Impact on Groundwater quality in Puttalam area due to over abstraction & improper agricultural practices

K. M. S. M. Kumarasinghe[1] , R. R. G. R. Rajapakse [2]

Water Resources Board, 2A, Hector Kobbakaduwa Mawatha, Colombo 07

Abstract

The water quality of Puttalam Limestone aquifer and surrounding area is recently affected by increasing Salinity, while certain areas of the Puttalam are also affected by Nitrate & Phosphate contamination in groundwater. The study area covers three secretariat divisions (Puttalam, Vanathavillu & Kalpitiya) which are identified as most affected areas on groundwater contamination. Puttalam and Vanathavillu areas are adversely affected due to high salinity in groundwater and over abstraction aggravated the condition resulting sea water encroachment at the coastal stretches & upcorning effect in certain places. The groundwater in Kalpitiya area is contaminated due to high improper pesticides and fertilizer applications for agriculture. This study is focused to assess the impact on groundwater due to agrochemicals & pesticides and over extraction. Another aspect of this study is to identify the levels of possible sea water intrusion due to over abstractions.

The monitoring points (dug wells / tube wells) were selected considering the issues identified and representing both shallow and deep aquifers. The sampling process was carried out for wet & dry period of the year. 52 water samples were collected during dry period (September-October 2011). Based on the results of chemical analysis performed for dry period, additional 50 samples were also collected during rainy season (February-March2012). These samples were analyzed for the elements of pH, EC, TH, TA, TDS, Ca, Na, K, Mg, Iron, Cl, Sulphate, F, Salinity, Nitrate and Phosphate. During the process, 144 Samples were analyzed for EC, pH, TDS, Phosphate and Nitrate as in-situ tests to identify the geochemistry of groundwater for the initial assessment at the site itself.

According to the chemical analysis, shallow aquifer in some areas indicates high contamination with Nitrate, Phosphate and increased salinity. Eththale, Alankuda, Norachchoelai, Minniya, Nirmalapura are the areas where mainly affected by Nitrate contamination of shallow groundwater. The Nitrate contamination pattern in groundwater of these areas (Nitrate concentration >10mg/l) is shown as localized zones. However, there is an indication of increased level of Nitrate contamination throughout the Kalpitiya area (NO3 level exceeds 5mg/l in many villages of Kalpitiya area). The analysis results are also indicated high Nitrate contamination in Puttalam urban area due to improper sanitation facilities. Shallow aquifer of the Mee oya shows higher salinity levels. But in deep aquifer, there is no indication of increased salinity levels. Some sampling points in the lagoonal areas as well as inland areas are shown site specific characteristics of increased EC and salinity levels. The phosphate contamination in deeper aquifers groundwater could also be identified in the upper part of Vanathavillu (Eluwankulama, Rahalmadu & Serakkuliya) indicating more than 2mg/l.

The geophysical applications of 1-D, 2-D resistivity imaging surveys, test well drilling, water level elevation contouring & aquifer test results indicated that the groundwater flow regime of the Puttalam Limestone region is highly complex due to regional geological and structural settings. Therefore assessment and distinguish of spatial distribution of different aquifers in the region is vital. In conclusive, the groundwater is mainly contaminated due to improper agricultural practices and lack of groundwater management plan in these highly vulnerable sand and limestone aquifer formations.

Introduction

Groundwater acts a vital role in Puttalam area for drinking, agricultural and other domestic purposes. The surface water sources are limited in the area and not adequate for ever-increasing water demand for these all activities. The Paddy cultivation and other cash crops of potatoes, onions, chilies & Tobacco are extensively cultivated in the region. The use of surface water for drinking and other requirement are less and hindered due to poor water quality. This aggravates the risk on groundwater sustainability and quality deterioration due to alarmingly higher abstraction levels.

