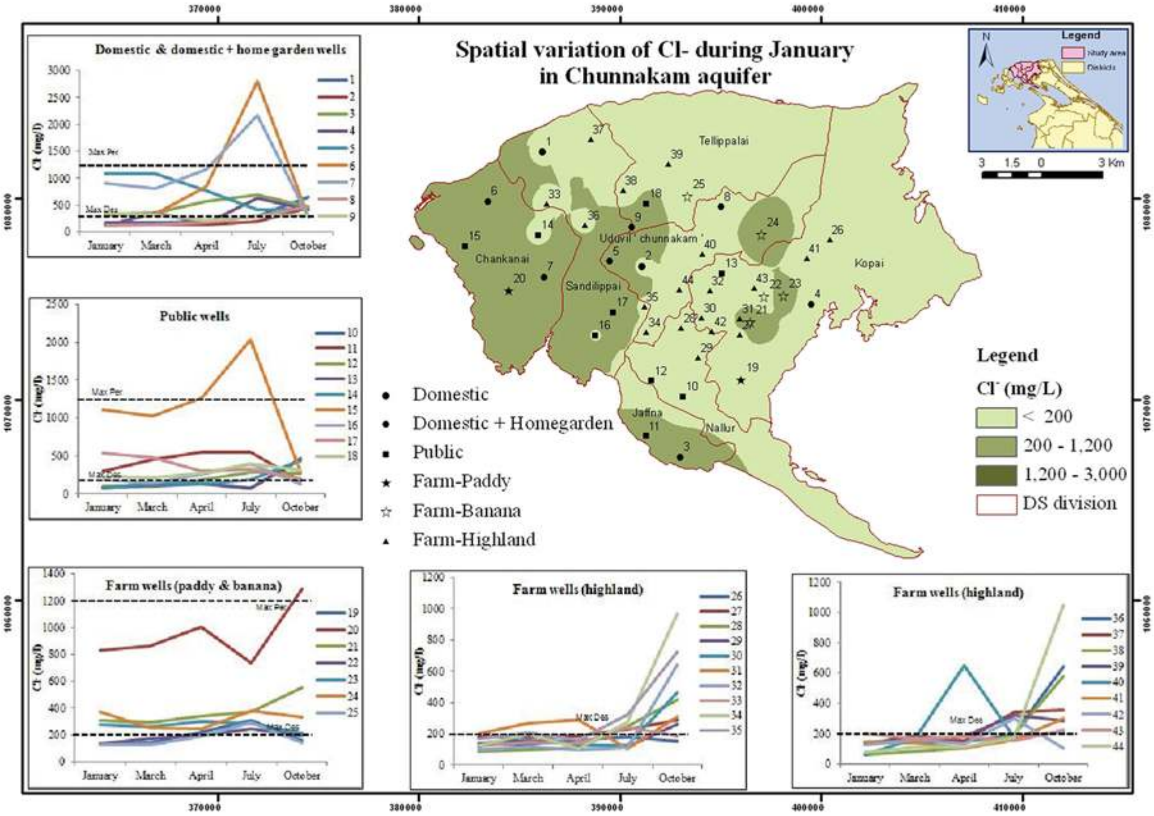
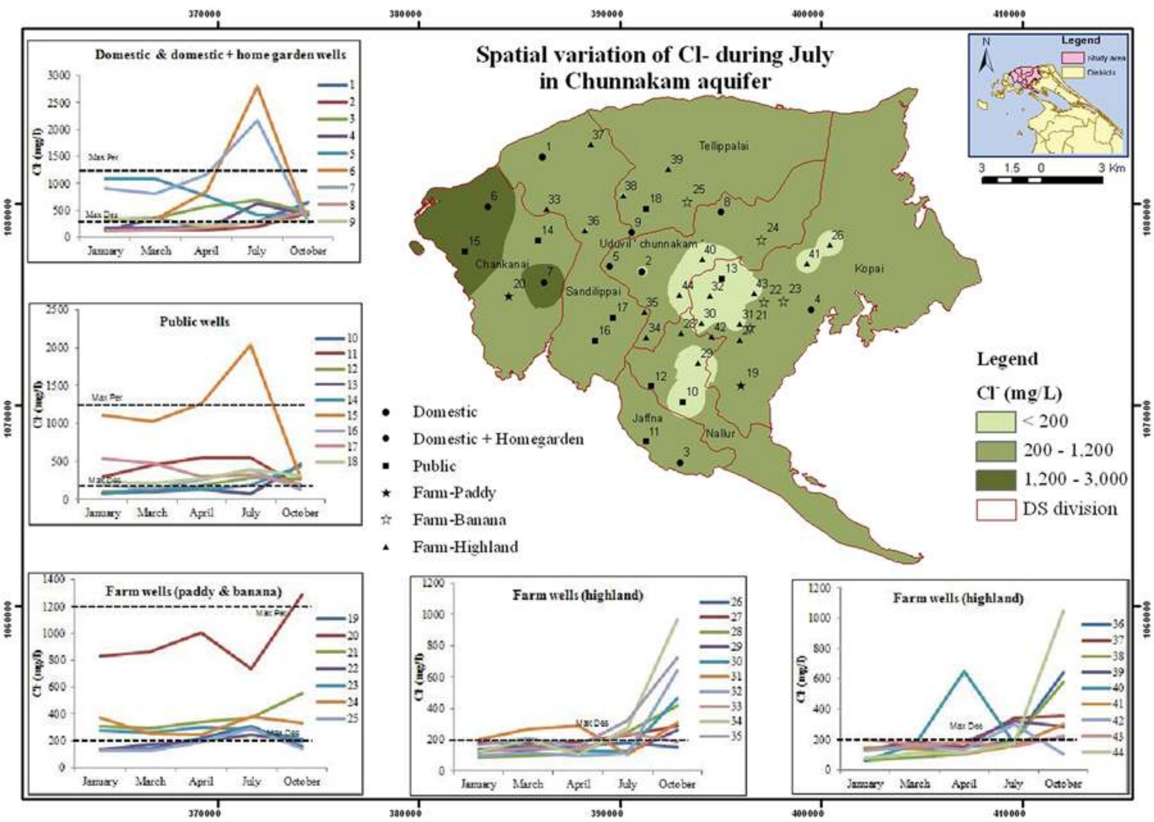


FIGURE 3.10. Spatial variation of chloride concentration during July.

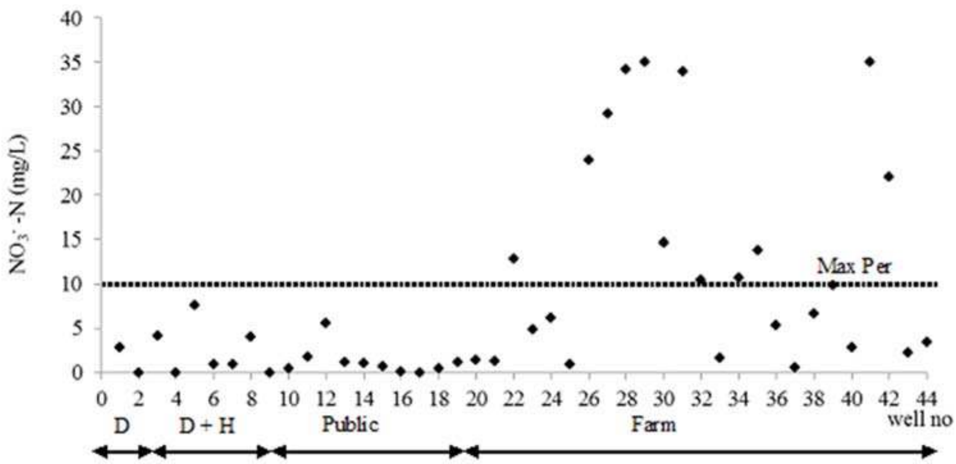


Chloride is a common non-toxic element present in small amounts in drinking water. Masarik (2007) said chloride has no health standard. Levels greater than 250 mg/l may cause a salty taste or corrosion of some metals. Although there is no health hazard, people are not willing to drink water with chloride concentrations due to the taste and the problems incurred when used for cooking purposes.

Nitrate - N

The nitrate-N concentration during January is shown in Figure 3.11. The nitrate-N concentration ranged from an undetermined value to 35 mg/l. All values from domestic, domestic with home garden and public wells were acceptable for drinking purposes during the end of the wet season as the nitrate-N values were below the limit of SLSI drinking water guidelines (10 mg/l). Among the farm wells monitored, 38% exceeded the limit of 10 mg/l and were not suited for drinking purposes. The most probable cause for the high concentrations in farm wells could be the excess fertilizers leached to the shallow groundwater. Gunasekaram (1983) studied groundwater contamination in the Jaffna Peninsula extensively and found that the nitrate levels exceeded the World Health Organization (WHO) limits, which he attributed to the mixing of abundant nitrogenous waste matter and synthetic and animal fertilizers reaching the shallow groundwater table. This was supported by Mageswaran and Mahalingam (1983) that a high nitrate-N content was present in the well water and soil.

FIGURE 3.11. Concentration of nitrate-N during January 2011.



The nitrate-N concentration during July is shown in Figure 3.12. The nitrate-N concentration ranged from an undetermined value to 24 mg/l. All values from domestic, domestic with home garden and public wells were below the recommended level for drinking by the end of the dry season. Among selected farm wells, 15% of the farm wells exceeded the limit of the Sri Lankan drinking water recommendation level of 10 mg/l and was not suitable for drinking purposes.

The spatial and temporal fluctuations of nitrate-N in wells under different usages are presented in Figures 3.13 and 3.14. The ranges of nitrate-N observed in domestic, domestic with home garden and public wells were an undetermined value to 12.1 mg/l throughout the year. Well number 5 (domestic and home gardening) and well number 13 (public well) had above permissible

FIGURE 3.12. Concentration of nitrate-N during July 2011.

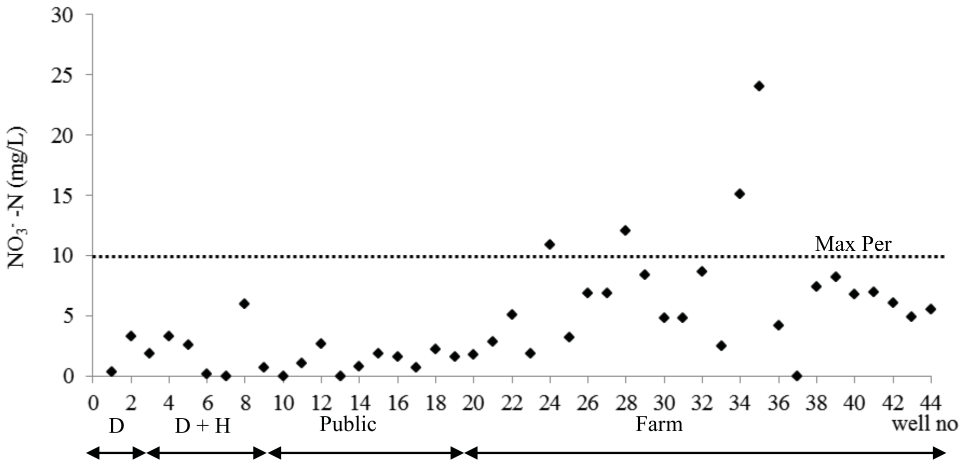
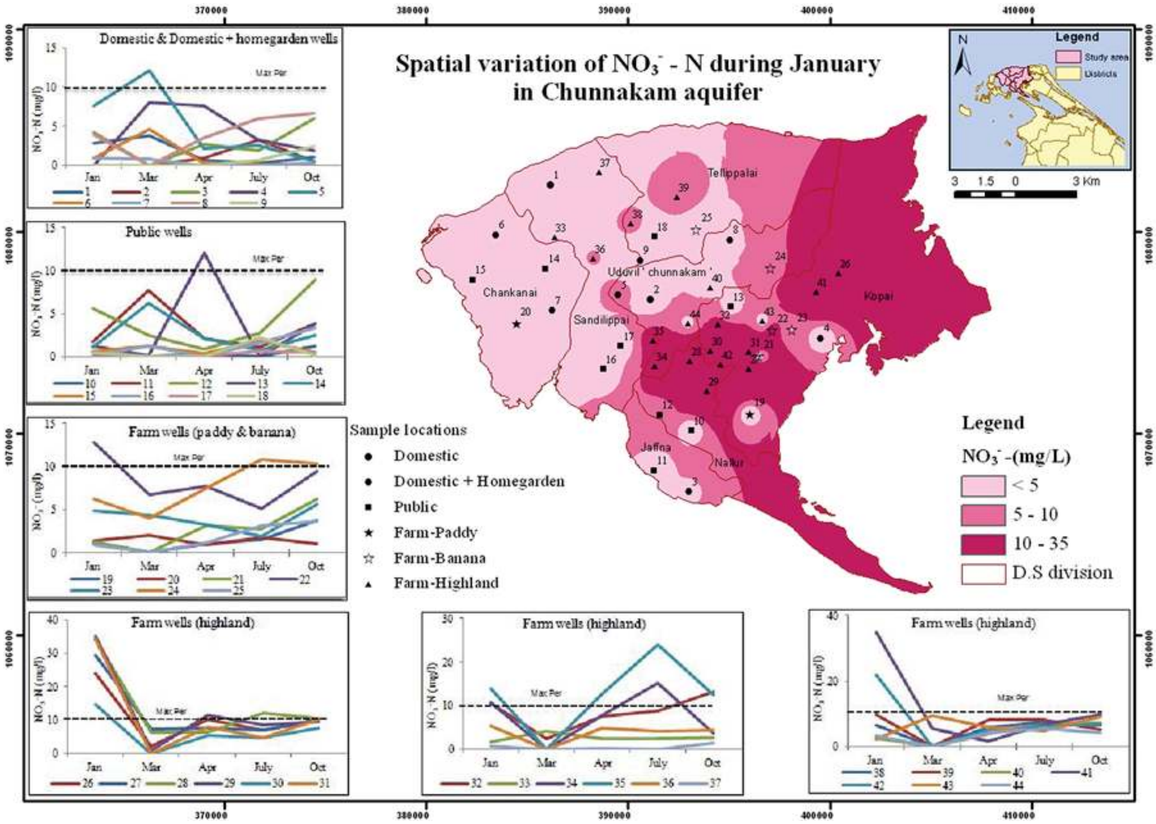


FIGURE 3.13. Spatial variation of nitrate-N during January.

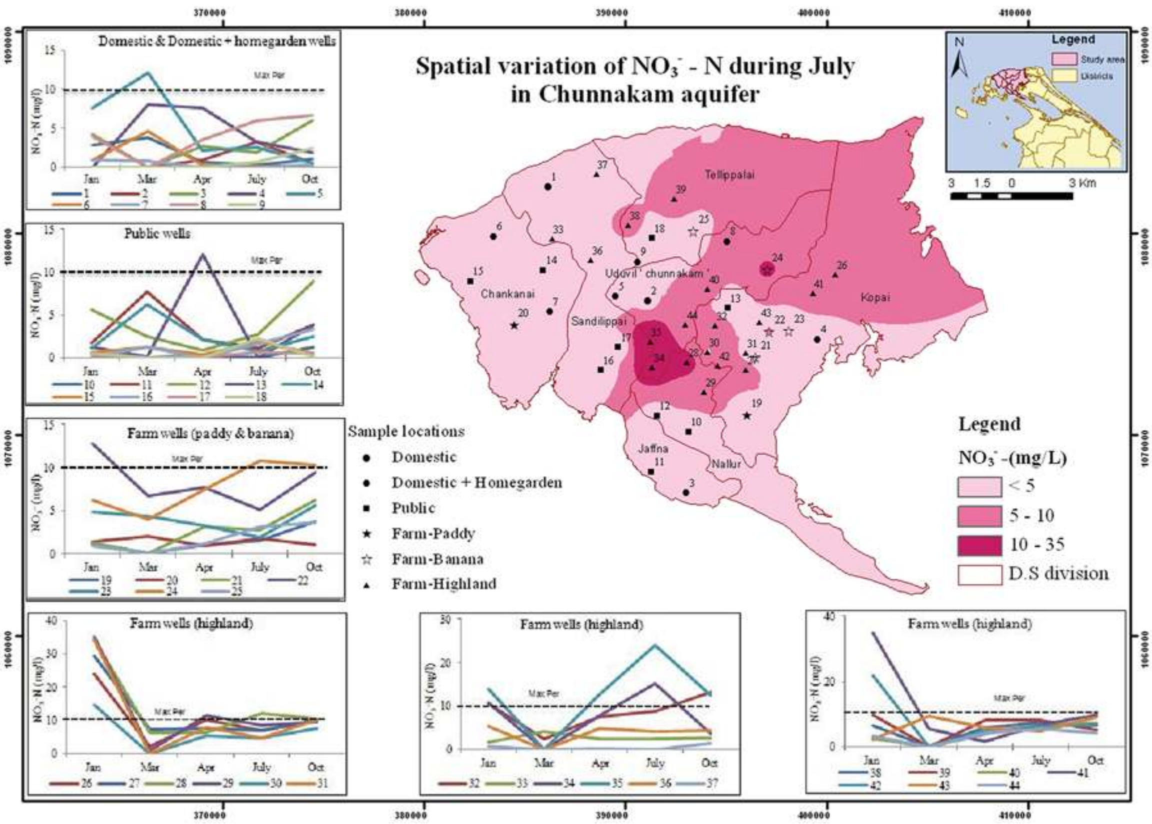


levels for drinking water during March and April, respectively. In all of the other domestic and public wells, the temporal variation of nitrate-N was below 10 mg/l throughout the year and did not have the problem of nitrate-N for drinking purposes. Normally, in home gardens, inorganic fertilizers were not used and the abstraction levels and the amount of irrigation are also less than farm wells.

