Assessment of Spatial and Temporal Behaviour of Saline Groundwater in a Coastal Aquifer: A Case Study from Pungudutivu Island, Jaffna, Sri Lanka

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ABSTRACT

Miocene limestone aquifer is the only source of water for drinking, domestic and livelihood purposes in the Jaffna peninsula and its neighbouring islands. Groundwater resources are increasingly becoming scarce in these areas due to deterioration of groundwater quality. Severe water scarcity due to salinisation of groundwater is the major problem in the study area, in Jaffna and imposes limitations on lives and livelihoods of the people. Current freshwater supplied via water bowsers are unable to fulfil the water requirements but have imposed water pricing on the local economy.

The present study is focused on demarcating fresh and saline groundwater bodies in the island and their spatial and temporal behaviour. 1600 wells were brought under initial monitoring to study the nature of water, whereas 36 representative sample localities amongst them were brought under monthly monitoring for Well-head and chemical parameters such as groundwater table depth, Electrical Conductivity (EC), Temperature, Total Dissolved Solids (TDS), Salinity, pH, HCO_3^- and Cl^- ions for a period of one year.

The study reveals that fresh groundwater resources are extremely scarce in the Pungudutivu Island where a majority of the wells (95%) are subjected to high salinity in the long dry season. Freshwater with an EC <1000 μS/cm are not found in the dry season and do not show a significant improvement in water quality even *with the annual rains showing that only 14% of wells fall below EC < 1000 μS/cm in the wet season.*

The flat and low elevated landscape with low elevated groundwater table and highly porous geological formations facilitate salinization of groundwater allowing mixing of sea water. Salinisation does not show any marked patterns either with local geology or land use. Detailed investigations are required to justify the sources and recommend appropriate remedial measures for sustainable livelihood development in the island.

INTRODUCTION

Water resources contribute towards a major share of water-induced human welfare and amongst such groundwater is vital to many nations, irrespective of their stage of economic development (Shah *et al.*, 2003). Regions that have sustainable groundwater balance throughout the world are shrinking day by day due to major effects of global warming and improper management of the resource (Gallucci, 2016). Deterioration of groundwater quality is a prime reason for water scarcity in many parts of the world, including Sri Lanka. Salinization of groundwater imposed due to various natural and anthropogenic processes are feared to impair the capacity of these regions in feeding their growing population (Molle *et al.*, 2003). In Sri Lanka, policies on dry zone rural agricultural development and urban water supply schemes based on groundwater promoted groundwater exploration and investigations since 1965 (Panabokke, 2007). Main focus was towards the north as serious problems related to groundwater salinization were first predicted in the limestone and sandy aquifers of the north, especially in the Jaffna Peninsula (Gunesekaram, 1983) as the Peninsula desperately relies on groundwater stored in the Miocene limestone formations and lagoonal and estuarine deposits to meet all its needs in the absence of surface water bodies (Arumugam, 1970). These investigations however, were abandoned since early 1980's due to political instability, leaving the resource towards a deteriorated condition in the absence of continuous monitoring and research, ignoring its role on livelihood and socio-economic development of the future.

In such context, availability and adequacy of freshwater for drinking, domestic, agricultural and other livelihood usages in the Jaffna Peninsula and the neighbouring islands were one of the serious concerns highlighted repeatedly as this groundwater is saline in many parts of the Peninsula, especially in the neighbouring islands due to complex hydrometeoric, hydrogeologic and hydrogeochemical conditions prevailing in these areas. In addition, high evaporation rates, sea salt sprays, saline water mixing due to natural and anthropogenic sources such as seawater intrusion and excessive extraction of groundwater respectively also contribute to the groundwater salinity in these areas (Nandakumar, 1983; Hidayathulla and Karunaratna, 2013). Contaminations from intense agricultural activities and unplanned urbanization too have posed serious threats to salinization of fresh groundwater in the Peninsula (Rajasooriyar *et al.*, 2002).