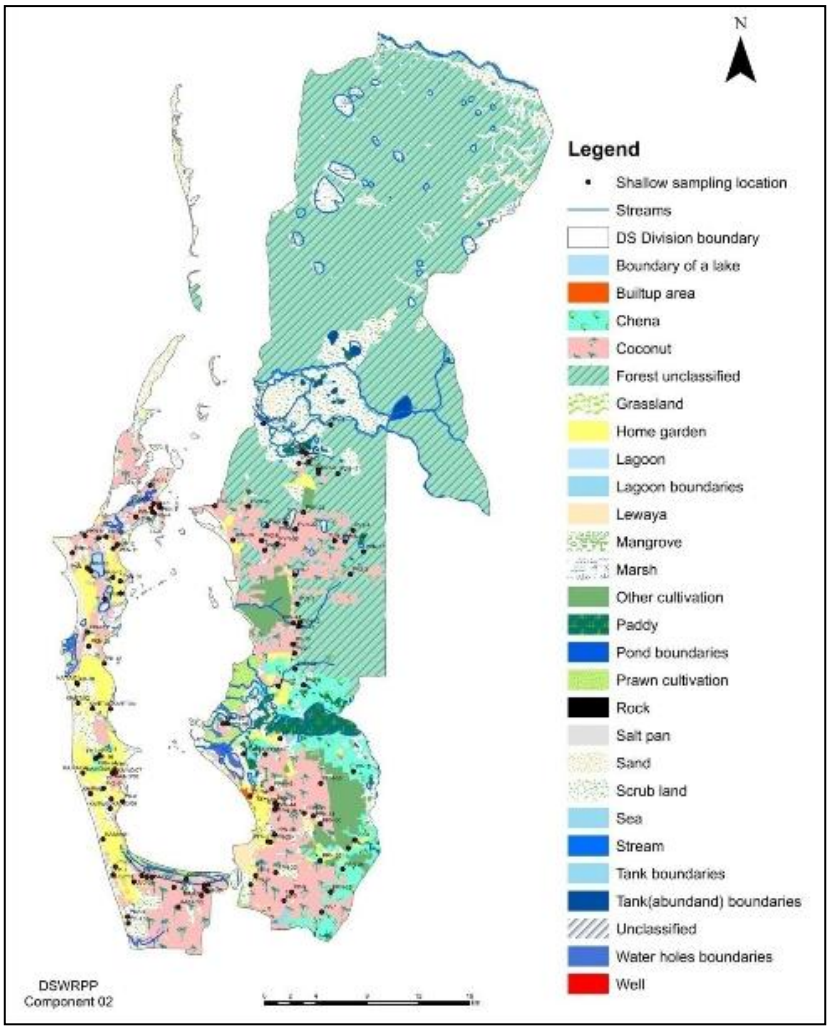

Figure 01: Landuse map of the study area

This study is dealt with Puttalam, Vanathavillu and Kalpitiya District Secretariat Divisions which were identified as most affected areas on groundwater sustainability and quality deterioration. Puttalam and Vanathavillu District Secretariat Divisions are within the Kala Oya and Mee Oya hydrological basins. The annual average rainfall of the area is 1000 – 1250 mm range and average daily temperature exceeds 28^0C (Meteorological Dept., 2011). Geologically, the coastal belt is underlain by the unconsolidated Miocene sedimentary sequence while the inland territory of the study area underlain by Precambrian western

vijayan complex (Cooray P.G., 1984). The spatiotemporal water chemistry of groundwater and flow behavior changes drastically over the different facies which originated due to structural block faulting specially within the limestone formation (Chinese report, 1982). Additionally, the landuse pattern, geology, groundwater flow regime are the major governing factors in the variation of groundwater chemistry (Chinese report, 1982). It is observed two distinguished temporal variations of water quality in groundwater during wet and dry period of the year. It is also observed depth-wise variation of groundwater chemistry in limestone aquifer while hard rock aquifer formations are not indicated such variations in the area (Wetselaar, R., Fox., J.J., Smith. G,D., Rum Ali M., Moermanto R.J. and Irdam Ahmad. 1993.).