Groundwater within the intensively cultivated area had high levels of nitrate-N concentrations. High nitrate-N concentration in groundwater was observed in highland crop land use during

January. Concentration of nitrate-N in paddy and banana land use had lower values than highland crops. Nitrate-N found in most of the highland crop land use wells exceeded the recommended Sri Lankan standard level for drinking purposes. The high nitrate-N values of 35 mg/l were observed at well number 29 (Thirunelveli) and well number 41 (Neervely), which are highland crops during January. Even though these wells are used for agricultural purposes, people who are working in the field use the well water for drinking. Jeyaruba and Thushyanthy (2009) noted that the level of nitrate-N concentration in water was influenced by the cropping system; high nitrate-N concentration in groundwater was observed in highland crops land use followed by mixed crops and banana and paddy.

FIGURE 3.14. Spatial variation of nitrate-N during July.



Cultivation of banana is normally under basin irrigation with organic fertilizers. Before planting of banana suckers, farmers bury green manures into the pits and they keep the plants in the field for approximately five years. Most farmers are not using any inorganic fertilizers 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 utilize the applied fertilizer and residual N will remain in the soil for the next crop. Since nitrogen retention increases with organic fertilizers, this may be the reason for low nitrate-N concentration in groundwater in land use under banana cultivation. Hence, one of the ways to reduce nitrate pollution of groundwater is by incorporating organic manures.

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 dissolved 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 of the groundwater table.

Nitrite - N

The spatial and temporal variations of nitrite-N for the selected wells during January and July are shown in Figures 3.15 and 3.16. The concentrations of nitrite-N values during January and July ranged from an undetermined value to 0.053 mg/l and 0.001 mg/l to 0.330 mg/l, respectively. Normally, nitrite gets oxidized 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 values above the maximum permissible level of 0.01 mg/l during October.

FIGURE 3.15. Spatial variations of nitrite-N ions during January.

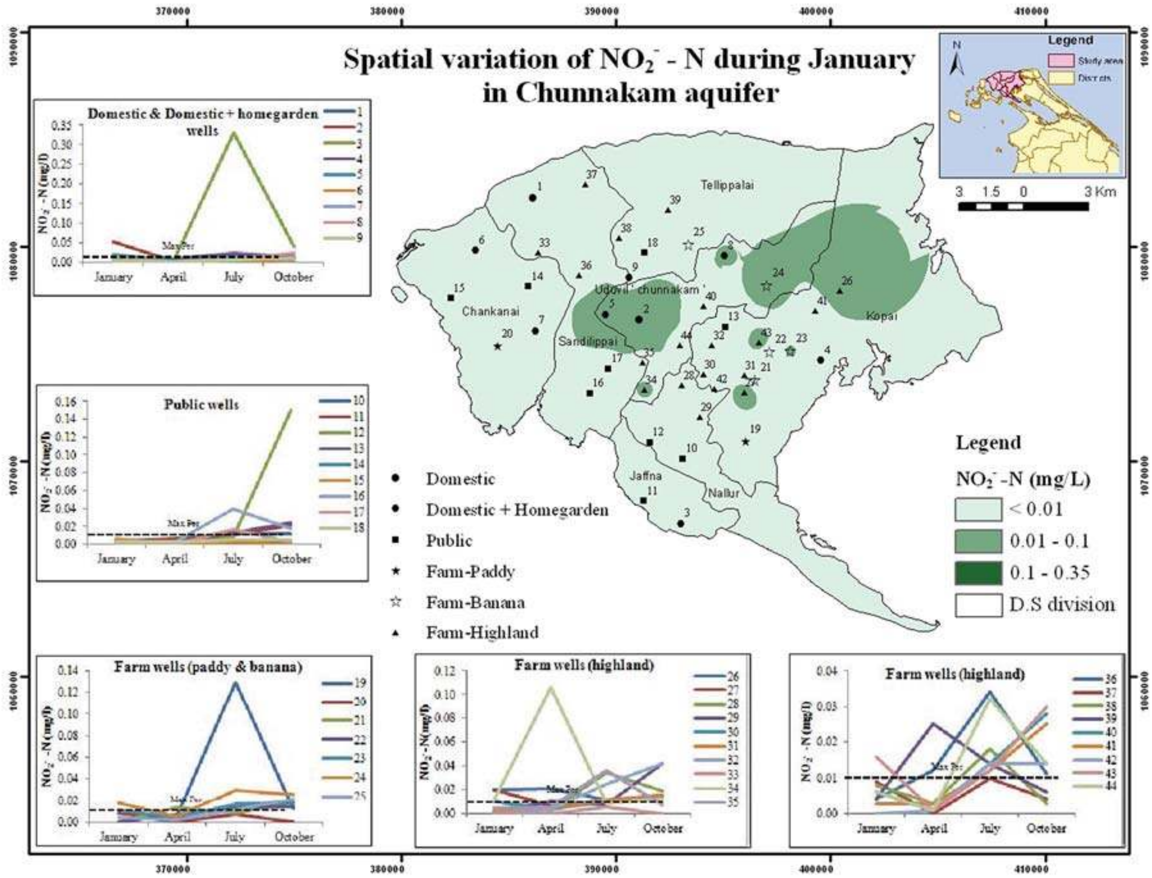
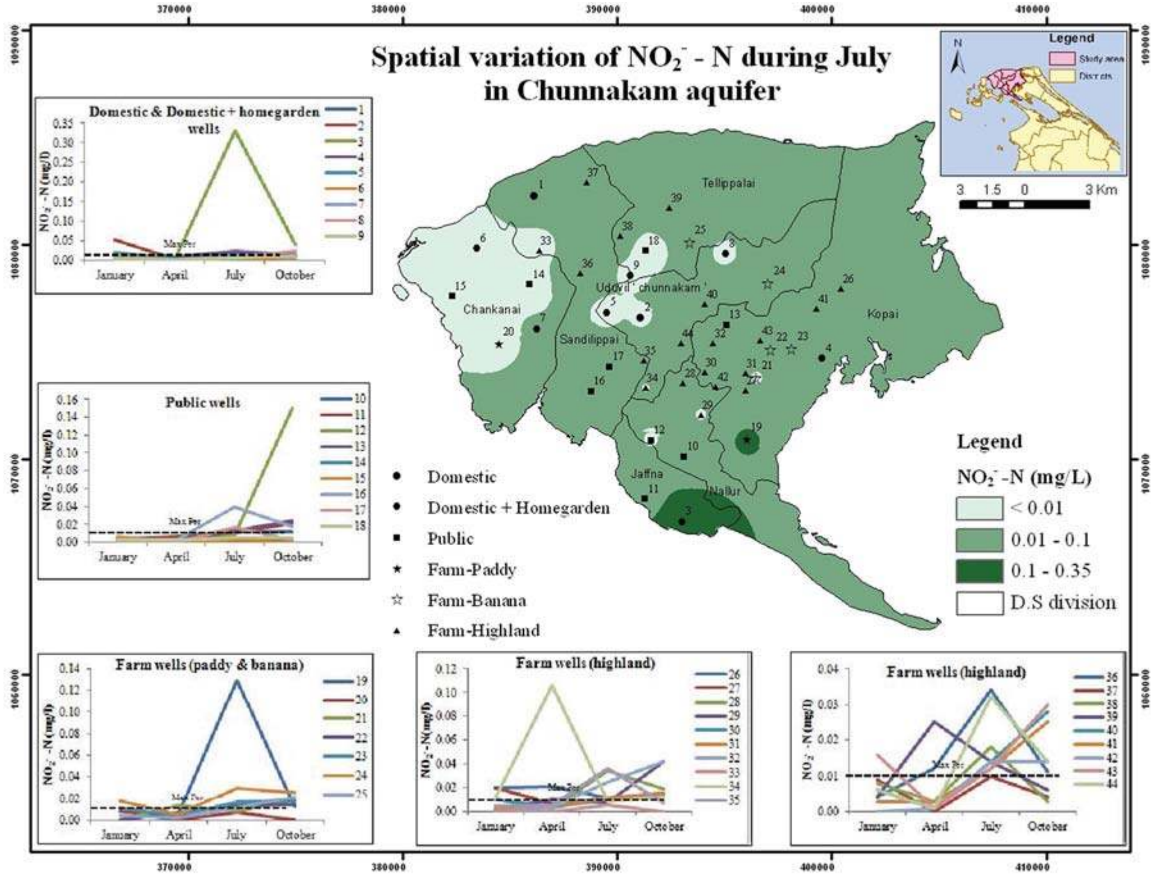


FIGURE 3.16. Spatial variations of nitrite-N ions during July.



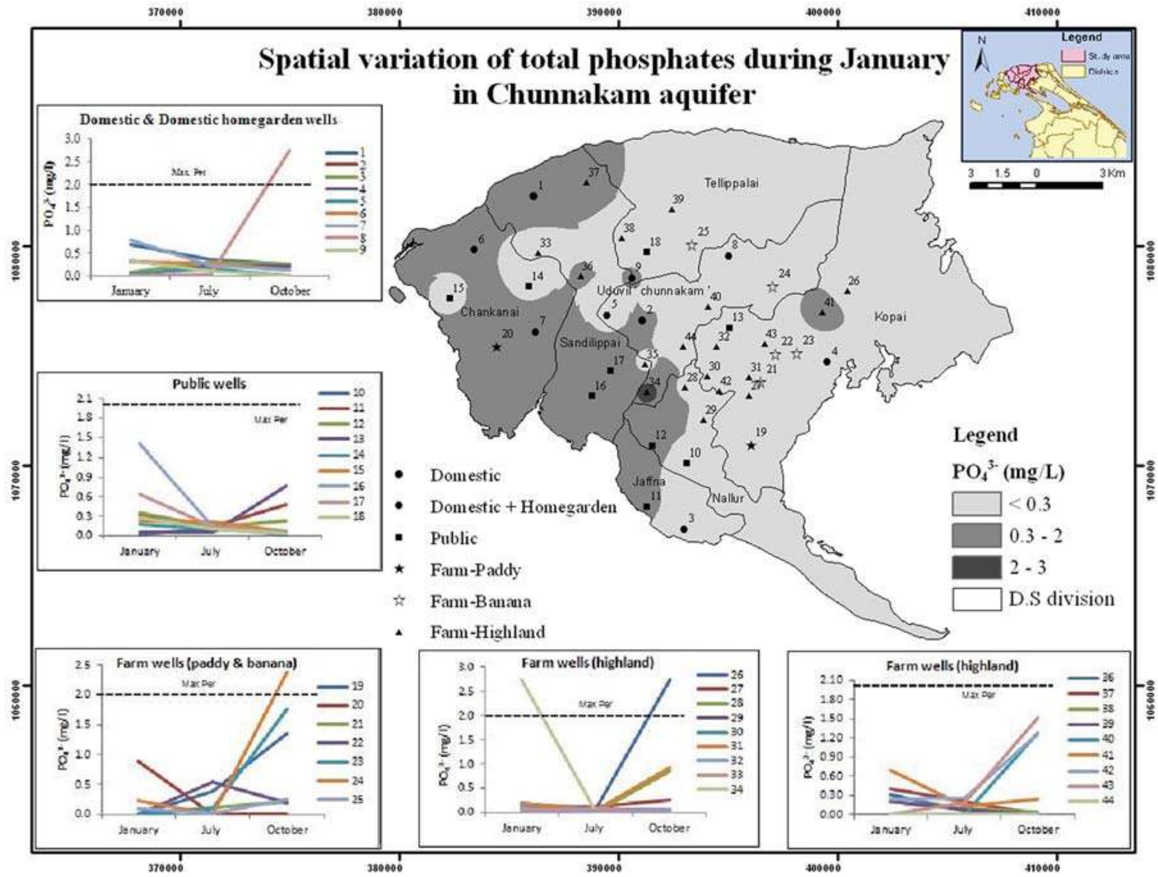
Total Phosphate

The spatial and temporal variations of total phosphate for the selected wells during January and July are shown in Figures 3.17 and 3.18. The concentrations of total phosphate values during January and July ranged from an undetermined value to 2.75 mg/l and from an undetermined value to 0.55 mg/l, respectively. Well numbers 8, 24, 26 and 34 were above SLSI permissible levels of 2.0 mg/l during the wet season. This increase may be due to leaching of phosphate from upper soil layers to groundwater. These wells are used for farming except for well number 8 which is used for domestic and home gardening. All other wells are suitable for drinking purposes throughout the year. Mageswaran (2003) showed that the amount of phosphate present in groundwater from most areas in the Peninsula ranged from 0 to 3 mg/l.

Fluoride

The average concentration of fluoride ranged from an undetermined value to 0.61 mg/l (Figure 3.19). Results revealed that 98% of the wells including domestic wells had water with less than 0.6 mg/l of fluoride, which leads to a deficiency in the amount of fluoride. The spatial variation of average fluoride concentration in the Chunnakam aquifer is shown in Figure 3.20. The recommended level of fluoride in drinking water is 0.6 mg/l to 1.5 mg/l (SLSI standard 614: part 1, 1983). Since fluoride enters the body mainly through drinking water, people in

FIGURE 3.17. Spatial variations of total phosphate ions during January.



these areas may have the risk of dental caries. Rajasooriyar et al. (2002) stated that 95% of wells from the Valikamam region were less than 1 mg/l due to the precipitation of insoluble calcium fluoride.

Calcium

Generally, calcium in the groundwater is derived from minerals that include limestone and dolomite. The concentration of Ca^{2+} during January 2011 is shown in Figure 3.21. The calcium concentration varied from 49 mg/l to 286 mg/l. The results showed that 95% of the measured wells had below the SLSI permissible level (240 mg/l). The calcium concentration during July varied from 28 mg/l to 196 mg/l (Figure 3.22). All wells are suited for drinking purposes by the end of the dry season.

The spatial distribution and temporal variation of calcium concentration with different land uses is shown in Figure 3.23 and 3.24. Well number 5 at Sankuvely was above the SLSI permissible level during October. Well number 6 was above the SLSI permissible level during March and October. Well number 7 at Sankarathai was above the SLSI permissible level during January and October. These three wells are used for domestic and home garden purposes. All farm wells were always below the maximum permissible level of SLSI guidelines. The higher values of calcium by the end of the wet season are observed near the coastal regions. Sivarajah (2003) reported that high amounts of calcium and phosphate in the drinking water may accelerate stone formation in the bladder. In addition to health effects, calcium may precipitate as calcium carbonate within plumbing and clog pipes. Detergents and soaps do not readily dissolve in hard water.

FIGURE 3.18. Spatial variations of total phosphate ions during July.

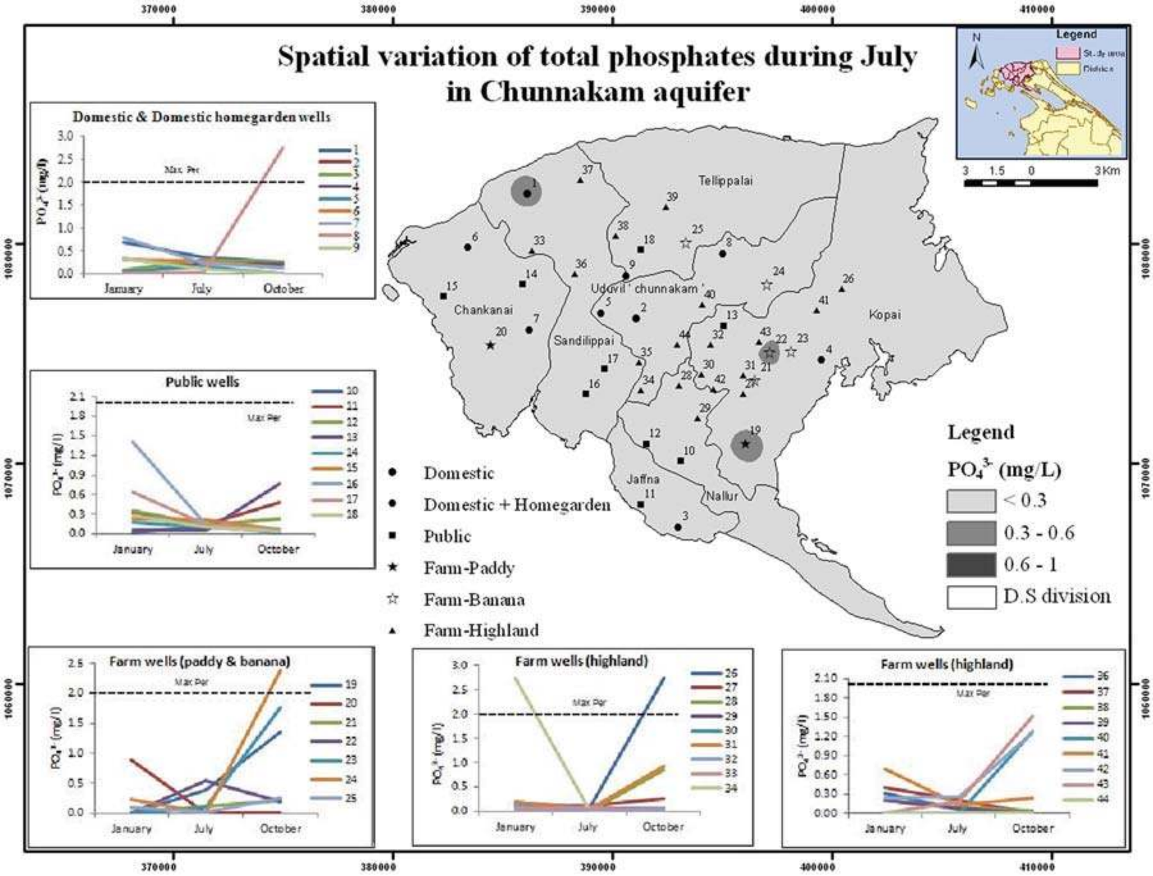


FIGURE 3.19. Average concentration of fluoride in 2011.