Livelihood potentials are very limited in Pungudutivu due to severe scarcity for freshwater which impose limitations on self-sufficient living, sustaining inhabitants, promoting resettlement at a post-war context and developing small scale economic activities (Divisional Secretary Office 2011). Measures taken for freshwater supplies via water tank vehicles are unable to fulfil the water requirements in Pungudutivu but have imposed water pricing on the local economy (Pungudutivu.org , 2008). Alternative measures have been proposed to bring water from regions within and outside the Jaffna Peninsula; however, such plans need scientific validation of the water scarcity in Pungudutivu in order to estimate the resource availability and to justify the need for water supply for the island by state organizations involved in water supply schemes to sustain livelihood in the island. Such scientific validation however, can help similar regions in the Peninsula with similar geologic environments, towards decision making on water resource management.

The present study was aimed on demarcating the spatial patterns of fresh and saline water bodies, their temporal behaviour and the reasons for same in the absence of scientific information to help with data for in-depth studies and policy and planning on water supplies for the islands of the Jaffna Peninsula.

Study area

Pungudutivu Island lies at a distance of 35 km from the southern end of the Jaffna Peninsula and located south-west and connected to the Peninsula by a causeway. It is a flat landscape with an area of 29 km^2 and the land surface elevation reaches up to 3.0 m above mean sea level (MSL) with an average elevation of 2.0 m MSL. The area is underlain by highly porous fossiliferrous limestone and the rocks occur close to the surface and outcrops in many areas. Three major soil types, namely beach sand, yellow-brown sand, and lagoonal and estuarine deposits, are found in the island (Cooray, 1984).

The Island experiences the typical dry zone climate of Sri Lanka, characterized by a wet and a long dry season. The average temperature is high reaching up to 35 °C. Rainfall received in the island is associated with inter-monsoon and the Northeast monsoon with an average annual rainfall of 1500 mm. Rainfall is the only source for groundwater recharge in Pungudutivu.

Pungudutivu is with a small number o population due to the unsettled conditions prevailed during the last three decades as well as severe water scarcity. The size of population in the island has reduced dramatically from 15,121 residents in 1991 to 4,100 in 2014 (Divisional Secretary Office, 2011).

METHODOLOGY

Selection and monitoring of sample wells

All accessible dug wells (approximately 1600) in Pungudutive were brought under the first stage of monitoring (using an opinion survey) in the absence of any scientific data or information, and 85 sample localities amongst them were selected for the second stage of monitoring considering various geologic, land elevation and land use patterns and the proximity of the locations to seas or lagoons with the help of GIS and RS. The 85 sample localities were selected from a 0.25 km^2 sampling grid and groundwater levels and Electrical Conductivity (EC) were monitored on three consecutive periods; dry (September, 2014), rainy (January, 2015) and end of the rainy period (February, 2015).

Based on the spatial patterns of EC and the groundwater table conditions, 36 wells covering both fresh and saline groundwater were selected for monthly monitoring. Depth to groundwater table (Dip meter), Electrical Conductivity, Temperature, Total Dissolved Solids, Salinity (HQ40d series model meter), pH (Sension$^+$, LPV series model meter), HCO_3^- and Cl^- ions were monitored covering a period of one year from April, 2015 to March, 2016. Monitoring and sample collection were done on dug wells that were under daily use and expected to reduce water stagnation, however, measurements were taken when the water table was static. Procedures of American Public Health Association, (APHA) were adopted for the determination of HCO_3^- and Cl^- ions.

RESULTS AND DISCUSSION

Fresh groundwater resources are extremely scarce in the Pungudutivu island where a majority of the wells (95%; 1520 nos.) are subjected to high salinity (Figure 1). Fresh and saline groundwater occurs at shallow depths where the depth to water table varies from 0.42 m to 3.54 m below the ground surface in the dry season and 0.02 m to 2.28 m in the wet season. All dug wells in Pungudutivu are exposed to the atmosphere and to high evaporation losses. Water table demonstrates a quick response with rains and reaches its peak with the rainfall received from September to December on this highly porous limestone of the island.