The occurrence of groundwater in this Miocene limestone formation which is confined to the North and Northwest coastal stretch of the island is characteristically different compared to the hard rock terrains towards inland of the country. Limestone formation is the prominent source for groundwater storage due to its extensively karstic nature and the presence of innumerable joints, fissures, solution cannels and chambers in it. Most of these openings are being constantly enlarged by solution, the slightly acid water which circulates in as an underground drainage system using the fissures and joints as the chambers and caverns as reservoirs of fresh water (Cooray, P.G., 1984).

The groundwater quality of limestone aquifer in Puttalam and surrounding area is recently affected by increased salinity while some part of the Puttalam area are also affected by Nitrate & Phosphate contamination in groundwater. The high salinity in Puttalam and Vanathavillu areas are possibly due to over abstractions of groundwater resulting sea water encroachment at the coastal stretches and or upcorning effect in certain places. The groundwater contamination in Kalpitiya area is also reported attributed to improper application of pesticides and fertilizer for agricultural practices. This study is focused to assess the groundwater chemistry in the region and identify the impact levels on groundwater due to excessive application of agrochemicals & pesticides. In addition, the extent of sea water intrusion due to over abstractions is also discussed.

Methodology

Literature Review

The literature review was basically focused on the following:

- The international guidelines of BS *(British Standards)* and ASTM*(American Standards of Testing Methods)* for methods of sample collection, analysis and selection of monitoring points according to the issues identified.

- Information available on various issues related to Groundwater contamination as a result of extensive agriculture, sea water intrusion due to over abstraction and

health implications identified related to poor water quality in the studies / projects carried out at previous occasions.

- Acquisition of required Hydrological, hydrogeological, landuse, climatic, geological and previous water quality data and information of the region.

Preliminary Survey

A complete reconnaissance survey on all existing relevant data has been carried out to understand the influence on regional and sites specific groundwater flow regime of the area.

Selection of monitoring sites for chemical analysis

At the initial phase of the program, preliminary field inspections were carried out to identify the possible impacts on the groundwater due to various processes at site specific level in the study area i.e. at waste disposal sites, possible point source pollution places due to industrial effluents, heavy agricultural area as well as poor water quality zones and high abstraction locations identified by the available information. During the process, 144 nos. of samples were analyzed for EC, pH, TDS, Phosphate and Nitrate as onsite tests to identify the geochemistry of groundwater as initial assessment.

The monitoring points were established considering the various issues *(i.e. industrial pollution by effluents, high salinity resulted by over abstraction, agricultural pollution, natural inherited formation characteristics etc.)* , Identified while representing both shallow and deep aquifers. The sampling process was carried out for wet & dry period of the year considering the variation of water chemistry during these seasons. 52 water samples were collected during dry period (September-October 2011). Based on the results of chemical analysis performed for dry period, additional 50 samples were also collected during rainy season (February- March2012). The all samples were analyzed for chemical parameters (pH, EC, TH, TA, TDS, Ca, Na, K, Mg, Iron, Cl, Sulphate, F, Salinity, Nitrate and Phosphate), heavy metals (Mn, Cu, Pb, Cd) and bacteriological testing at identified vulnerable locations.

Assessment of flow regime

The groundwater head measurement was monitored at identified groundwater sources to assess the groundwater flow behavior of the area. The elevation of the monitoring point was obtained by Differential GPS with respect to the mean sea level (masl). The flow pattern was monitored on quarterly basis to identify the spatio-temporal variation while monitoring of groundwater level fluctuations too.