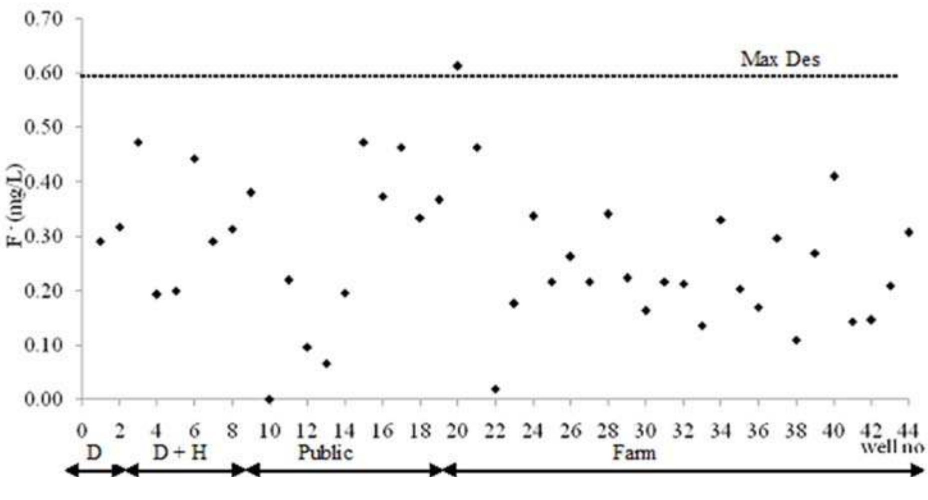


FIGURE 3.20. Spatial variation of average concentration of fluoride.

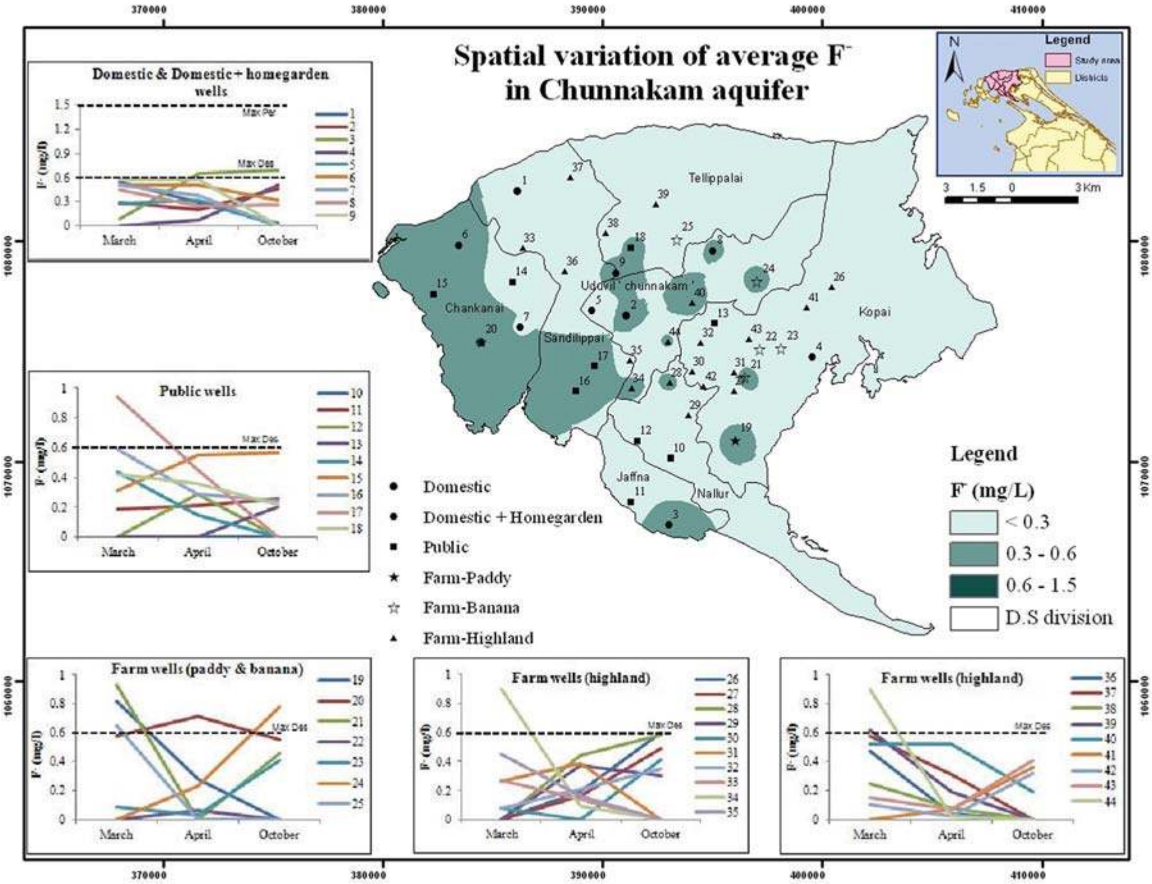


FIGURE 3.21. Concentration of calcium ions during January 2011.

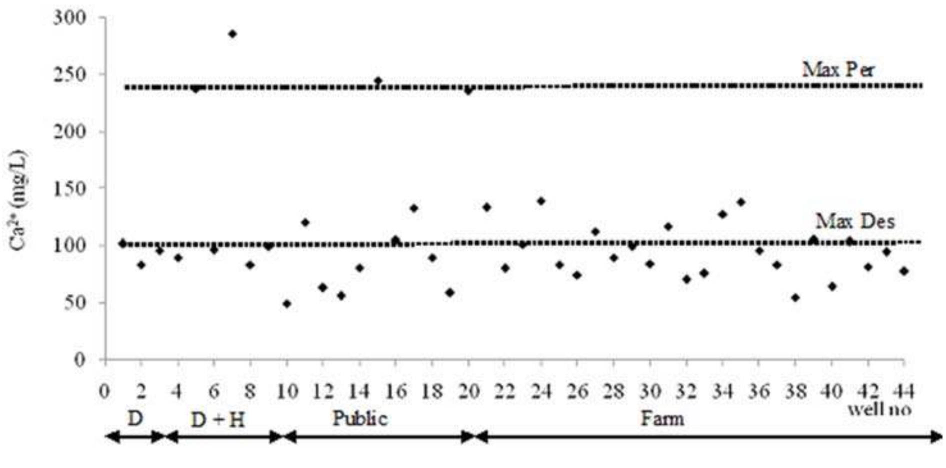


FIGURE 3.22. Concentration of calcium ions during July 2011.

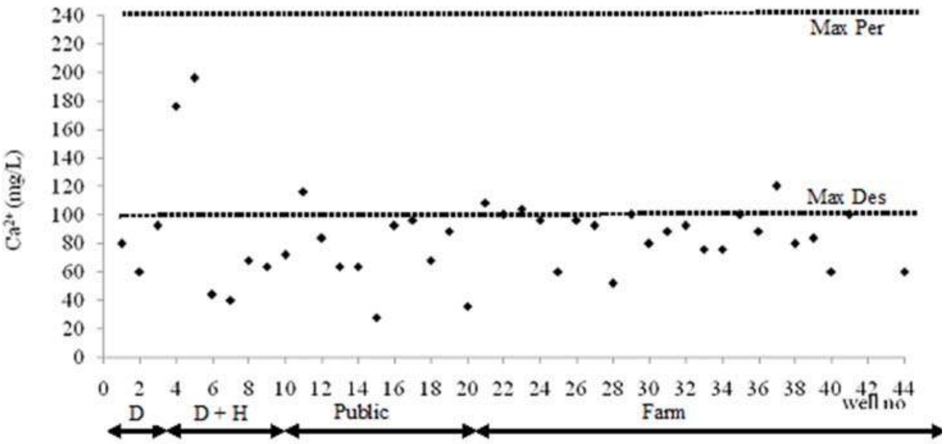
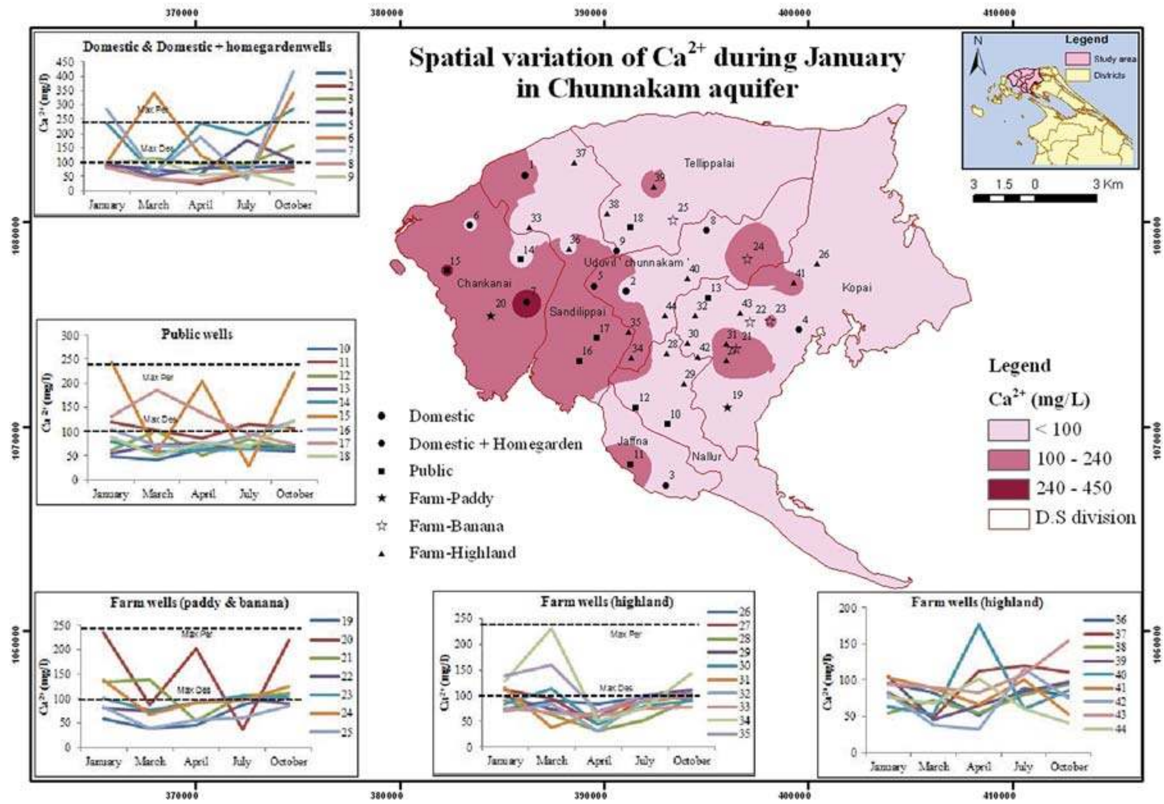


FIGURE 3.23. Spatial variations of calcium ions during January.



Magnesium

The total hardness is relatively high in water due to the presence of calcium, magnesium, chloride and sulfate ion. Calcium and magnesium are primarily found in groundwater due to the dissolution of limestone and the substantial contribution from the weathering of rocks.

The spatial and temporal variation of magnesium concentration during January and July with different land uses is shown in Figures 3.25 and 3.26. The distribution of concentration of magnesium by the end of the wet season in the study area ranges from 1 mg/l to 53 mg/l. The highest concentration

FIGURE 3.24. Spatial variations of calcium ions during July.

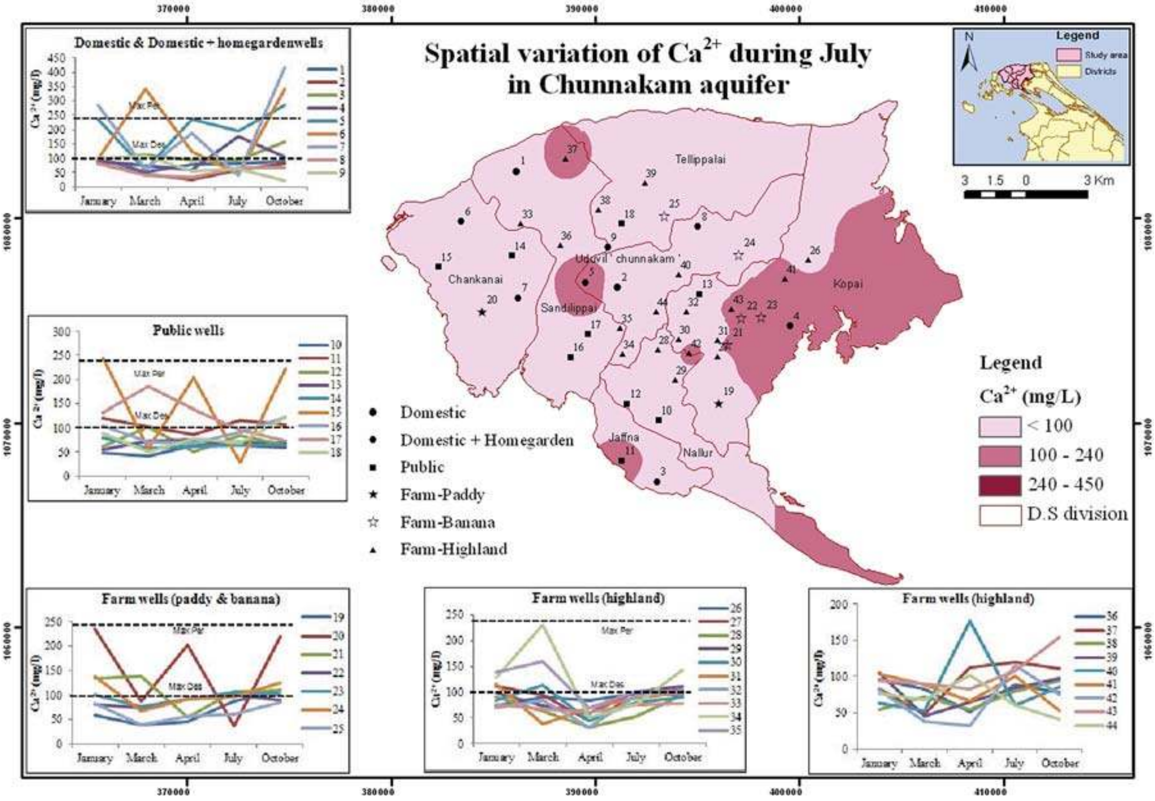
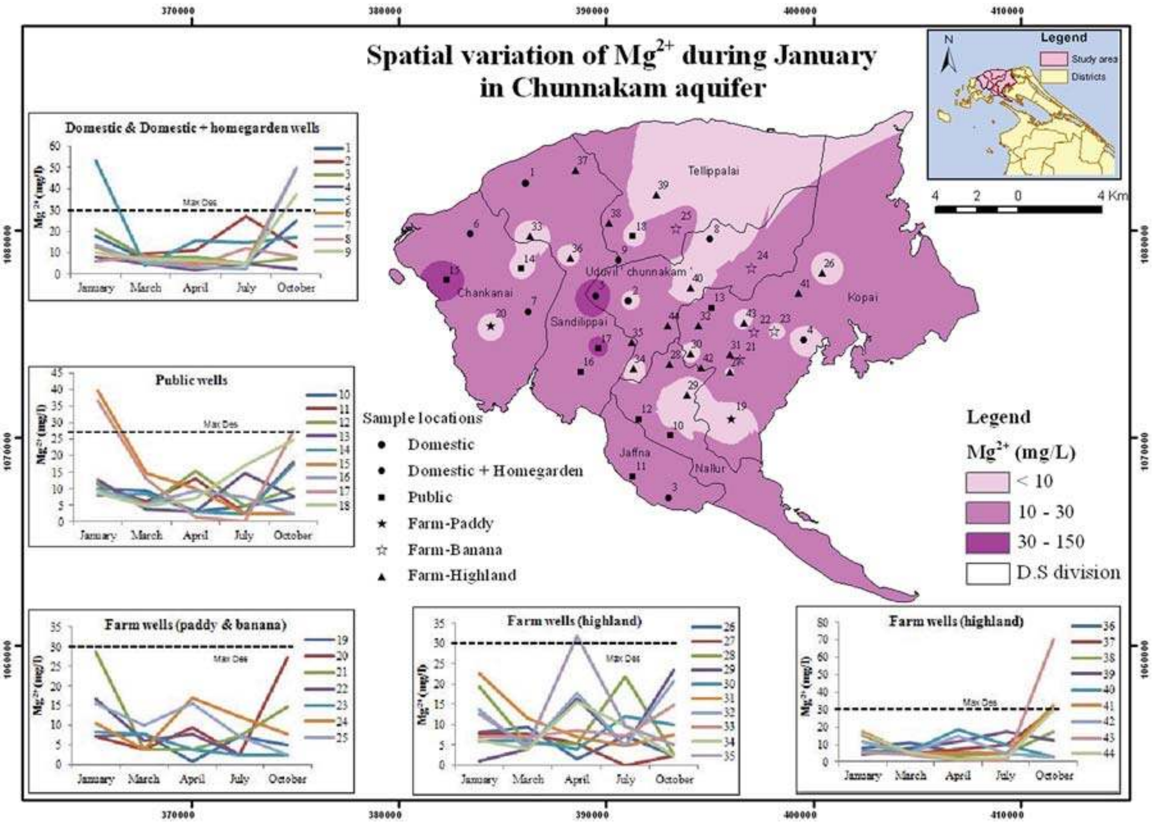
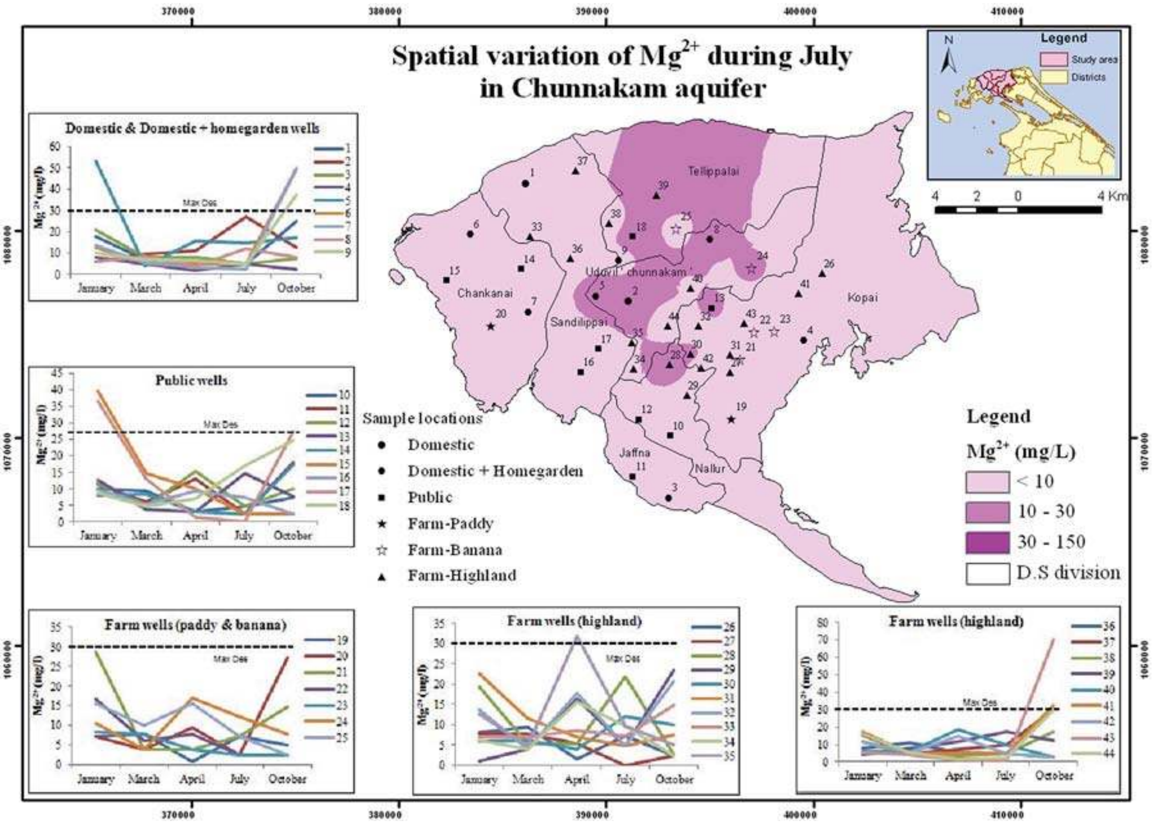


FIGURE 3.25. Spatial variations of magnesium ions during January.



of 53 mg/l of magnesium was found in Sankuvely (well number 5). The results showed that all measured wells were below the permissible level of SLSI guidelines for drinking purposes (150 mg/l). The distribution of concentration of magnesium by the end of the dry season in the studied area ranges from an undetermined value to 27 mg/l. This showed that all tested wells were always below the desirable level of 30 mg/l prescribed by SLSI guidelines. The water in all the wells was acceptable for drinking purposes.