A limited number of wells of the Pungudutivu are with EC values below <1,500 μS/cm and remains isolated in nature. Saline groundwater occurs in very close proximity to the fresh groundwater wells which are found in a few locations in the Southern, Southeastern and central parts of the island. These sites are the only available sources for drinking in the study area (Figures 1 and Figure 2).

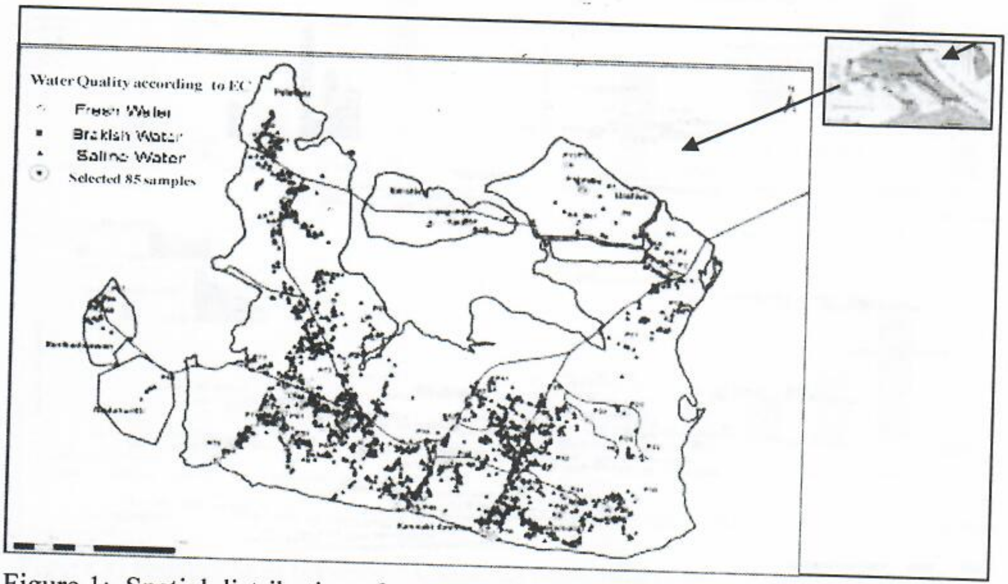

Figure 1: Spatial distribution of groundwater quality in the Pungudutivu area

Only a few groundwater wells fall under the standard freshwater limits, and wells with EC <1000 μS/cm are not found in the dry season. Freshwater falling under the above EC levels occurs in small amounts in the wet season following the annual rains. Dilution from rainfall do not show vast improvement in water quality whereas only 14% of wells fall below EC <1000 μS/cm in the wet season. In general, the EC values vary from 1,293 μS/cm to >35,000 μS/cm in the dry season with a median of 6,540 μS/cm, and 374 μS/cm to 28,200 μS/cm in the wet season with a median of 2,765 μS/cm. Though the median EC levels show a major decline in the wet season, they however fall above 2,500 μS/cm limits defined by the EU and WHO (Figure 2.0) and requires further investigations as suggested by the EU and WHO (EU, 2014). Majority of the well waters do not even fall under the Sri Lankan drinking water quality guidelines of EC 3,500 μS/cm where the percentage of wells below the said levels is 20% in the dry season and 64% in the wet season. Even though a short term improvement in water quality or the reduction in EC occurs along with rainwater dilution, it does not imply any effect on reducing salinity in majority of the wells.