Hydrogeological assessment through Two Dimensional (2D) Geophysics

In addition to water quality and head monitoring surveys, the 2D imaging geophysical surveys were carried out. The aim of these surveys were to interpret the subsurface hydrogeological, geological and structural conditions in limestone aquifer including structurally weak zones, thickness of soil overburden, weathered rock and to observe possible changes in the groundwater quality with depth. This 2D imaging resistivity survey method was applied which is one of the most prominent technique in groundwater prospecting (San Antonio, October 24, 2005). The ***AGISuperSting R8/IP*** is 8-channel memory earth resistivity meter with higher accuracy and lowest noise levels. The system includes ***SuperSting R8/IP*** equipment, switching unit which is capable to handle 112 electrodes and the passive cable system of 5m spacing to connect the 112 electrodes. Therefore, one survey line is expanded to 560 m on the ground surface and the probing depth is approximately 100 -130 m below the ground level depending on the resistivity array chosen.

10 Nos. of such surveys were carried out at locations where the subsurface hydrogeology is required to interpret, thus enabling subsequent assessment of regional hydrogeology of the entire area. The surveys were carried out at 5m electrode spacing at maximum and 2m in certain places depending on the requirement of probing depth. Dipole- Dipole technique was applied in most situations considering the necessity of interpreting the subsurface depth beyond 100 m in the limestone area. The raw data were analysed in the ***EarthImager*** *2D software* to obtain the inversion images where indicates the subsurface resistivity as a 2D section with a span of 560 m maximally. The careful and accurate interpretation of these sections through the personal experience with the support of additional background information i.e. borehole data, quality data, geological and structural information plays a major role in the final assessment.

Results and Discussion

The chemical analysis, heavy metal analysis and bacteriological analysis were carried out on the samples collected at the identified locations during the field activities of this study.

The analysis result indicated high Nitrate & Phosphate contamination of groundwater as well as increased salinity levels in the shallower aquifer especially in Kalpitiya and Puttalam areas. Eththale, Alankuda, Norachchoelai, Minniya and Nirmalapura villages (more than 70% of the monitoring locations of these villages) are in Kalpitiya DSD which is mostly affected with Nitrate contamination of shallow groundwater. The Nitrate contamination pattern in groundwater of these areas (Nitrate concentration >10mg/l as N) show in the form of localized zones. However, there is a considerable threat of Nitrate contamination throughout the Kalpitiya area (Nitrate level exceeds 5mg/l in many villages of Kalpitiya area). This high elevated Nitrate level in groundwater is possibly due to the extensive

application of agrochemicals in Kalpitiya area since there are no alternative sources which might have contributed. It is observed that the Puttalam urban area is also affected with high Nitrate contamination (Nitrate concentration >10mg/l) in groundwater. The microbiological testing result indicates this might attributed due to poor sanitation.

Phosphate contamination of groundwater in deeper aquifers could also be identified at upper stretch of Vanathavillu (Eluwankulama, Rahalmadu & Serakkuliya) indicating more than 2mg/l. However it is not indicated in the shallow aquifer of the same area. This reveals that the phosphate contaminated groundwater may flow towards this deeper aquifer from a different area in the region. However, detail investigations are required to confirm this process. Phosphate distribution of shallow groundwater is also indicated high values (more than 2mg/l) in Puttalam town area.