FIGURE 3.26. Spatial variations of magnesium ions during July.



Bicarbonate

The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate and hydroxide compounds. The spatial and temporal variation of bicarbonate concentration for the selected wells during January and July with different land use is shown in Figures 3.27 and 3.28. The results revealed that the bicarbonate values of selected wells by the end of the wet season varied from 53 mg/l to 394 mg/l and bicarbonate values of selected wells by the end of the dry season varied from 49 mg/l to 488 mg/l. In general, bicarbonate values increased from July to October. The higher values of bicarbonate are observed near the coastal regions in the Chunnakam aquifer (Figure 3.24).

Carbonate

The limestone aquifer is rich in carbonates. The spatial and temporal variation of carbonate concentration for the selected wells during January and July with different land uses are shown

FIGURE 3.27. Spatial variations of bicarbonate ions during January.

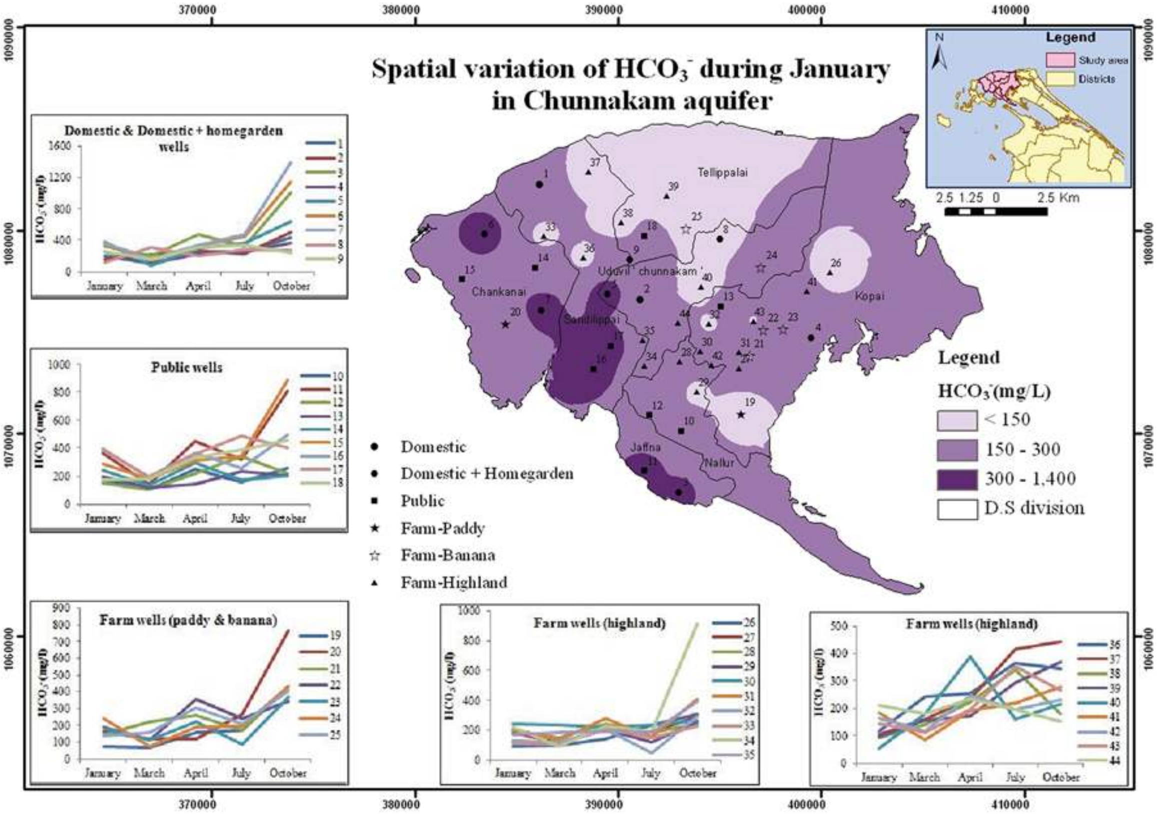
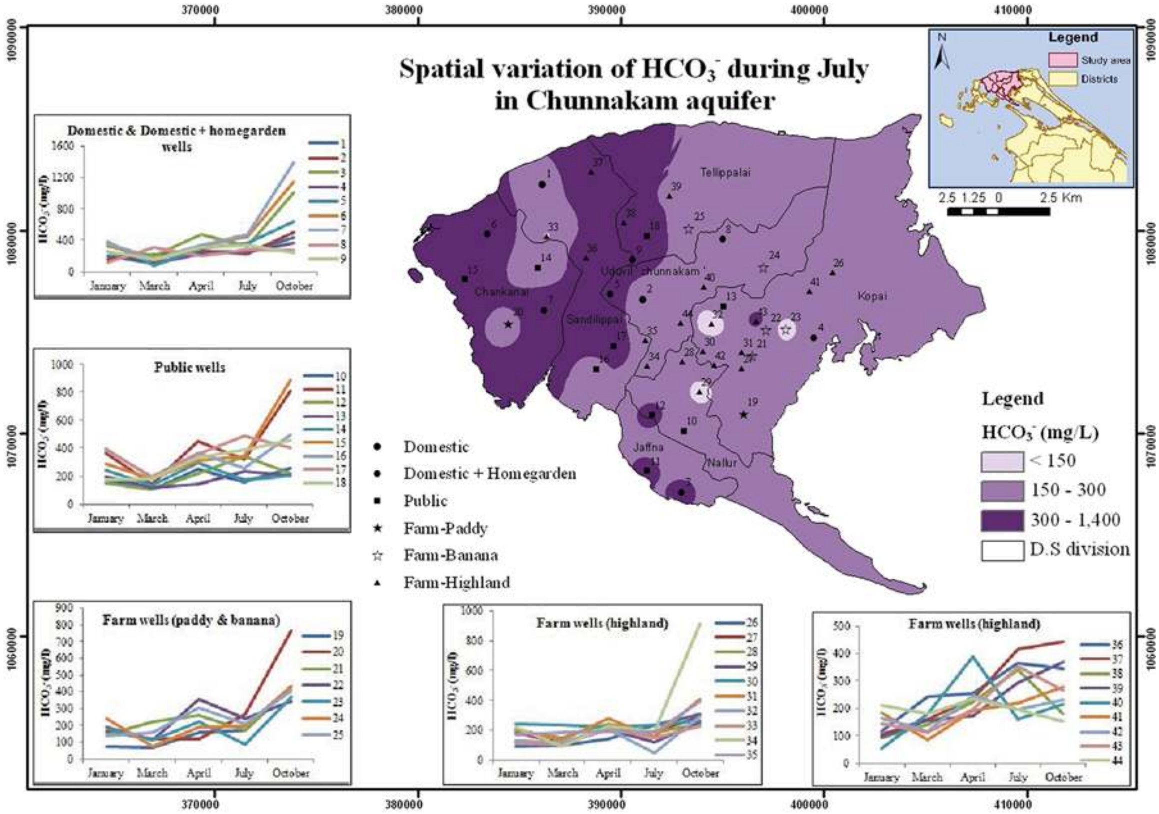
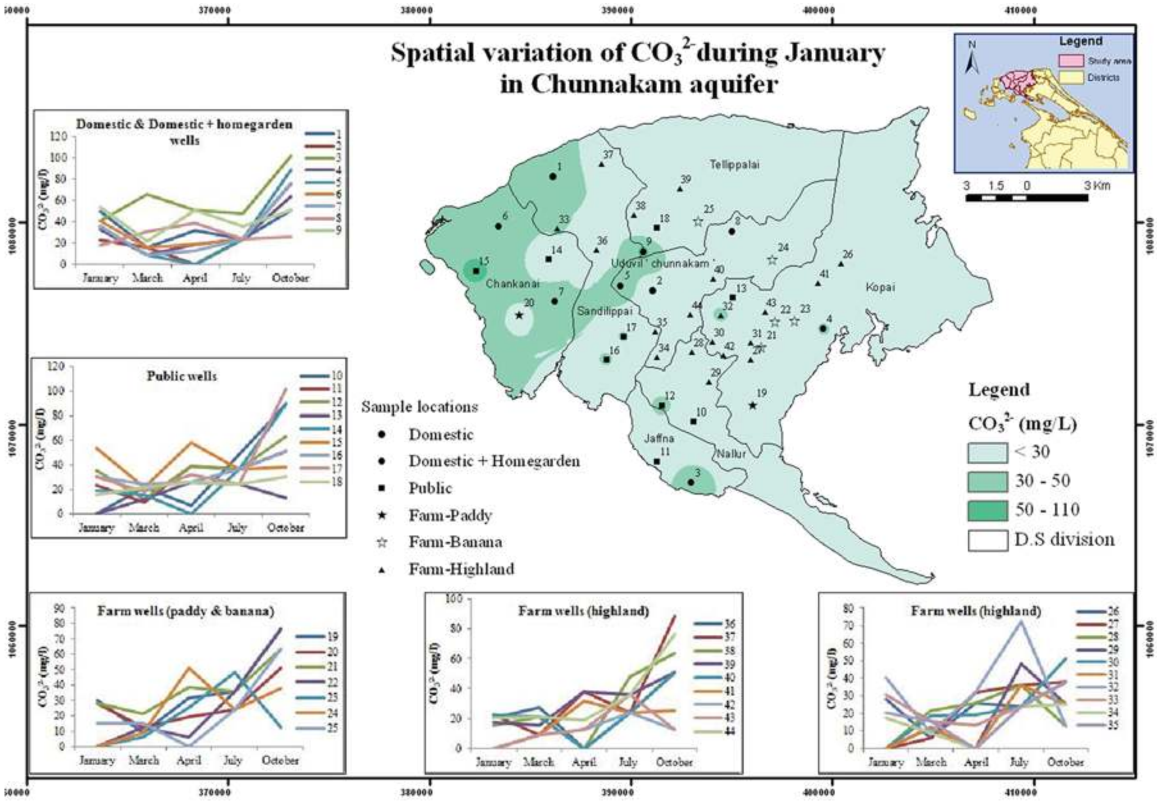


FIGURE 3.28. Spatial variations of bicarbonate ions during July.



in Figures 3.29 and 3.30. The results revealed that the carbonate values of selected wells by the end of the wet season varied from an undetermined value to 53 mg/l, and by the end of the dry season varied from 24 mg/l to 72 mg/l. Waters flowing through limestone brings the carbonate to the groundwater, which increases the alkalinity. The peak total alkalinity during the dry season may be due to high evaporation. Highly alkaline waters are unpalatable and may force consumers to seek other water sources.

FIGURE 3.29. Spatial variations of carbonate ions during January.



Iron

The spatial and temporal variation of iron for the selected wells during July is shown in Figure 3.31. The concentration of iron values during July ranged from an undetermined value to 0.31 mg/l. All wells are below the permissible SLSI level of 1.0 mg/l throughout the year and the water is suitable for drinking purposes. Iron values of most of the wells increased towards the dry season and some of the wells were above the desirable level of 0.3 mg/l during October. Well number 20, which is located in a paddy field, had a high value of iron concentration of 0.58 mg/l during October.

Manganese

Manganese is naturally occurring in many surface water and groundwater sources, particularly in anaerobic or low-oxidation conditions, and this is the most important source for drinking water (WHO 2011). The spatial and temporal variation of manganese for the selected wells during January and July are shown in Figures 3.32 and 3.33, respectively. The concentration of manganese values

FIGURE 3.30. Spatial variations of carbonate ions during July.

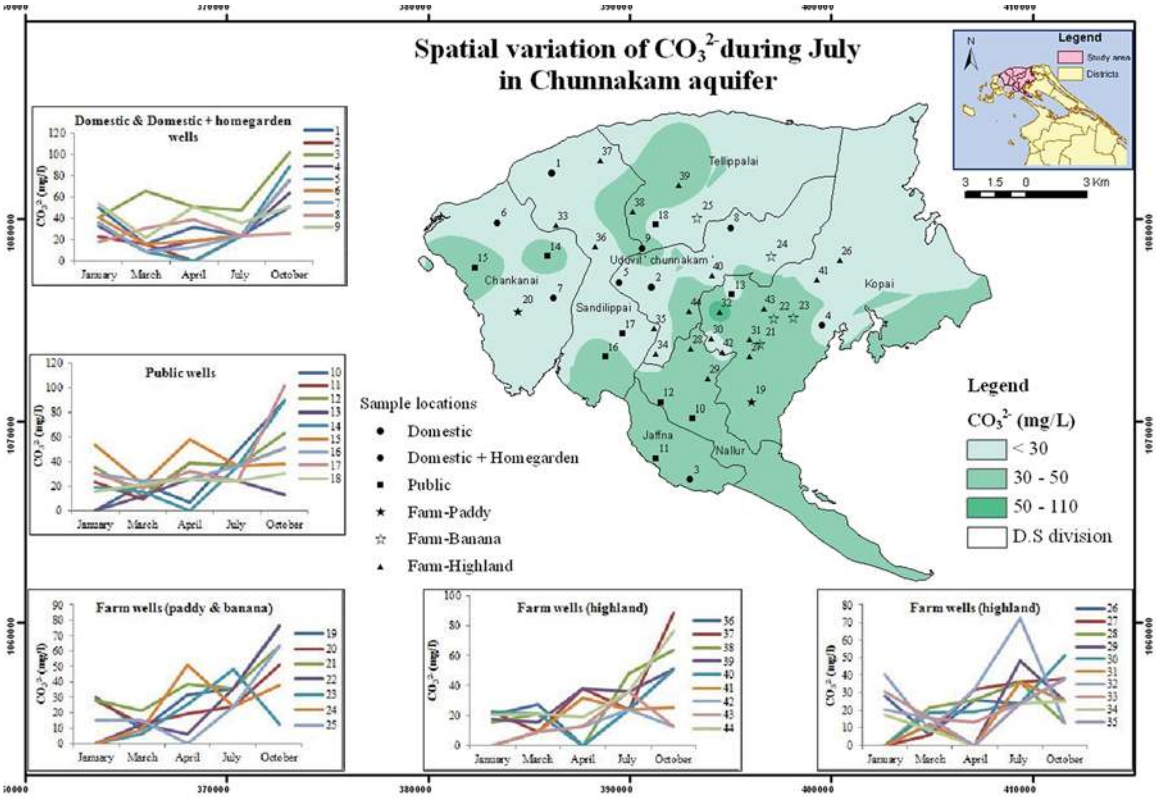


FIGURE 3.31. Spatial variation of iron during July.