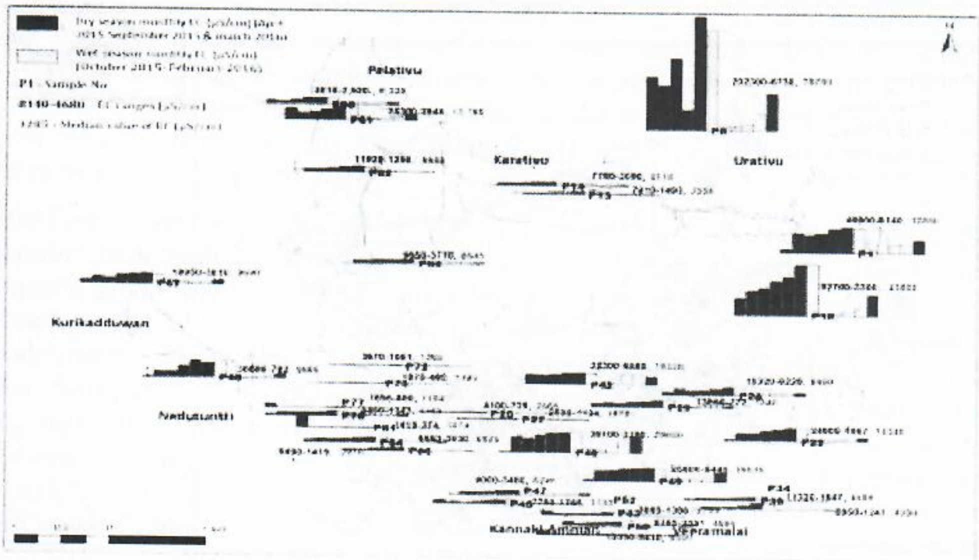

Figure 2: Spatial Patterns of EC - April, 2015- March, 2016

High EC values (3,500 µS/cm - >60,000 µS/cm) are found in many parts in Pungudutivu, and groundwater with very high EC levels (>35,000 µS/cm) are found on the North-eastern part (Figure 2). Though there are marked patterns on fresh or saline water distribution or in the levels of salinity in Pungudutivu, either the fresh or saline groundwater bodies do not show any marked relationship with the local geology, land use, water table elevations or the location nearer to the sea or lagoons and suggest that the said have limited impact on the occurrence of fresh or saline groundwater (Figure 3).

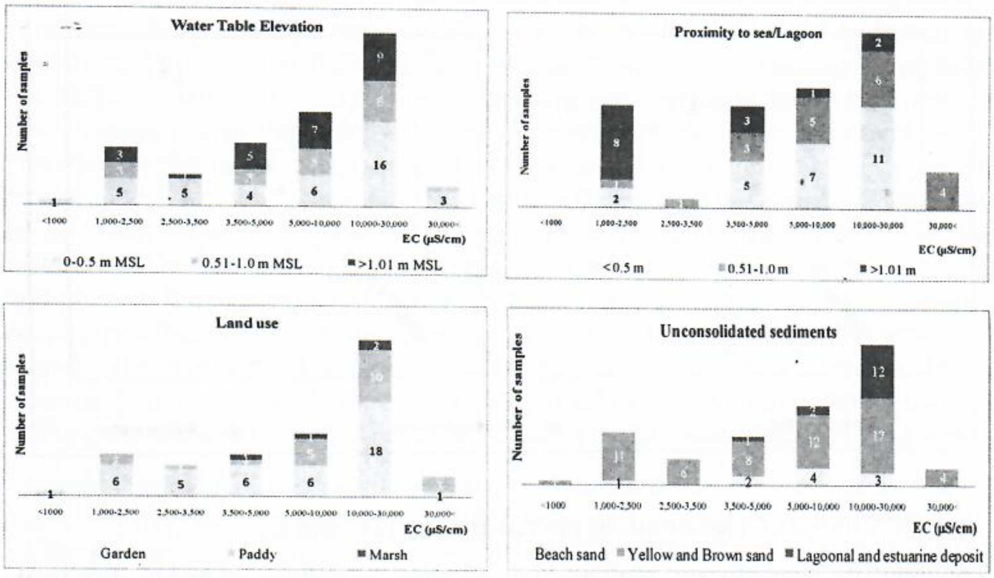

Figure 3: Relationship between EC against proximity to sea/Lagoon, Land use, Geology and Water Table Elevation

TDS in groundwater show similar patterns to that of EC and reach very high TDS values up to >20,000 mg/L. TDS in the dry season range from 288 mg/L - >20,000 mg/L with a median of 3,480 mg/L indicating the nature of highly mineralized waters whereas in the wet season TDS range from 180 mg/L - > 20,000 mg/L with a median of 1,413 mg/L. TDS in a majority of the wells (98%) exceed the Sri Lankan Permissible limits of 500 mg/L in the dry season whereas in the wet season the percentage decreases to 90.