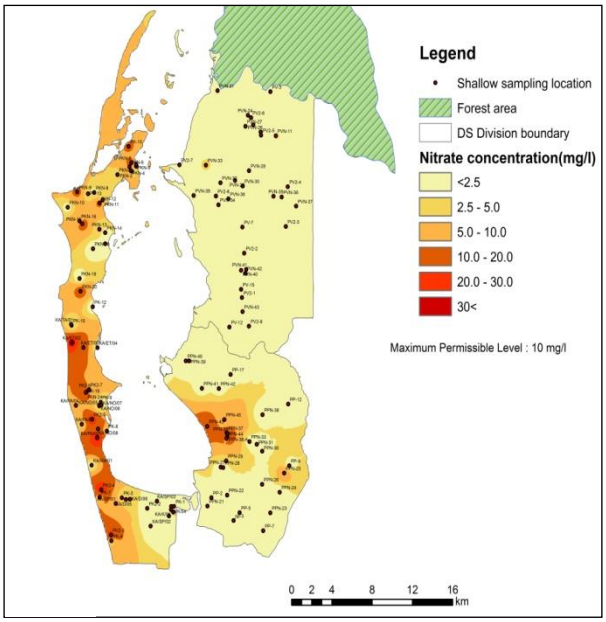

Figure 02: Nitrate distribution of the shallow aquifer in the study area

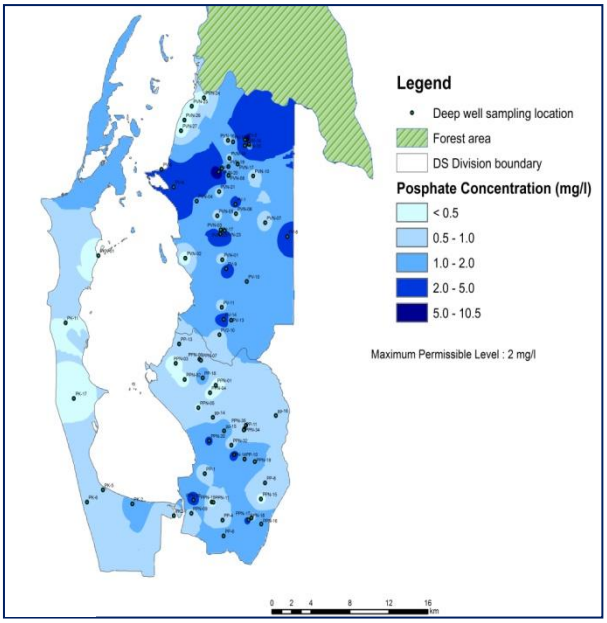

Figure 03: Phosphate distribution of the deep aquifer in the study area

Groundwater of the shallow aquifer of the surrounding area of Mee oya shows high Electrical conductivity values. However, there is no indication of increased EC & Salinity levels in groundwater of deeper aquifer. Some sampling points in the lagoonal areas as well as inland areas were observed increased EC & Salinity levels which are site specific characteristics.

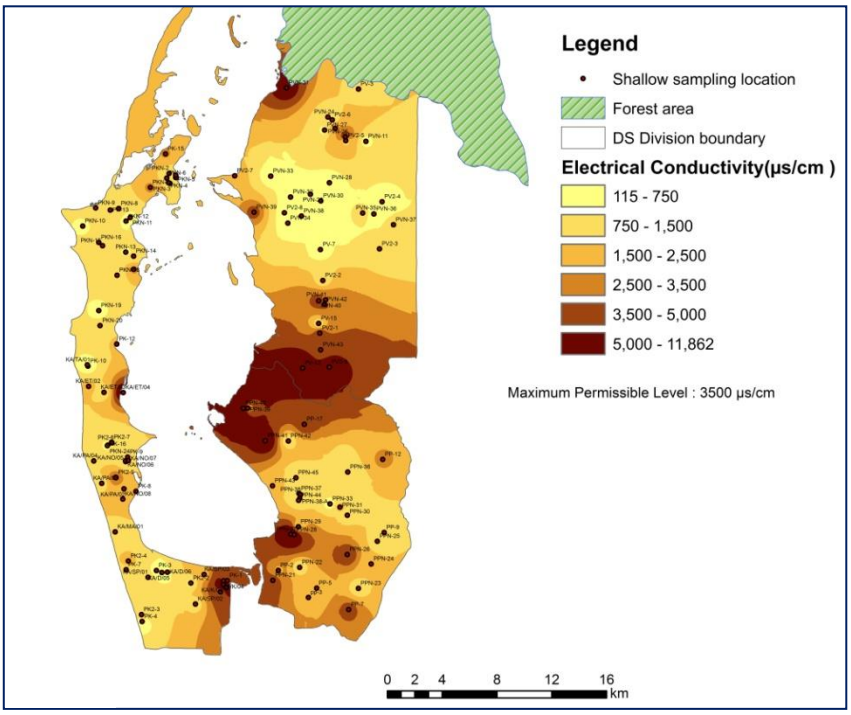

Figure 04: Electrical conductivity distribution in the shallow aquifer of the study area