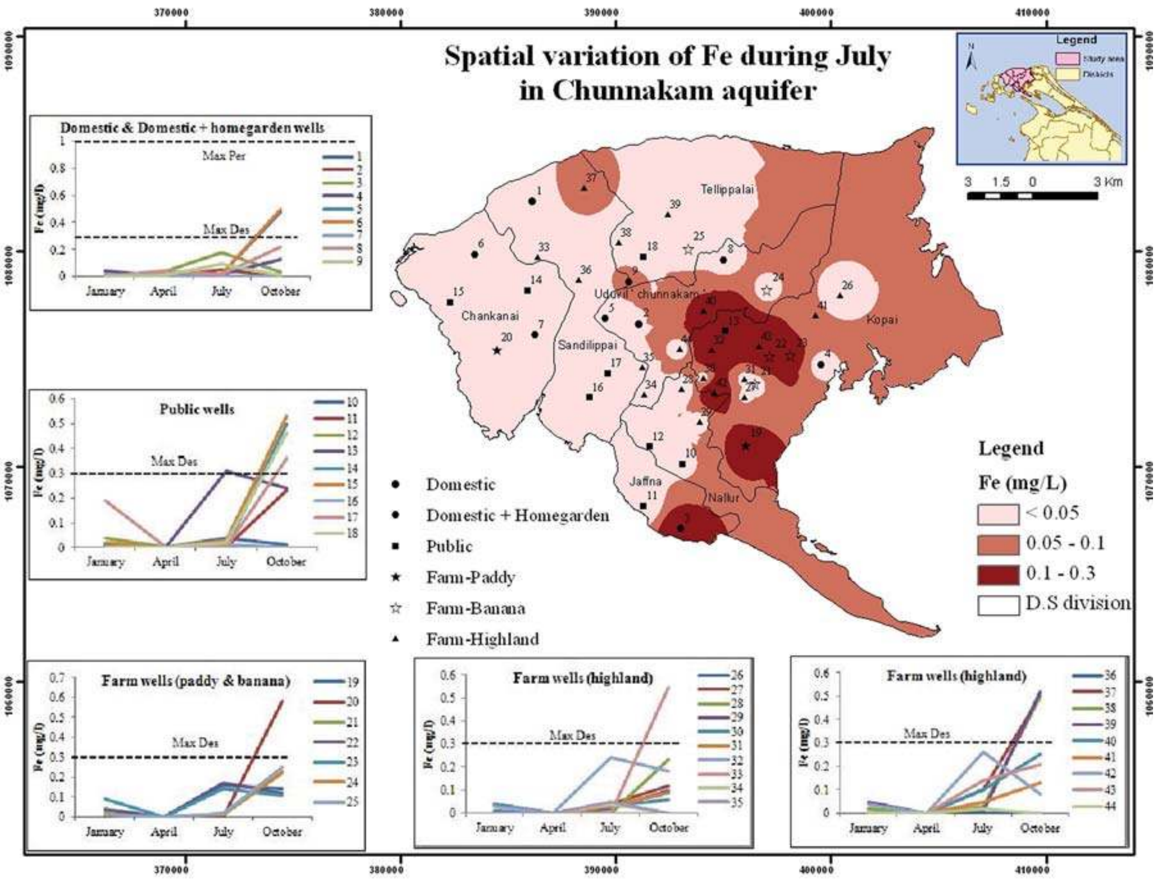
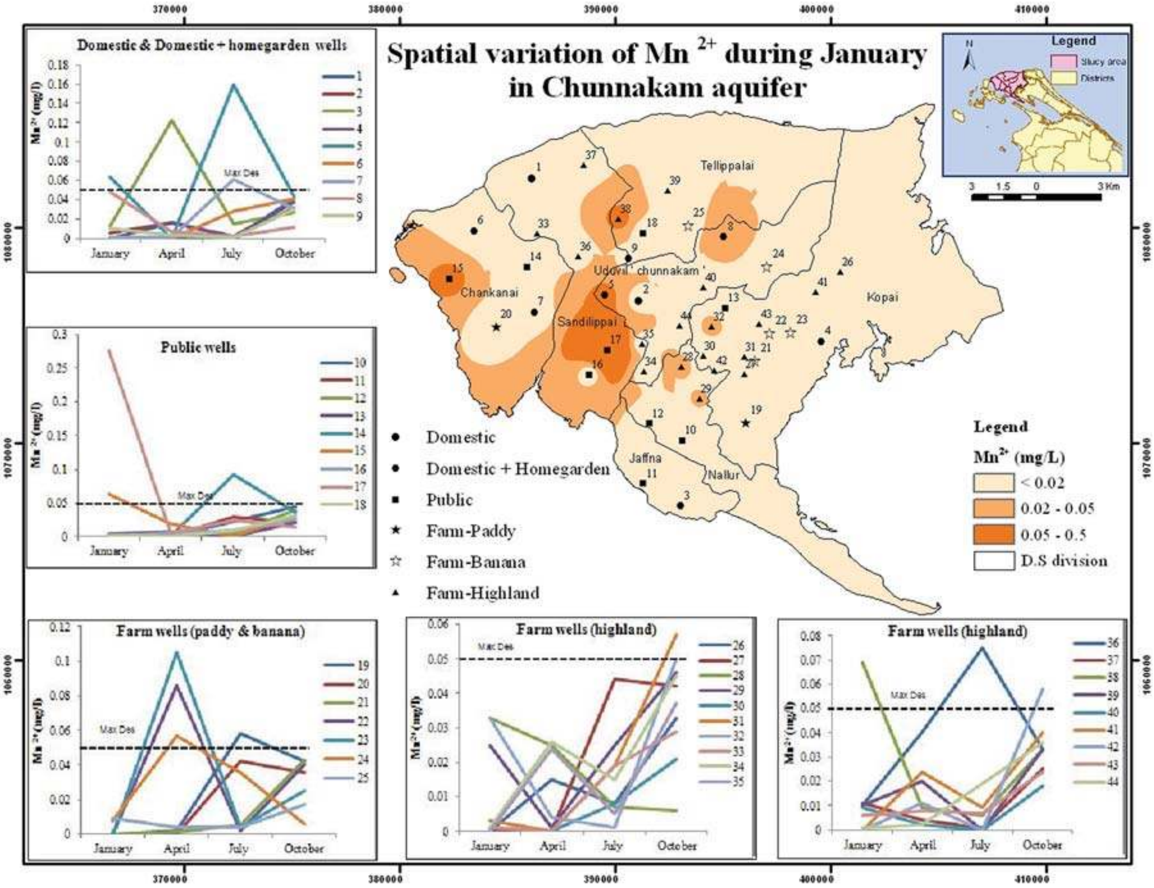


FIGURE 3.32 Spatial variations of manganese ions during January.

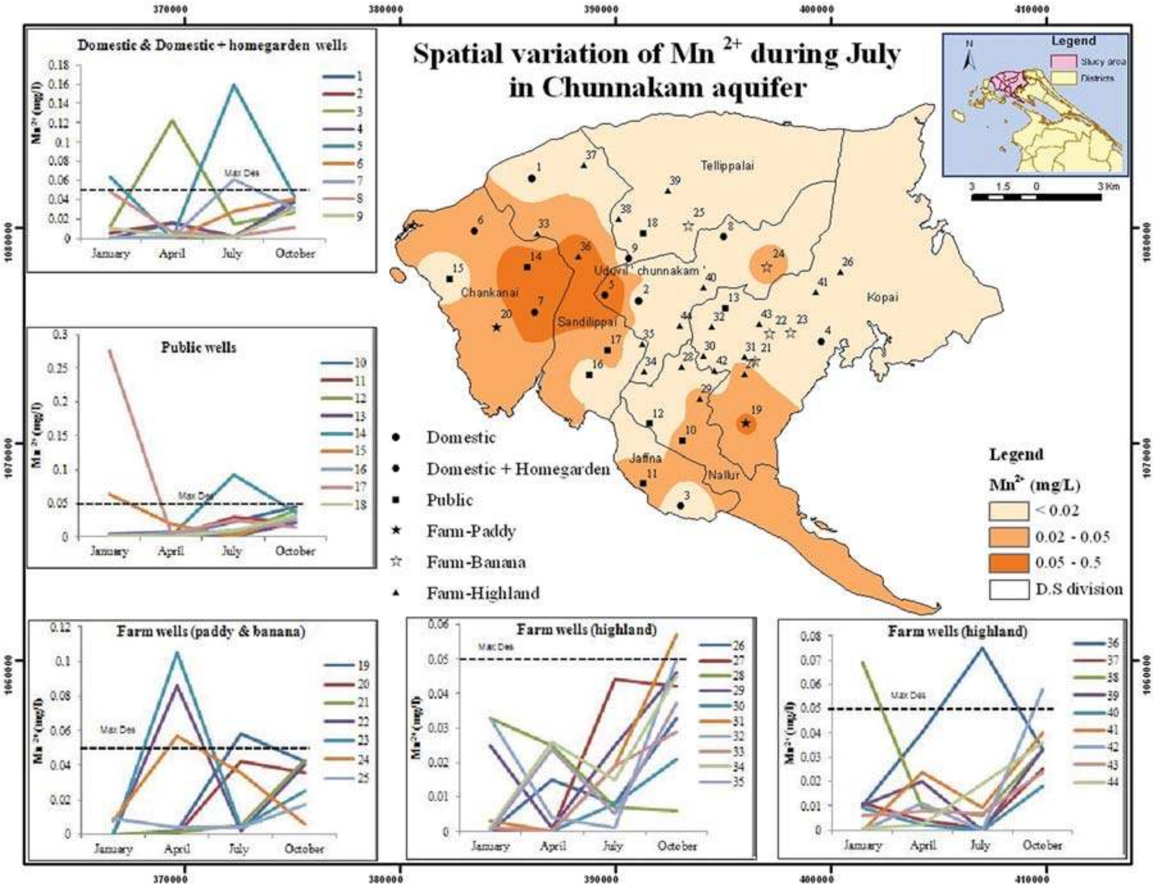


during January and July ranged from an undetermined value to 0.276 mg/l and an undetermined value to 0.160 mg/l, respectively. All wells are below the permissible SLSI level of 0.5 mg/l throughout the year and suitable for drinking purposes.

Sulfate

Sulfates occur naturally in groundwater combined with calcium, magnesium and sodium as sulfate salts (Kendall 1992). The spatial and temporal variations of sulfate for the selected wells during January and July are shown in Figures 3.34 and 3.35. The concentrations of sulfate values ranged from 4 mg/l to more than 500 mg/l in January and from 15 mg/l to more than 500 mg/l in July. This could have been more than the value of 500 mg/l. However, the measurability of the meter used was only up to 500 mg/l. Well number 5 was above the permissible level throughout the year. It also had a high value of EC concentration (Figures 3.5 and 3.6). The higher values are observed near the coastal regions. The high concentrations of sulfate could result in taste.

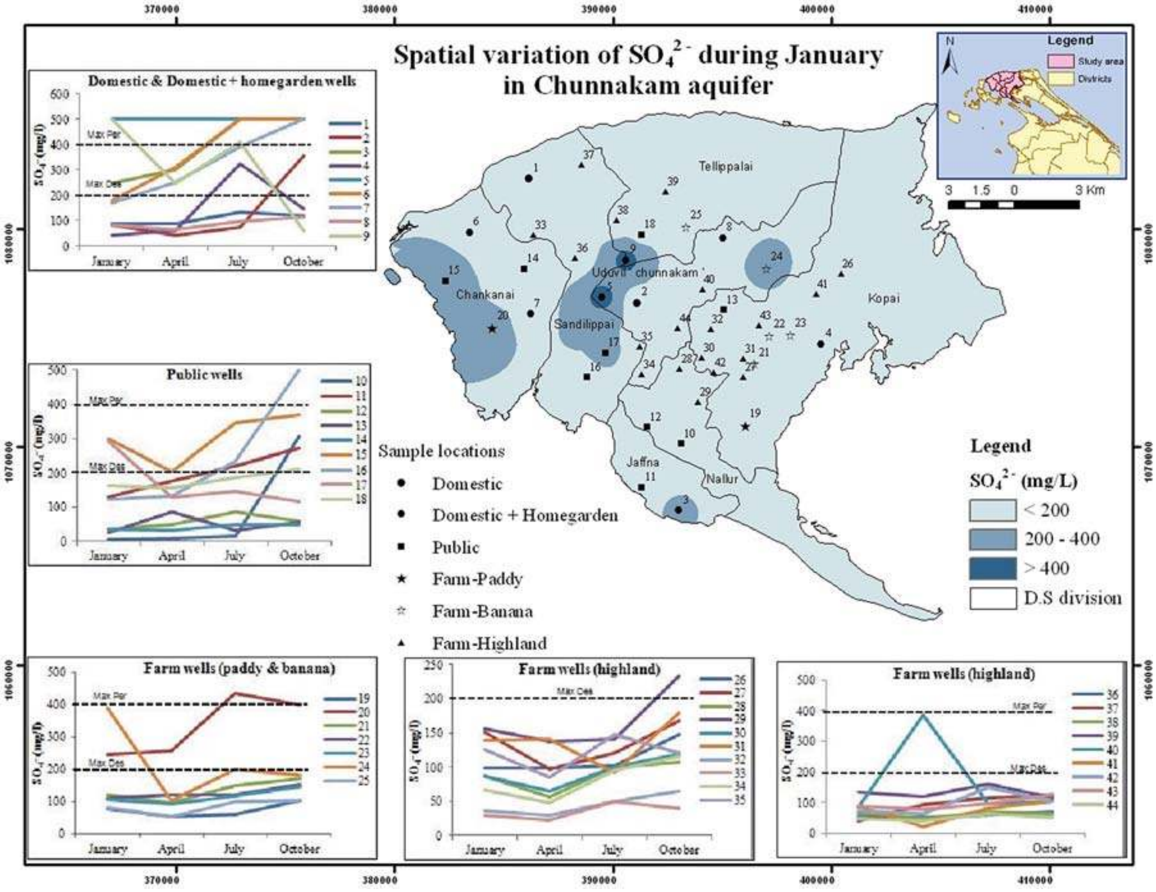
FIGURE 3.33. Spatial variations of manganese ions during July.



Sodium

The spatial and temporal variations of sodium during January and July are shown in Figures 3.36 and 3.37, respectively. The distribution of concentration of sodium during January ranges from 16 mg/l to 675 mg/l. Out of the selected wells, 18% were above the permissible level of WHO for drinking purposes (200 mg/l). The distribution of sodium during July ranges from 16 mg/l to 1,091 mg/l. Out of the selected wells, 16% were above the WHO permissible level of 200 mg/l. Well numbers 6, 7, 11, 15 and 20, which are located near the coastal areas, have a high sodium problem throughout the year. Well number 9 (located at Elalai) was also above the permissible level during all months of the year in 2011. No health-based guideline value is proposed, however, sodium may affect the taste of drinking water at levels above about 200 mg/l (WHO 2011). The higher values of sodium are observed near the coastal regions of the Chunnakam aquifer and could be related to seawater intrusion. The above result is similar to the spatial distribution of EC, chloride and sulfate (Figures 3.5, 3.6, 3.9, 3.10, 3.34 and 3.35).

FIGURE 3.34. Spatial variations of sulfate ions during January.



Potassium

The spatial and temporal variations of potassium for the selected wells during January and July are shown in Figures 3.38 and 3.39. The concentrations of potassium values during January ranged from an undetermined value to 152 mg/l and from an undetermined value to 63 mg/l in July. Higher values were observed near the coastal regions of the Chunnakam aquifer. Potassium enters into a drinking water system from natural geological sources, detergents, mining and agricultural wastes.

Toxic heavy metals

Toxic heavy metals such as Cd, Pb and As in the Chunnakam aquifer system were reported in very low concentrations, but in some cases Cd was exceeding the WHO limits for drinking water standards. The sources could be the heavy usage of agrochemicals. Arsenic was present in less than 10 ppb (WHO standard).

Conclusion

Spatial and temporal distribution maps of various water quality parameters produced based on a systematic study is the first of this nature for the Jaffna Peninsula. Wells located in the coastal area indicated high values of EC, sodium, chloride and sulfate. Since most of the farm wells are located

FIGURE 3.35. Spatial variations of sulfate ions during July.

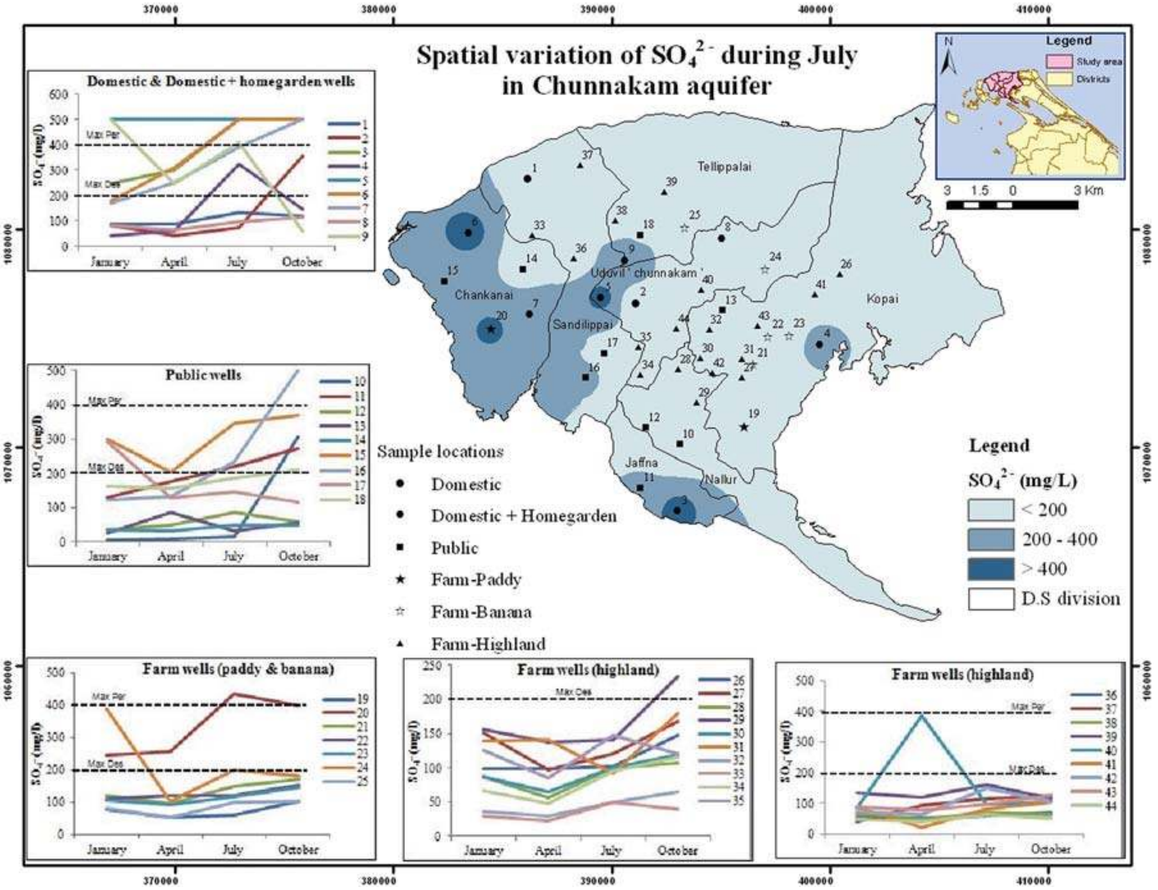


FIGURE 3.36. Spatial variations of sodium ions during January.