Chloride (Cl^-) concentrations too imply high concentrations and vary between 76 mg/L and 38,000 mg/L in the dry season with a median of 2,081 mg/L and 46 mg/L and 9,700 mg/L in the wet season with a median of 834 mg/L in the study area. Chloride concentrations in the dry season indicate very high Cl^- concentrations far beyond the standard seawater Cl^- concentrations of 19,000 mg/L. Pungudutivu groundwater samples plotted against TDS and EC portrays positive correlation with the TDS (R=0.999) and EC (R=0.998) (Figure 4). All groundwater samples fall on the 1:1 ratio line on Cl-TDS and Cl-EC plots and suggest chloride as a primary source that contributes to the increase in TDS and EC in groundwaters of Pungudutivu, which is probably the mixing of saline waters. High Cl^- concentrations beyond the seawater Cl^- indicate possible other sources for the contribution of Cl^- in Pungudutivu, probably high evaporation effects on groundwaters.

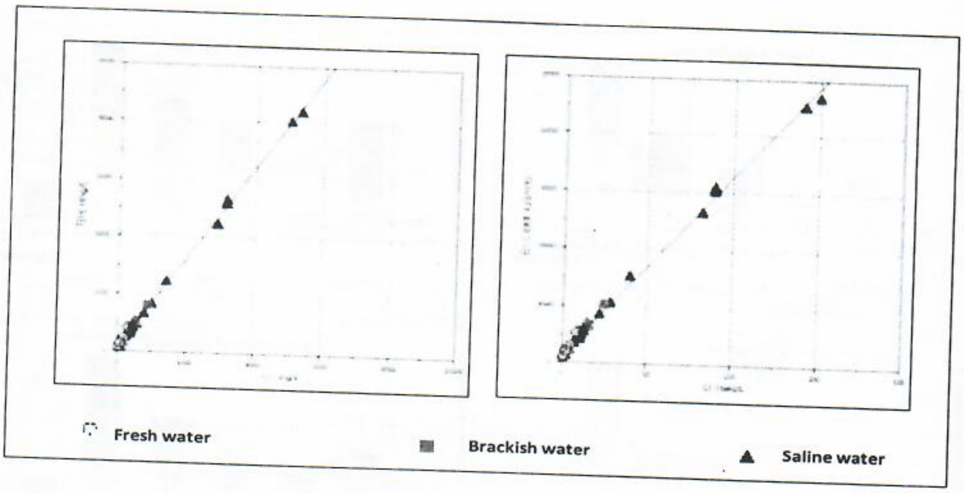

Figure 4: Chloride Concentrations plotted against TDS and EC

Puungudutivu groundwater implies high alkaline conditions probably due to the nature of the underlying limestone and calcarious sands. HCO_3^- concentrations of groundwater in the study area vary from 13 mg/L to 800 mg/L in the dry season and 19 mg/L to 830 mg/L in the wet season and high HCO_3^- is found only in the fresh groundwater bodies indicating formation of HCO_3^- is primarily from the weathering processes induced by carbonic acid (H_2CO_3) as seen in most of the shallow groundwater environments globally (Katz *et al*., 1997). pH of the well waters in the study area too show more alkaline conditions in both seasons and the pH values vary from 6.31 to 9.04 in dry season with a median of 8.07 and 6.73 to 9.34 in the wet season with a median of 7.9. The pH of a solution that in contact with calcium carbonate and open to the atmosphere can be expected to be about 8.3, however, groundwater in carbonate aquifers can exemplify pH values less than 8.3 due to dissolution of carbonate minerals or limestone that releases higher levels of carbon dioxide compared to the atmospheric levels of CO_2 and resulting pCO_2 (Joshua *et al*., 2013) as seen in the groundwater of Pungudutivu where the median pCO_2 is -2.62, much higher than the atmospheric pCO_2 levels.