In Kalpitiya area, most of the land is covered by the *crop cultivation*. The overburden of the area is completely off sand underlain by limestone basement. The thickness of these sand beds is spatially varied and densely distributed agriculture activities are observed on these sand beds. In addition, the farmers extract high amount of groundwater for their activities. In general, farmers are flooded the cultivated land two or three times per day for watering the crops and there is no efficient use of new irrigation techniques such as drip irrigation, sprinkle system. Further, the application of fertilizers and pesticides are six times higher than the recommended levels, according to the sources of Irrigation Department. Therefore, the possibility of agrochemicals infiltrating into the groundwater of these areas is at high risk level due to these specified reasons. During the dry season, the concentration of Nitrate in groundwater is increased by approximately 1 to 5 mg/l range. The shallow groundwater bearing zones in the Kalpitiya area can be existed as isolated water lenses (pockets) which are associated with sand dune structures.

Electrical Conductivity (EC) distribution in deep aquifer of the study area is observed at 400 to 2000 uS/cm range except the localized peaks where it rise up to maximum of 4000 uS/cm. These occasional increased EC values are identified in the area where controlled by the characteristics of aquifer medium. This spatiotemporal behavior of EC in the region is getting more complex due to high heterogeneity of the subsurface layers within the same facies or formations.

The Piper Tri-linear diagram is indicated that many shallow wells as well as deep wells fall into a zone of where if sea water was plotted in the diagram. The groundwater quality of deep aquifer at Puttalam, Vanathavillu and Kalpitiya shows predominantly Na-K-Cl type with some mixing towards Ca-Mg-HCO3 type during both wet and dry period in the year. The similarity of groundwater quality shows the coastal regions property which most notably the mixing with sea water.

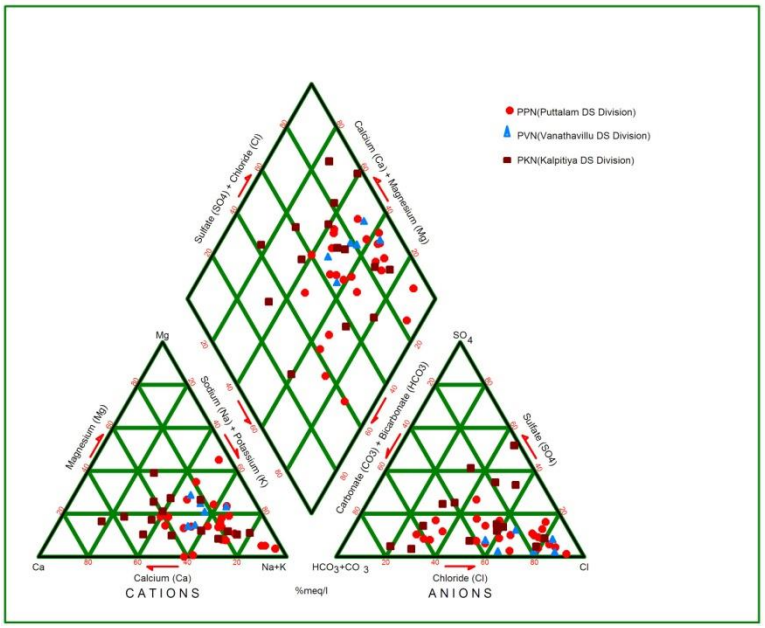

Figure 05: Piper diagram showing the water quality type in the area for both deep wells and shallow wells

There is several limestone layers could be identified with in the unconsolidated sedimentary formation of the region indicated from the available borehole data. Some of these formations are large in thicknesses while thin minor layers could also be identified from the sample logging data of the boreholes. These water bearing limestone layers have significant difference in aquifer properties and different water chemistry as well. Therefore the groundwater water quality of a source well largely depends on how far the each layer has been penetrated by the well. In this aspect, it is vital to determine the subsurface conditions through 2 Dimensional imaging Resistivity surveys which were carried out at the identified zones. The cross section shown below is at the coastal line of Vanathavillu area (~2 kms towards inland from the coastal line).