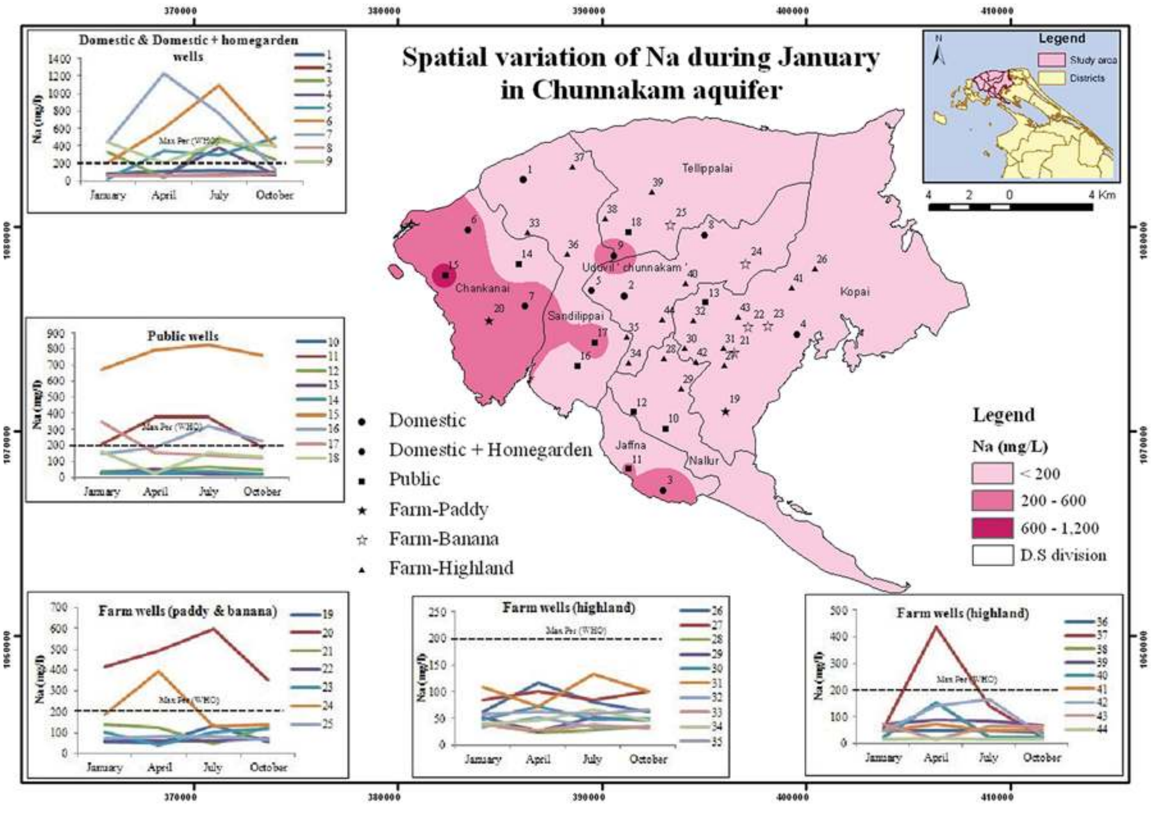


FIGURE 3.37. Spatial variations of sodium ions during July.

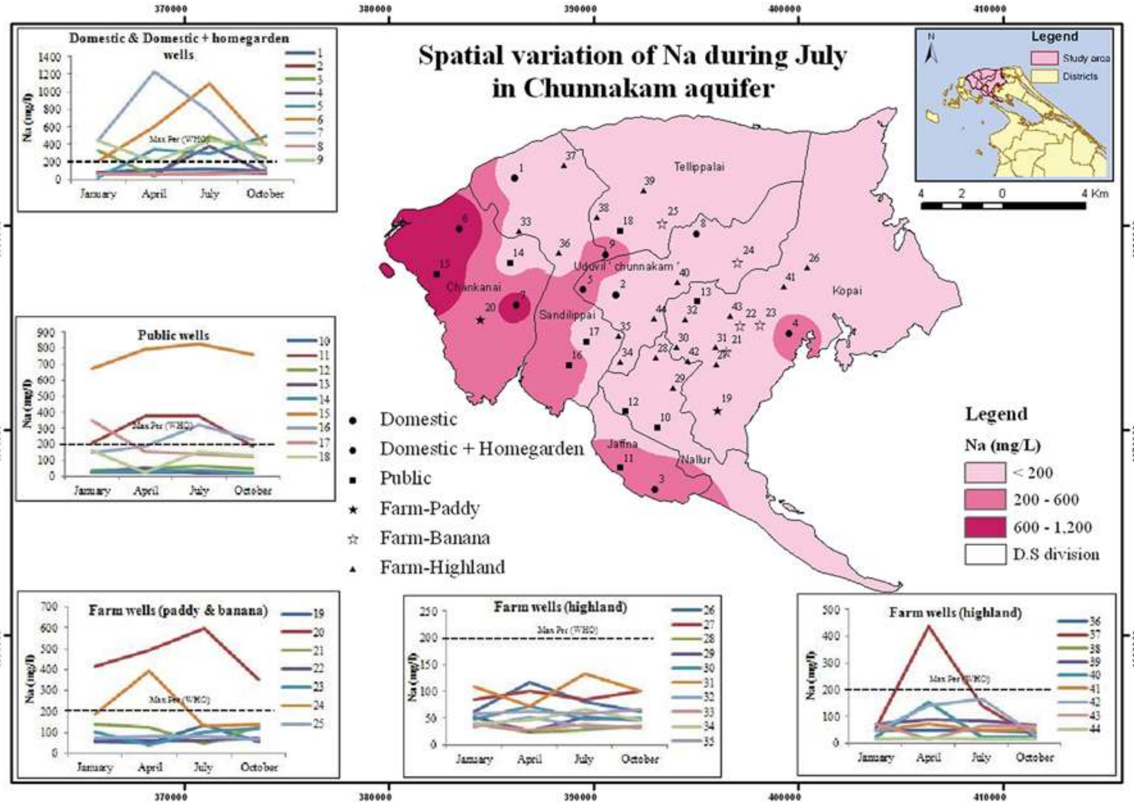


FIGURE 3.38. Spatial variations of potassium ions during January.

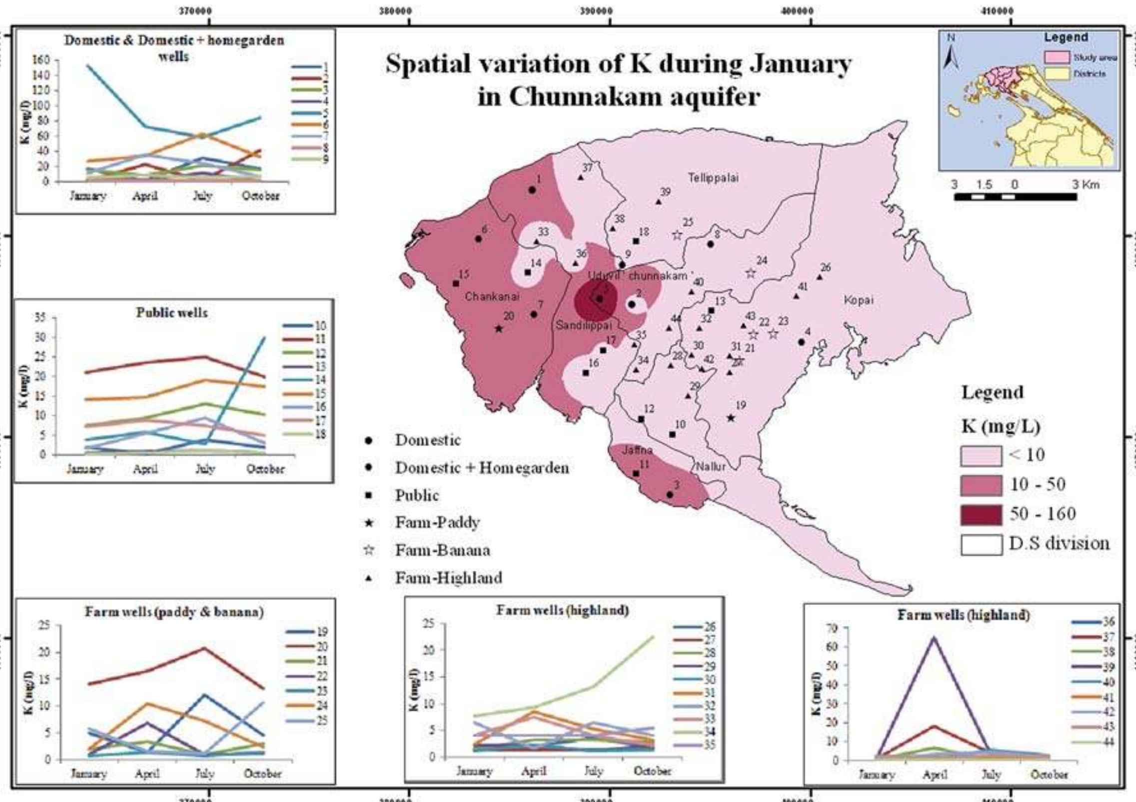
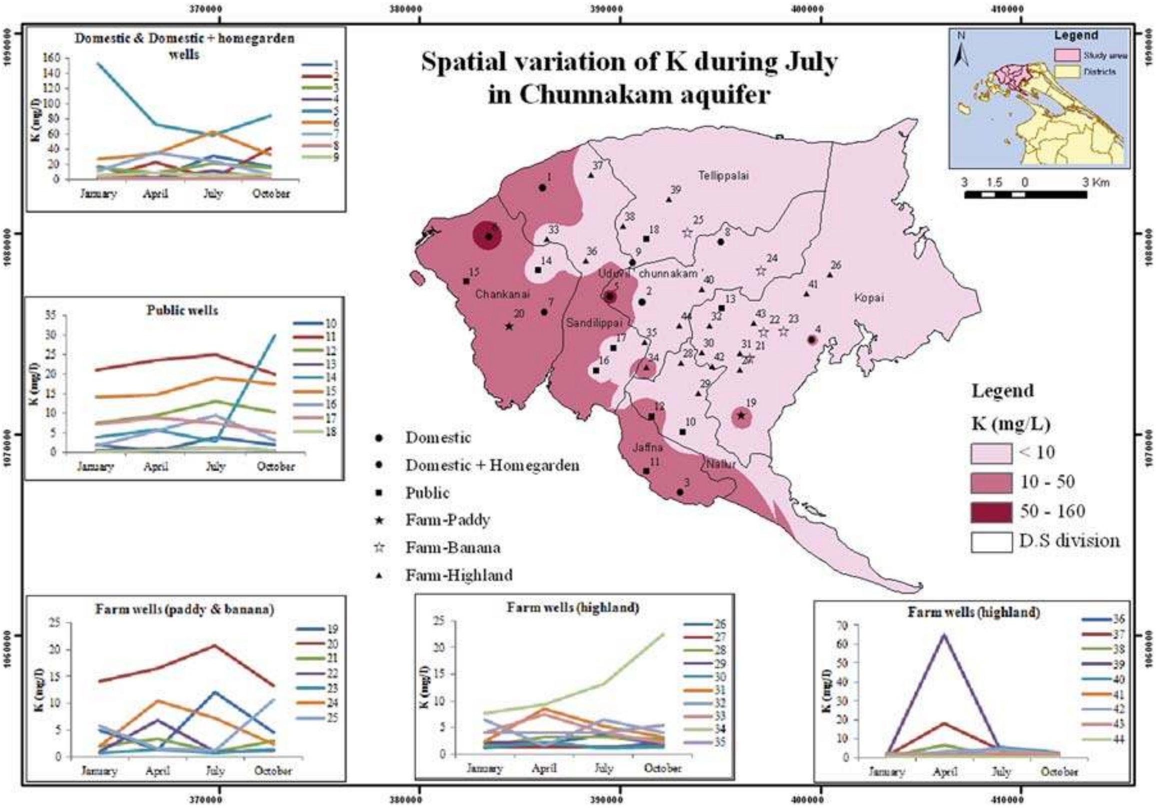


FIGURE 3.39. Spatial variations of potassium ions during July.



further inland, their water quality is generally superior to domestic and public wells. However, farm wells contain nitrate-N levels above the acceptable level for drinking purposes. Elevated levels of EC, nitrate-N and low levels of fluoride were the identified problems compared to SLSI drinking water standards in the Chunnakam aquifer. The level of nitrate-N concentration of water was influenced by the cropping system, as high nitrate-N concentration of groundwater was observed in highland crops land use followed by banana and paddy cultivation in the Valikamam area of the Chunnakam aquifer in the Jaffna Peninsula.

Recommendations

- Continuous monitoring of groundwater quality in wells is necessary to avoid the potential health hazards to people in the area.
- High levels of nitrate (N) in groundwater are a serious health threat to people living in farming areas. While promoting the use of bio-fertilizers, awareness should be created on the hazards due to the excessive use of chemical fertilizers in agriculture.
- Efficient irrigation water management practices should be introduced to prevent the leaching and buildup of nitrate in groundwater.
- Awareness on the problem of potential dental caries due to the use of drinking water containing low fluoride levels should be enhanced in the Jaffna District. In addition, the use of toothpaste containing fluoride should be promoted.

References

Dissanayake, C.B. and S.V.R. Weerasooriya, (1985).The hydro geochemical atlas of Sri Lanka.Natural resources, energy and science authority of Sri Lanka, Colombo.pp: 17-26.

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

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

Jothivenkatachalam, K., Moscow, S. and P.Subramani.(2011). Agricultural activities impact on groundwater of Cauvery river belt in Papanasamtaluk, Tamilnadu, India.Der ChemicaSinica. 2011, 2 (2): 199-206.

Kendall, P. (1992). Drinking water quality and health no. 9.307.Colorado State University Cooperative Extension, Fort Collins,Colorado. pp 1-3.

Kraft, H. (2002). Study on water supply, rain water harvesting, waste water and solid waste management in Jaffna municipal council. Jaffna Rehabilitation Project (JRP). January, 2002. Sri Lanka. pp 13-33.

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. and R. Mahalingam. (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.

Masarik, K. (2007). Interpreting drinking water quality results.Center for watershed science and education.pp 2-5.

Mikunthan, T and C.S. De silva. (2008). Vulnerability assessment for shallow aquifer using chemical quality of groundwater: A case study from Thirunelvely and Kondavil in Jaffna District. Tropical Agricultural Research. 20: 303-312.

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

Nandakumar, V. (1983).Natural environment and groundwater in Jaffna Peninsula, Sri Lanka.Climatological notes, Tsukuba, Japan. 33:155-164.

Nandasena, K.A., Gunawardhana, D.K.S.N. and K.M.A. Kendaragama.(2005).Groundwater quality of three agroecological zones of Sri Lanka.Journal of soil science society of Sri Lanka. 17: 20-30.

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

Puvaneswaran, P. (1986). Geomorphology of the Valukkaiaru drainage basin, Sri Lankan.Journal of South Asian studies. 1:43-58.

Rajasooriyar, L., Mathavan, V., Dharmagunawardhane, H.A. and V. Nandakumar. (2002). Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka. In: Sustainable groundwater management. Hiscock, K.M., Rivett, M.O. and Davison, R.M. (Eds).Geological Society, Londan. 193: 181 – 197.

Sivarajah, N. (2003). Health related problems of water pollution in Jaffna. International workshop on environmental management in north- east Sri Lanka. 1st- 4th December, 2003. Thirunelvely, Jaffna, Sri Lanka.pp 89-94.

Specification for potable water physical and chemical requirements. Sri Lanka standard 614: part 1 (1983). Sri Lankan Standards Institution, Colombo, Sri Lanka. pp 5-10.

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

CHAPTER IV

NITROGEN BUDGET AND GROUNDWATER VULNERABILITY ASSESSMENT

Introduction

Nitrate-N is considered as one of the key pollutants affecting water resources. The primary anthropogenic N source in groundwater is leaching from agroecosystems, although in some regions human waste disposal can also be an important source. Nitrite levels in groundwater are often high in Sri Lanka and are generally correlated with the rate of use of nitrogen fertilizer.

Groundwater nitrogen originates at the land surface as organic nitrogen, ammonium, nitrite or nitrate. Nitrate is the primary form of nitrogen reaching the water table. The reduced forms, organic nitrogen and ammonium, may reach the saturated zone under conditions of high hydraulic loading, high organic carbon loads or shallow depths to the water table (Baedecker and Back 1979; Bouwer et al. 1980). Organic nitrogen may be deaminated to ammonium; ammonium or nitrate may be assimilated by microbes (Behnke 1975). Ammonium may be sorbed by aquifer sediments or nitrified to nitrate under oxygenated conditions. Nitrate is generally transported conservatively in oxygenated groundwater until discharge (Behnke 1975; Hem 1985; Weiskel and Howes 1992). In the absence of oxygen, nitrate may be converted to inert di-nitrogen gas through heterotrophic denitrification (Knowles 1982; Korom 1992).

Overuse of synthetic nitrogen fertilizer

Nitrogen (N) is an essential input for the sustainability of agriculture. However, nitrate contamination of groundwater is a worldwide problem due to the excessive use of nitrogenous fertilizers (Birkinshaw and Ewen 2000; Saadi and Maslouhi 2003). Since Nitrate is soluble and negatively charged it has a high mobility and potential for loss from the unsaturated zone through leaching (Chowdary et al. 2005; DeSimone and Howes 1996). Elevated nitrate concentrations in drinking water can cause methemoglobanemia in infants and stomach cancer in adults (Wolfe and Patz 2002). Therefore, the United States Environmental Protection Agency (USEPA) has established a maximum contaminant level (MCL) of 10 mg/l NO_3-N (50 mg/l NO_3) (USEPA 2000) for drinking water.