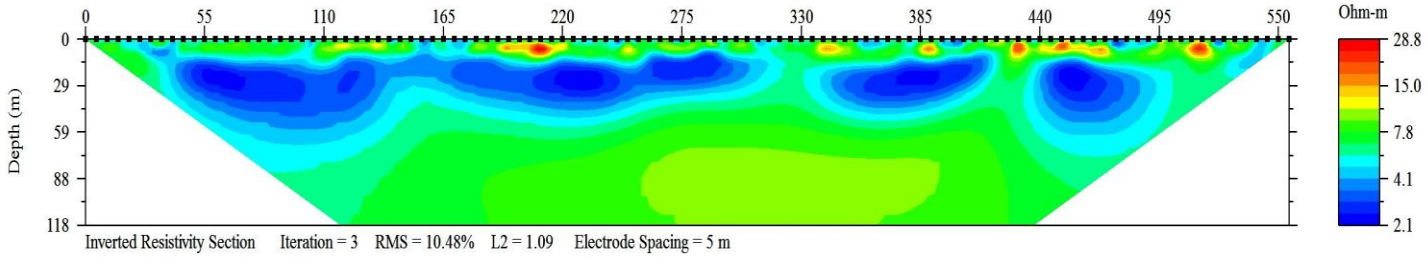

Figure 06: 2-D resistivity image carried out at Vanathavillu area

The top most part of the cross section indicates dry sand layer indicating comparatively high resistivity values. The subsurface low resistivity area (in blue color) shows clay rich layer. The bottom layer is higher in resistivity compared to the above clay layer indicating limestone layer. This layer has more complex structure and formations such as fault zone, cavities and clay filled cavity zones etc. These are confirmed with the information of drilled borehole data.

It is reported that the water demand in the Puttalam area is 70% fulfilled by groundwater extractions. The demand is ever increasing due to increase of population and heavy agricultural practices. This present setup demands the necessity of implementing a proper groundwater management mechanism otherwise the impact on groundwater would not be reversible in the future.

The graph shown below indicates the over extraction of groundwater in some of the sampling locations in Puttalam and Vanathavillu area. Tentative total groundwater volume of 7,250m^3 per day is withdrawn from these locations.

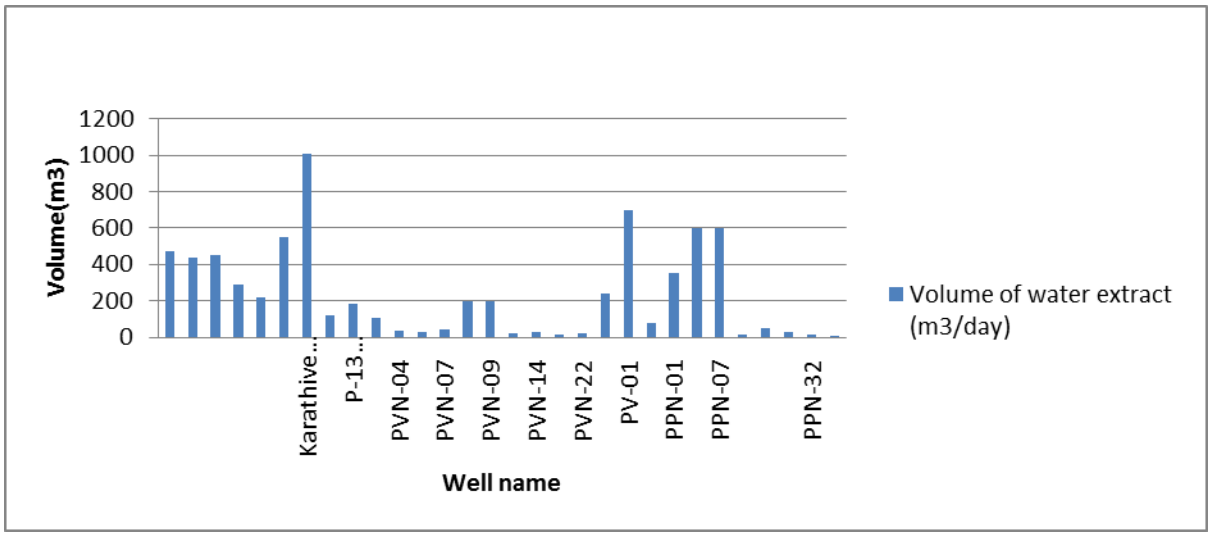

Figure 07: Groundwater extraction of some sampling points in the study area

Conclusions and Recommendations

Shallow aquifer in some areas indicates high contamination with Nitrate, Phosphate and there is a tendency to increase the salinity level. Eththale, Alankuda, Norachchoelai, Minniya, Nirmalapura are mainly affected with Nitrate contamination of shallow groundwater. The Nitrate contamination pattern in groundwater of these areas (Nitrate concentration >10mg/l) show in form of localized pockets. However, there is a gradual tendency of increasing Nitrate contamination throughout the Kalpitiya area (NO3 level exceeds 5mg/l in many villages of Kalpitiya area). In Puttalam urban area is also affected with Nitrate contamination due to improper sanitation facilities. Shallow aquifer of the surrounding area

of Mee oya shows high Electrical conductivity values. But in deep aquifer, there is no indication of increasing EC & Salinity. Some sampling points in the lagoonal areas as well as inland areas showed site specific characteristics of increased EC & Salinity levels. The phosphate contamination in deeper groundwater aquifers could also be identified in the northern part of Vanathavillu (Eluwankulama, Rahalmadu & Serakkuliya) indicating more than 2mg/l.

In Kalpitiya area, it is necessary to identify whether there is any possibility of spreading the Nitrate contamination for other surrounding well fields which are located near the affected wells. The distribution of Nitrate variation in groundwater of the affected area should also be studied with the cultivation type, fertilizer type and the seasonal variation to find out the most affected reasons for the Nitrate contamination in the area.

The geophysical applications of 1-D, 2-D resistivity imaging surveys, test well drilling, water level elevation contouring & aquifer tests result indicated that the hydrogeological flow regime of the Puttalam Limestone region is highly complex due to regional geological and structural settings (the details are not given in this paper). Therefore assessment is required in focusing on the different aquifers separately without considering as singly aquifer formation existed. Based on the results on these areas, the groundwater is mainly contaminated due to improper agricultural practices in high sensitive aquifer formations as well as due to lack of groundwater management plan.

Acknowledgments

We gratefully acknowledge the assistance and help given by all supporting staff of Water Resources Board.

References

Cooray P.G., 1984. Geology of Sri Lanka

Mats Lagmanson, Advanced Geosciences, Inc.,12700 Volente Rd., Bldg. A,Austin, Texas 78726

"THE EXPLORATION AND WELL DRILLING REPORT ON WATER RESOURCES IN CHILAW SRI LANKA": The exploration team of China Water Supply Project in Puttalam (Chilaw) Sri Lanka July 30, 1987

Wetselaar, R., Fox., J.J., Smith. G,D., Rum Ali M., Moermanto R.J. and Irdam Ahmad. 1993. Grounwater nitrate in east Java. Indonesia. Journal of Australian Geology and Geophysics, 14, 273-277.

World Health Organization (1984). Guidelines for drinking water quality Vol.1: Recommendations. Geneva. p:79