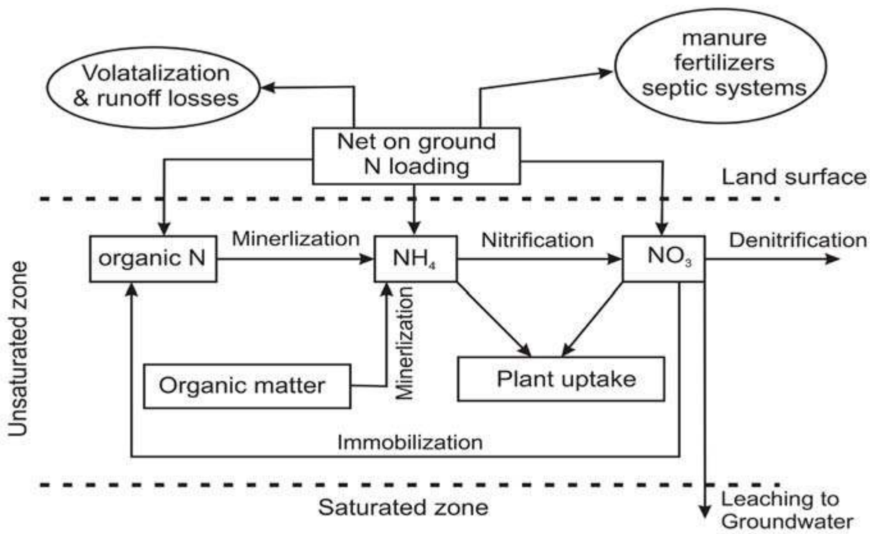
Although nitrogen input is essential for high crop yields, excess use of N fertilizer does not promise a substantial increase in crop productivity. Overuse of N fertilizer results in diminishing crop returns (Tilman et al. 2002), and leads to diminished environmental quality and human well-being (Matson et al. 1998; Galloway et al. 2003; Liu and Diamond 2005). High concentrations of nitrate-N have long been recognized as a health hazard in drinking water. More recently, the contribution of groundwater nitrogen to surface water nutrient budgets has also been recognized (Valiela et al. 1990). China, now the largest consumer of synthetic N in the world, accounting for 32% of the world's total consumption (Heffer 2009).

Overuse of synthetic nitrogen fertilizer has become widespread across Sri Lanka, similar to that of some other countries, resulting in severe environmental problems. If the excessive application of nitrogen fertilizer is not brought under control, Sri Lanka's waters will continue to deteriorate. Very high concentrations of Nitrate-N found in drinking water wells ranged from 7.1 to 15.3 mg/l in Jaffna (Jeyaruba and Thushyanthy 2009), and in 56% of 225 groundwater samples taken in the Kalpitiya area (Liyanage et al. 2000). These show that a large number of people in Sri Lanka were affected by the increased concentrations of nitrate content in drinking water of 50 mg/l. Hence, the purpose of this study is to investigate the threats to groundwater in the Jaffna aquifers with a specific focus on nitrate budgeting, mapping of vulnerability of the aquifers to nitrate contamination, and to compare the loads of nitrate from agriculture.

Nitrogen budgeting

For nitrogen budget calculations, characterization of nitrogen sources and identification of areas with heavy nitrogen loadings from point and non-point sources is essential. The conceptual model of nitrate fate and transport in groundwater integrates several components: (i) watershed hydrology; (ii) spatial distribution of on-ground nitrogen loadings; (iii) detailed assessment of all nitrogen sources in the study area; (iv) approximate description of the nitrogen dynamics in the unsaturated zone; (v) realistic estimation of nitrate leaching to groundwater; (vi) understanding the groundwater flow system; (vii) accounting for groundwater–surface water interactions with the proper characterization of N-transformations in surface water bodies; and (viii) detailed description of nitrate fate and transport processes in groundwater (Refsgaard et al. 1999; Lasserre et al. 1999; Birkinshaw and Ewen 2000; Nolan et al. 2002; Almasri and Kaluarachchi 2004; Ledoux et al. 2007; Almasri 2007). Accurate nitrate budgeting is difficult due to the complex interactions between land use practices, on-ground nitrogen loading, groundwater recharge, soil nitrogen dynamics and soil characteristics. This complex interaction is conceptually illustrated in Figure 4.1. The modeling framework accounts for point and non-point sources of nitrogen. This integration is of great importance to realistically account for the different processes that nitrogen undergoes, and in order to arrive at rational estimates of nitrate concentrations in groundwater.

FIGURE 4.1. Conceptual schematic representations of nitrate occurrences in groundwater. Note that nitrate concentration in groundwater is ultimately a function of on-ground nitrogen loading.



Source: Modified after Almasri and Kaluarachchi 2004.

Methodology

The nitrate concentration data used in this study were obtained entirely from the laboratory analysis and questionnaire survey. All available data were assembled into a single composite database to facilitate the analysis. The total number of wells sampled in the Chunnakam aquifer is 44. The coverage of wells with measurements of nitrate and nitrite concentrations in the database is for the study period from January 2011 to August 2011.

A questionnaire survey was also conducted together with chemical analysis in order to obtain estimations of how much N was used for agriculture based on the land, crop and the time. The questionnaire survey and soil sampling was restricted to the agricultural wells in the study area. Soil sampling was carried out, at the end of the growing season (dry season), on the first 20 cm of soils, collected into plastic bags, closed tightly to minimize the air space and air dried to prevent the breakdown of the organic matter. Total C and N analysis was carried out from the CHN elemental analyzer (EA 1110, CE Instruments, Italy).

Groundwater vulnerability assessment based on Nitrogen

Use of DRASTIC

DRASTIC is an acronym for an empirical model with seven variables, namely, depth to the groundwater table, net groundwater recharge, aquifer media, soil media, topography, impact of vadose zone media and hydraulic conductivity of the aquifer (Aller et al. 1985). The model, DRASTIC, was developed by Aller et al. (1985). In this study, DRASTIC was used together with modified DRASTIC to assess groundwater vulnerability of the Chunnakam aquifer system in Jaffna. This method is considered as a standardized method for evaluating groundwater vulnerability to contamination and has been used elsewhere (Fritch et al. 2000; Shukla et al. 2000; Al-Zabet 2002). The DRASTIC method has also been applied in many different climates, including Sri Lanka (Babiker et al. 2005; Werz and Hötzl 2007; Jayasekera et al. 2011).

A vulnerability assessment provides the intrinsic vulnerability of a given region to potential contamination using hydrologic and recharge properties independent of a contaminant (Jayasekera et al. 2011). In DRASTIC, each of the hydrogeologic factors is assigned a rating from 1 to 10 based on a preset range of values. The weight assigned by Aller et al. (1985) to each variable is as follows: depth to water table and impact of vadose zone - 5; net recharge - 4; aquifer media and hydraulic conductivity - 3; soil media - 2; and topography - 1. The DRASTIC Index (DI) is given as shown in Equation (4.1):

$$\text{DI} = DwDr + RwRr + AwAr + SwSr + TwTr + Iw\,Ir + CwCr \qquad (4.1)$$

where: *Dw*, *Rw*, *Aw*, *Sw*, *Tw*, *Iw* and *Cw* are the weights allocated to depth, recharge, aquifer media, soil media, topography, impact and conductivity, respectively. Similarly, *Dr*, *Rr*, *Ar*, *Sr*, *Tr*, *Ir*, and *Cr* are the ratings allocated to depth, recharge, aquifer media, soil media, topography, impact and conductivity, respectively.

The intrinsic vulnerability of the area is estimated by the DRASTIC. Aller et al. (1985) defined DRASTIC qualitative index categories for vulnerability as: 1–100 (low); 101–140 (moderate); 141–200 (high); and >200 (very high). The depth to the groundwater table was measured at the same 44 well locations where sampling was performed. The net recharge was estimated based on the previous observations.

Modified DRASTIC method

The modified DRASTIC method (Liang et al. 2009; Nobre et al. 2007) was also used in this study to determine the nitrate-specific vulnerability of the aquifers. Assigned ratings and weights to the on-ground nitrogen loading are then added to the final DRASTIC index values, obtained using Equation (4.2) to produce a composite index of groundwater vulnerability by nitrate.

$$CDI = DI + NwNr \quad (4.2)$$

where: CDI is the composite DRASTIC index, and *Nw* and *Nr* are the weight and rating given to the total on-ground nitrogen loading.

The total on-ground nitrogen loading consists of two parts; agricultural loading due to fertilizer and non-agricultural loading due to sanitation and human waste. The human and sanitation nitrogen loading of 14.3 g per capita per day was estimated assuming that the ammonia concentration is negligible based on Jayasekara et al. (2011). Agricultural nitrogen loadings were estimated using the fertilizer and irrigation nitrogen loadings observed through on-site measurements and interviews. The ratio of nitrogen content by weight in each fertilizer type and the total amount of fertilizer applied by each fertilizer type for different crops in different land uses was estimated through the results from the questionnaire survey.

Results and Discussion

Nitrogen distribution across the Chunnakam groundwater and soil

Average concentrations of nitrate-N and nitrite-N for the entire year and the entire area during the study period were 4.869 and 0.014 mg/l, respectively. The average number of wells exceeding the permissible level of NO_3–N is approximately 6-12, which is about 14-28% of the 44 wells. The average concentration of total nitrogen present in soil was 0.168%, and the minimum and maximum concentrations were 0.126 and 0.206%, respectively (Table 4.1). Low concentrations of nitrogen are normal in soils with low organic matter concentrations, because nitrogen is present in soil primarily as a component of organic matter. Carbon: nitrogen ratios ranged from 7.8 to 31 with an average of 10.5 (Table 4.1).

Fertilizer application

Based on the questionnaire survey, it was evident that fertilizer application is far beyond the regulatory limits (Table 4.2). Although agriculture in Jaffna utilizes only a small area of Sri Lanka's arable land area, it's contribution to agricultural production is considerable. Substantial growth in the use of synthetic nitrogen (N) fertilizer in Sri Lanka with the government subsidy has provided significant economic and social benefits, including higher farm incomes, improved food consumption and the maintenance of national food security although it had been a silent pollutant source for the environment.

TABLE 4.1. Total Nitrogen (T-N%) and Carbon (T-C%) in soil samples collected from the top 15 cm of the soil.

Sample No.	T-N%	T-C%	C:N
4	0.206	2.222	10.786
12	0.181	1.681	9.287
13	0.174	5.398	31.023
19	0.132	1.065	8.068
22	0.126	1.329	10.547
24	0.159	1.498	9.421
26	0.129	1.051	8.147
28	0.186	1.768	9.505
30	0.128	1.242	9.703
31	0.188	1.608	8.553
35	0.232	1.903	8.202
40	0.151	1.543	10.218
41	0.171	1.342	7.848
42	0.162	1.312	8.098
44	0.194	1.579	8.139

Nitrogen loading at the surface

As shown in Figure 4.1, the nitrogen loading at the surface is generated from a variety of sources. These include fertilizer input (including manure), septic systems, dairy farm lagoons and irrigation. A comprehensive assessment of each source was not possible but estimates of the loading from the major sources were made by making certain assumptions. As mentioned above, a comprehensive survey of the fertilizer amounts used in various farms according to the crop type was undertaken (Table 4.2) to determine the surface loading of nutrients. A variety of inorganic fertilizer types are used in the study area. The amount of surface loading depends on the nitrogen content of the fertilizer. Based on the fertilizer type (both inorganic and organic), an estimate of the nitrogen content was made. Using this information, the total surface loading of nitrogen for areas served by agricultural wells was computed. A summary of results from the N-loading computation is presented in Table 4.3.

TABLE 4.2. Estimates of inorganic and organic fertilizer loads for the study area.

Well Number	Crop	Area (m^2)	Inorganic fertilizer type	Amount (kg)	Organic fertilizer type	Amount (kg) (fresh)
21	Banana	2,016			Cow dung	1,000
					Green manure	1,000
22	Banana	1,512			Cow dung	750
23	Banana	2,520			Cow dung	2,500
	Beetroot	1,008	Urea	20		
			Basal	10		
24	Tobacco	2,016	Urea	50	Cow dung	1,000
			Ammonium sulphate	50		
	Beetroot	4,032	Urea	100		
			TDM	60		
	Onion	504				
26	Onion	2,217.6	Basal	60	Cow dung	1,100
			Urea	36		
			Ammonium sulfate	22		
	Onion	4,536	Basal	112.5	Cow dung	2,250
			Urea	67.5		
			Ammonium sulfate	45		
27	Cabbage	1,209.6	Basal NPK	30	Cow dung	270
			Urea	24		
			TDM	30		
	Pumpkin	1,209.6	Urea	12		
			NPK	12		
	Banana	1,209.6				
28	Cassava	2,016			Cow dung	1,750
	Amaranthus	504	Urea	2		
	Beans	504	Urea	2		
	Snake gourd	504				
29	Beetroot	2,520	NPK	125	Cow dung	2,820
			Urea	62.5		
	Chilli	2,520	NPK	125		
			Urea	62.5		
	Beetroot	806.4	Urea	40		
	Onion	1,260	NPK	62.5		
			Ammonium sulfate	31.25		
			TDM	18.75		
30	Tobacco	1,512	Urea	75	Cow dung	1,800
	Onion	604.8	Urea	15		
			MOP	9		
	Amaranthus	705.6	Urea	7		
31	Tobacco	1,209.6	Urea	100	Cow dung	1,000
	Beetroot	604.8	Urea	30		
			MOP	1		
	Onion	604.8	Basal NPK	6		
			TSP	1.2		
			Urea	12		
34	Cassava	2,016			Cow dung	500
35	Tobacco	2,520	Urea	75	Cow dung	1,250
			V1	62.5		
			Ammonium sulfate	62.5		
	Capsicum	504				
	Chilli	504				
36	Tobacco	1,764	Urea	150	Cow dung	1,000
	Onion	1,764	V1 Mixture	50		
			Urea	50		
	Pumpkin	1,764	Urea	50		

(Continued)

TABLE 4.2. Estimates of inorganic and organic fertilizer loads for the study area (continued).

Well Number	Crop	Area (m^2)	Inorganic fertilizer type	Amount (kg)	Organic fertilizer type	Amount (kg) (fresh)
37	Onion	3,528	Urea	80	Cow dung	1,000
			Ammonium sulfate	80		
38	Tobacco	1,323	Urea	37.5	Cow dung	175
			Basal NPK	37.5		
	Beetroot	441	NPK	12.5	Green manure	1,250
			Urea	7.5		
			TDM	12.5		
	Tomato	441	NPK	12.5		
			Urea	7.5		
			TDM	12.5		
	Onion	441	TDM	12.5		
			Urea	5		
	Pumpkin	882	V1	25		
			TDM	15		
39	Onion	441	TSP	22.5	Cow dung	75
			Urea	12.5		
			MOP	12.5		
	Beetroot	3,528	Urea	200	Cow dung	300
			MOP	48		
41	Onion	2,016	Urea	50	Cow dung	2,000
			Ammonium sulfate	50		
	Banana	2520				
42	Beetroot	1,814.4	Basal V1 mixture	45	Cow dung	1,800
			Urea	45		
43	Banana	1,008				
	Onion	604.8	Ammonium sulfate	6	Cow dung	1,000
			Urea	5		
			V1	10		
	Leeks	403.2	Urea	15		
	Tobacco	1,008	Urea	30		
44	Tobacco	2,016	Urea	100	Cow dung	2,000
			Ammonium sulphate	60		
	Total	73,117.8				

Notes: m^2 = square meters
TDM: Top Dressing Mixture, NPK: Nitrogen, Phosphorous, Potassium fertilizer, MOP: Muriate of Potash: TSP: Triple Super Phosphate and V1: Fertilizer mixture recommended by Department of Agriculture.

Using the area served by the agricultural wells, nitrogen loading per square kilometer can be calculated and compared with the second major source of nitrogen loading which is domestic waste. The surface loading of nitrogen over the study area is equivalent to about 58.8 metric tonnes/km^2 for the period of study. Assuming the ammonia content to be negligible, Jayasekera et al. (2011) has reported a unit value of 14.3 g/per capita per day for the total nitrogen content in human and kitchen waste. Using this figure and a population density of 790 persons/km^2, the surface loading of nitrogen from domestic sources was computed yielding an average figure of 4.1 metric tonnes/ km^2 per day. Finally, the other known source of nitrogen loading at the surface is irrigation. The average abstraction from farm wells for agricultural activities varies from 13 m^3/day to 19 m^3/ day (Jeyaruba and Thushyanthy 2009). For the 19 agricultural sites corresponding to the sampling wells, it was assumed that they were irrigated for 100 days a year. The average concentration of NO_3-N in the 19 wells is computed by using the water quality data as 8.32 mg/l. Using these assumptions, the surface loading from irrigation within the study site is computed as 506 kg/year, which is equivalent to 3.46 metric tonnes/km^2.

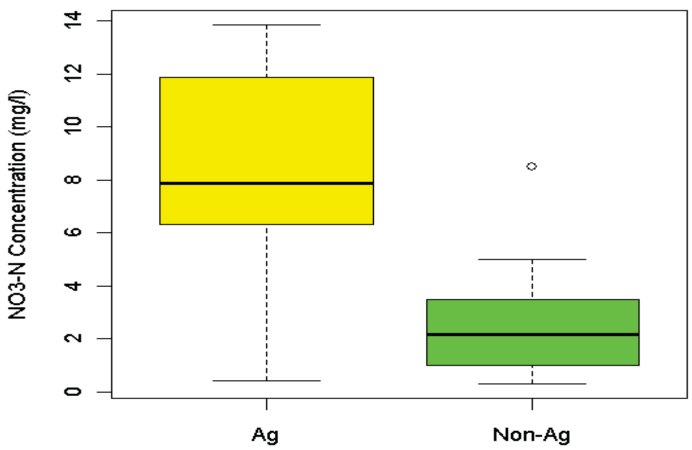
TABLE 4.3 Total surface loading of N in areas served by agricultural wells.

Agro-well number	Crop type	Area (m^2)	Total N-load (kg)
21	Banana	2,016	100
22	Banana	1,512	75
23	Banana	2,520	250
	Beetroot	1,008	15
24	Beetroot	4,032	86
	Onion	504	0
	Tobacco	2,016	140
26	Onion	6,753.6	493.1
27	Banana	1,209.6	0
	Cabbage	1,209.6	63
	Pumpkin	1,209.6	8.4
28	Amaranthus	504	1
	Beans	504	1
	Cassava	2,016	175
	Snake gourd	504	0
29	Beetroot	3,326.4	358.25
	Chilli	2,520	56.25
	Onion	1,260	33.125
30	Amaranthus	705.6	3.5
	Onion	604.8	7.5
	Tobacco	1,512	217.5
31	Beetroot	2,419.2	226.5
	Onion	604.8	7.2
	Tobacco	1,209.6	150
34	Cassava	2,016	50
35	Capsicum	504	0
	Chilli	504	0
	Tobacco	2,520	193.75
36	Onion	1,764	35
	Pumpkin	1,764	25
	Tobacco	1,764	175
37	Onion	3,528	164
38	Beetroot	441	330
	Onion	441	10
	Pumpkin	882	14
	Tobacco	1,323	43.75
	Tomato	441	13.75
39	Beetroot	3,528	130
	Onion	441	13.75
41	Banana	2,520	
	Onion	2,016	240
43	Banana	1,008	0
	Leeks	403.2	7.5
	Onion	604.8	106.3
	Tobacco	1,008	15
44	Tobacco	2,016	268
	Total	73,117.8	4,302.13

The surface loading figures corresponding to the fertilizer input, domestic sources (sewage and kitchen waste, etc.) and irrigation show an important contrast. The nitrogen loading at the surface for the domestic sources and irrigation is of the same order of magnitude. However, the loading from fertilizer input is much larger and is about 15 times higher than the other two sources. This finding suggests that the fertilizer input in agricultural areas constitute a significant contribution to the nitrogen content in the groundwater and soils in agricultural areas of Jaffna.

The effect of high nitrogen input through fertilizer application can be observed in the NO_3-N data obtained from sampling the wells in the study area. Figure 4.2 shows the box-whisker plots of NO_3-N for both agricultural wells and non-agricultural wells. It is clear that the NO_3 levels for the agricultural wells are about four times higher than the same levels for non-agricultural wells. The heavy fertilizer usage for agriculture in the Jaffna region appears to have resulted in elevated levels of NO_3 levels in groundwater in the region, and the resulting concentrations, at times, are higher than the guidelines established by WHO which is 10 mg/l for NO_3-N.

FIGURE 4.2. Box and whisker plots of NO_3-N for agricultural and non-agricultural wells.



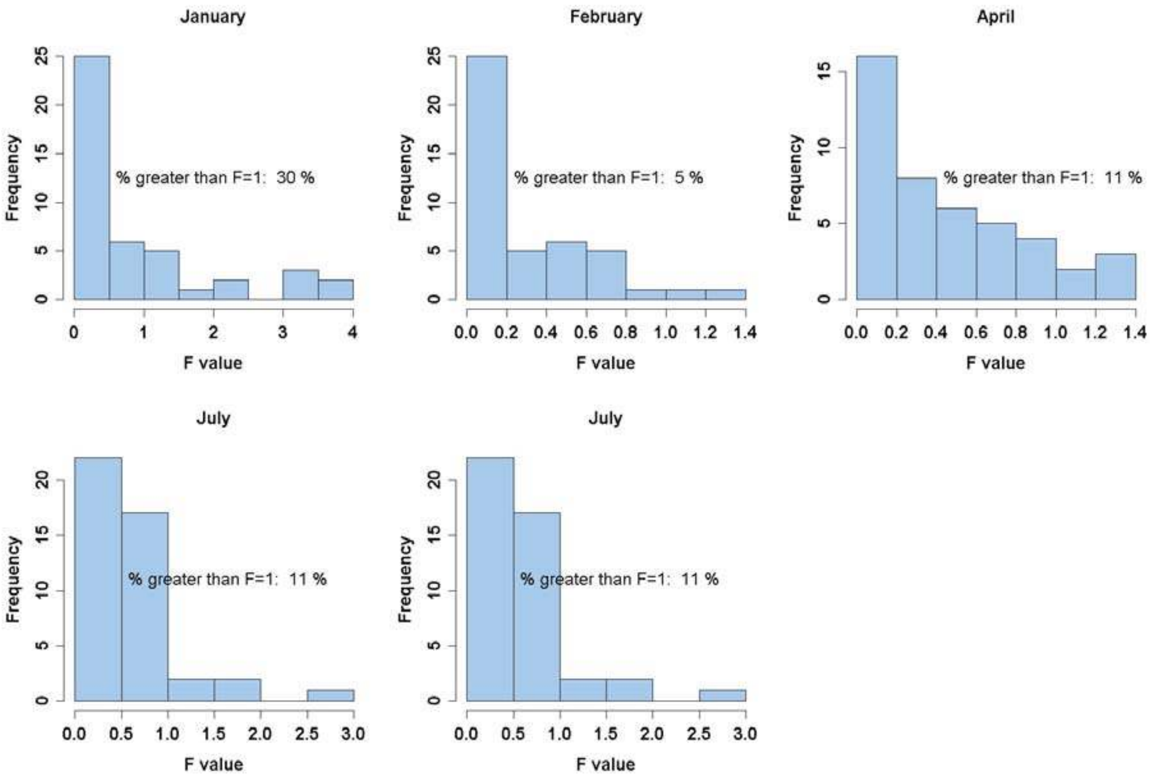
Following Jayasekera et al. (2011), we define a composite measure to determine the significance of high nitrate and nitrite values. WHO has provided guidance values (GV) for both NO_3-N and NO_2 as 10 mg/l and 0.2 mg/l, respectively. The sum of the ratios of observed NO_3-N and NO_2 with the corresponding GVs should not exceed 1 (Jayasekera et al. 2011) as shown in Equation (4.3) below:

$$F = \frac{C_{nitrate}}{GV_{nitrate}} + \frac{C_{nitrite}}{GV_{nitrite}} \leq 1 \qquad (4.3)$$

From the data at both agricultural wells and non-agricultural wells, the ratio F was calculated and they were summarized as histograms (Figure 4.3).

The percentage number of wells which exceed the WHO threshold of 1 for the ratio F in the study area is in the range of 5%-30%. In particular, data corresponding to January and October show the highest number of wells for which F is greater than unity and February has the lowest frequency of wells with F greater than 1. It is evident that a high percentage of wells exceed the NO_3 and NO_2 thresholds established by WHO.

FIGURE 4.3. Frequency distributions of ratio F (Jayasekera et al. 2011) for the NO_3-N and NO_2 data in the study area.



Groundwater Vulnerability

The DRASTIC model was used to assess the vulnerability of the study region using a composite index which combines seven variables that characterize the vulnerability of the aquifer system for potential contamination. Quantitative estimates of the variables needed for the DRASTIC methodology are shown in Table 4.4.

Depth to the water table was determined from the field observations. Net recharge was computed using the rainfall observations for the 2007-2011 periods and an estimate of the fraction of rainfall-recharge. The average rainfall for this period was 1,539 mm. Groundwater recharge rates of the limestone aquifer range from 23% to 25% of annual rainfall as determined by the Modified Soil Moisture Balance (Rushton et al. 2006) for the same period. This was confirmed by another model, Water Table Fluctuation (WTF) method, which provides estimates of 26% to 29%. Groundwater recharge using the soil moisture balance model for ten years from 1971 to 1980 in five agrarian service centers was estimated by Thiruchelvam et al. (1994), and the results showed that 31 to 45% of the rainfall was recharged into the aquifer. Further, he reported that, on average, about 33% of the total rainfall is recharged into the aquifer. For DRASTIC calculations, an average recharge rate of 30% was assumed. The Jaffna peninsula consists largely of karstic limestone and, therefore, the aquifer media in DRASTIC was assumed to be limestone. The category of soil media available in DRASTIC tables closest to what is found in the study region was silt loam. The general topography of the study region has a slope of about 2% and that was used as the topography parameter in DRASTIC. The impact of vadose zone media was determined from DRASTIC tables by assuming that the vadose zone consists of sand and gravel with significant silt and clay. Finally, since there were no measurements of hydraulic conductivity, it was assumed that it is very high for the karstic system in Jaffna. The hydraulic conductivity values were assumed to be over 2,000 gpd/ft^2 (gallons per day per square feet), which is at the upper end of the scale in DRASTIC for that variable.

TABLE 4.4. Estimates of the seven variables used for computing the DRASTIC index for the study region. The rating and weights were obtained from the published literature on DRASTIC.

DRASTIC index	Variable	Estimate	Rating	Weight
D	Depth to water table	5-15 feet*	9	5
R	Net recharge	18.2 inches*	9	4
A	Aquifer media	Limestone	6	3
S	Soil media	Silt loam	4	2
T	Topography	2%	10	1
I	Impact of vadose zone media	Sand and gravel with significant silt and clay	6	5
C	Hydraulic conductivity	> 2,000 gpd/ft^{2*}	10	3

Note: *As DRASTIC requires variables in English units, estimates in the International System of Units (SI) were converted.

The DRASTIC index corresponding to estimated values in Table 4.4 is 177. This is a composite value for the entire study region. Based on the qualitative index categories for vulnerability, the computed DRASTIC index is in the 'high' category. It follows that the study region has a high intrinsic vulnerability for contamination. This level of vulnerability is a result of a variety of factors as seen from the ratings (Table 4.4) being at the upper end of the scales corresponding to their variables. A combination of factors involving the shallow water table, high net recharge, limestone aquifer, low topography and the high hydraulic conductivity make the Jaffna Peninsula highly vulnerable to contamination.

Specific vulnerability of the aquifer attributable to nitrate was determined by using the Modified DRASTIC index. Basically, the modified index is calculated by adding a nitrate-specific quantity, N_rN_w, to the regular DRASTIC index, where N_r is the rating corresponding to nitrogen loading and N_w is the associated weight. The surface loading of nitrate-nitrogen is available from Table 4.2, and following Jayasekera et al. (2011), the ratings with a range of 1 to 5 were calculated by using equal loading intervals. In addition, the weight for nitrogen loading was assumed to be 5 for the calculation of the Modified DRASTIC index which ranged from 182 to 197. This value is somewhat higher than the DRASTIC index reported above indicating the added pollution potential from nitrate.

Conclusions

The Modified DRASTIC index (DI) value computed, as explained above, increased from DI=177 to a range of 182 to 197. In spite of the increase, the Modified DI values show that the aquifer vulnerability specific to nitrate contamination remains in a 'high' category. However, the high end of Modified DRASTIC index is closer to the threshold value for transiting the vulnerability from the 'high' category to a 'very high' category. In conclusion, the aquifer system in Jaffna remains highly vulnerable to nitrate-specific contamination. The risk of contamination is largely attributed to the heavy use of fertilizer for agriculture in the area.

References

Aller, L., Bennett, T., Lehr, J. H., & Petty, R. J. (1985). DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings. U.S. EPA, Robert S. Kerr Environmental Research Laboratory, Ada, OK, EPA/600/2–85/0108, 576, 163.

Almasri, M. N., & Kaluarachchi, J. J. (2004). Assessment and management of long-term nitrate pollution of ground water in agriculture-dominated watersheds. Journal of Hydrology, 295.

Almasri, M. N., 2007. Nitrate contamination of groundwater: a conceptual management framework. Environmental Impact Assessment Review 27, 220–242.

Al-Zabet, T. (2002). Evaluation of aquifer vulnerability to contamination potential using the DRASTIC method. Environmental Geology, 43, 203–208. doi:10.1007/s00254-002-0645-5.

Babiker, I. S., Mohamed, M. A. A., Hiyama, T., & Kato, K. (2005). A GIS based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, Central Japan. Science of the Total Environment, 345, 127–140

Baedecker, M. J., and W. Back, Hydrogeological processes and chemical reactions at a landfill, Ground Water, 17, 429-437, 1979.

Behnke, J., A summary of the biogeochemistry of nitrogen compounds in ground water, J. Hydrol., 27, 155-167, 1975.

Birkinshaw, S. J., & Ewen, J. (2000). Nitrogen transformation component for SHETRAN catchment nitrate transport modelling. Journal of Hydrology, 230, 1–17.

Bouwer, H., R. C. Rice, J. C. Lance, and R. G. Gilbert, Rapid infiltration research at Flushing Meadows Project, Arizona, J. Water Pollut. Control Fed., 52, 2457-2470, 1980.

Chowdary, V. M., Rao, N. H., & Sarma, P. B. S. (2005). Decision support framework for assessment of non-point-source pollution of groundwater in large irrigation projects. Agricultural Water Management, 75, 194–225.

DeSimone, L. A., and B. L. Howes, Denitrification and nitrogen transport in a coastal aquifer receiving wastewater discharge, Environ. Sci. Technol., 30, 1152-1162, 1996.

Fritch, T. G., McKnight, C. L., Yelderman, J. C., & Arnold, J. G. (2000). An aquifer vulnerability assessment of the Paluxy aquifer, Central Texas, USA, using GIS and a modified DRASTIC approach. Environment Management, 25, 337–345.

Galloway J.N. Aber, J.D., Erisman, J.W., Seitzinger, S.P., Howarth, R.W., Cowling, E.B., Cosby, B.J. The Nitrogen Cascade, Bioscience 53 (2003): 341.

Heffer, P. Assessment of Fertilizer Use by Crop at the Global Level 2006/07–2007/08, (International Fertilizer Industry Association, Paris, France, 2009, 8-11. 1179.

Hem, J. D. (1985). Study and interpretation of the chemical characteristics of natural water (3rd ed.). U.S. Geological Survey Water-Supply Paper 2254, 263.

Jayasekara, D.L., Kaluarachchi, J., Villholth, K.G. 2011. Groundwater stress and vulnerability in rural coastal aquifers under competing demands: a case study from Sri Lanka Environ. Monito. Assess. 176, 13-30.

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

Knowles, R., Denitrification, Microbiol. Rev., 46, 43-70, 1982.

Korom, S. F., Natural denitrification in the saturated zone: A review, Water Resour. Res., 28, 1657-1668, 1992.

Lasserre, F., Razack, M., Banton, O., 1999. A GIS-linked model for the assessment of nitrate contamination in groundwater. Journal of Hydrology 224, 81–90.

Ledoux, E., Gomez, E., Monget, J.M., Viavattene, C., Viennot, P., Ducharne, A., Benoit, M., Mignolet, C., Schott, C., Mary, B., 2007. Agriculture and groundwater nitrate contamination in the Seine basin. The STICS–MODCOU modelling chain. Science of the Total Environment, in press. doi:10.1016/j.scitotenv.2006. 12.002.

Liang, C. P., Lin, C. W., Jang, C. S., & Chen, J. S. (2009). Assessment of contamination potential of nitrate-N in natural recharging aquifers of the Choushui River alluvial fan, Taiwan: Development and prediction of a modified GIS-based DRASTIC model. Geophysical Research, 11, EGU 2009–1942.

Liu J. and J. Diamond, China's environment in a globalizing world, Nature 435 (2005):

Liyanage, C.E; Thabrew,M.L and Kuruppuarachchi D,S.P (2000) Nitrate pollution in ground water of Kalpitiya. J. National. Sci. Council of Sri Lanka, 28 (2) 101-112.

Matson, P.A., Naylor, R., Ortiz-Monasterio, I., Matson, P.A., Naylor, R., Ortiz-Monasterio, I. Integration of Environmental, Agronomic, and Economic Aspects of Fertilizer Management, Science 280, (1998) 112.

Nobre, R. C. M., Rotunno Filho, O. C., Mansur, W. J., Nobre, M. M. M., & Cosenza, C. A. N. (2007). Groundwater vulnerability and risk mapping using GIS, modeling and a fuzzy logic tool. Journal of Contaminant Hydrology, 94, 277–292. doi:10.1016/ j.jconhyd.2007.07.008.

Nolan, B.T., Hitt, K., Ruddy, B., 2002. Probability of nitrate contamination of recently recharged ground waters in the conterminous United States. Environmental Science and Technology 36 (10), 2138–2145.

Refsgaard, J.C., Thorsen, M., Jensen, J.B., Kleeschulte, S., Hansen, S., 1999. Large scale modeling of groundwater contamination from nitrate leaching. Journal of Hydrology 221, 117–140.

Rushton, K.R., V.H.M. Eilers, R.C. Carter. 2006. Improved soil moisture balance methodology for recharge estimation. Journal of Hydrology, 318: 379-399.

Saadi, Z., & Maslouhi, A. (2003). Modeling nitrogen dynamics in unsaturated soils for evaluating nitrate contamination of the Mnasra groundwater. Advances in Environmental Research, 7, 803–823.

Shukla, S., Mostaghimi, S., Shanholt, V. O., Collins, M. C., & Ross, B. B. (2000). A county-level assessment of ground water contamination by pesticides. Ground water monitoring review, 20(1), 104–119.

Thiruchelvam, S., Abegunawardena, P., Gunawardena, R.N. (1994) An Economic Analysis of Groundwater Use for Sustainable Agriculture in the Jaffna District. Tropical Agricultural Research, Vol. 6, pp 113- 22.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S. Agricultural sustainability and intensive production practices, Nature 418, (2002) 671.

USEPA. (2000). Drinking water standards and health advisories. U.S. Environmental Protection Agency, Office of Water. 822-B-00-001.

Valiela, I., J. Costa, K. Foreman, J. M. Teal, B. L. Howes, and D. Aubrey, Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters, Biogeochem. 1, 0, 177-197, 1990.

Weiskel, P. K., and B. L. Howes, Differential transport of sewage derived nitrogen and phosphorus through a coastal watershed, Environ. Sci. Technol., 26, 352-360, 1992.

Werz, H., & Hötzl, H. (2007). Groundwater risk intensity mapping in semi-arid regions using optical remote sensing data as an additional tool. Hydrogeology Journal, 15, 1031–1049.

Wolfe, A.H., Patz, J.A., 2002. Reactive nitrogen and human health: acute and long-term implications. Ambio 31 (2), 120–125.

Contact Information

Dr. Herath Manthrithilake
Head, Sri Lanka Development Initiative
International Water Management Institute
127, Sunil Mawatha
Pelawatta, Battaramulla
Sri Lanka
Telephone: +94-11 2880000
E-mail: h.manthri@cgiar.org
Website: www.iwmi.org