Fresh groundwater occurrence in Pungudutivu exemplifies rather unusual patterns because coastal aquifers underlain by limestone have proved to be excellent aquifers in holding large amounts of freshwater in many parts of the world (Katz *et al*., 1997) including the sedimentary belt of north-western and northern Sri Lanka (Hidayathulla and Karunaratna, 2013) though their water hardness is high and pose serious threats for salinization of groundwater close to the coast due to natural discharge, tidal variations or excessive extraction of groundwater. Coastal aquifers with sedimentary formations hold large amounts of fresh waters as described by the principle developed by Gyben and Herzburg however, such occurrence of groundwater cannot be seen in Pungudutivu as fresh groundwater bodies occur as small isolated fresh water bodies along with larger extents of saline water bodies. Occurrence of freshwater bodies strongly suggest that they might be of small fresh water pockets occur on a dense, more saline conditions or occurs on perched conditions. Such situation demonstrates that the physiographic and hydrogeologic conditions do not favour the occurrence of a thick freshwater lens above and below the MSL as explained by Gyben and Herzburg and the major factor that probably poses limitations in Pungudutivu is the flat terrain as the average ground surface elevation in the island is 2.0 m MSL with a groundwater table elevation ranging from 0 m to 1.85 with median 0.55 m (Figure 3.0). The flat landscape and horizontal groundwater level in the study area seems to make the lateral groundwater flow insignificant and do not imply any hydraulic connection within neighbouring areas and promote the occurrence of freshwater bodies as isolated formations by imposing remote possibilities on the development of a thick fresh groundwater lens in the island. The above said might probably be the major reason for the limited occurrence of freshwater bodies and mixing of saline waters in majority of the wells in Pungudutivu as well as for the saline nature of surface water bodies in the area.

Though it is evident that the occurrence of freshwater is very limited to meet the basic and livelihood requirements of the inhabitants of Pungudutivu, identification of the primary conditions however needs further justification via detailed chemical and geophysical investigations. Moreover, there is an urgent need to practice rainwater harvesting using roof catchments and improved ground catchments to re-initiate sustainable water management and ecological stability at a post-war context. Further, there is a vital need to explore the possibilities for sufficient fresh water supplies to the island to meet with the immediate water requirements.

CONCLUSIONS

Fresh groundwater resources are extremely scarce in the Pungudutivu island and found only in a few locations in the Southern and South western of the island as perched conditions or pockets floating on dense saline waters. More than 95% of the wells are subjected to low or high grades of salinity and very high saline waters occur in the North-eastern parts of the island. Improvement in water quality by seasonal/monsoonal rains is insignificant and only 14% of wells contain good quality water in terms of EC (<1000 µS/cm) with dilution of rain water. TDS levels of drinking water quality of 500 mg/L have exceeded in 98% of the wells.

Groundwater wells with high EC match with high TDS and Cl^- levels and increase in TDS and EC in groundwaters with Cl^- indicate that a source rich in Cl^- is the prime source for salinity, which is probably the mixing of saline waters. High Cl^- concentrations beyond the seawater Cl^- indicate possible other sources for the contribution of Cl^- in Pungudutivu, probably the impact of high evaporation on groundwater.

High HCO_3^- and a median pH of 8.3 in Pungudutivu groundwater with high pCO_2 indicates that H_2CO_3 is the prime source of the dissolution of carbonate rocks. This however, increases the alkalinity of the freshwater bodies in the island.

The flat landscape and horizontal groundwater level in the study area make the lateral groundwater flow insignificant in Pungudutivu. Highly porous geological formations and low elevation of the water table favour mixing of infiltrated rainwater with saline waters at shallow depths (as well as in surface water bodies) without forming a fresh groundwater lens of significant thickness.

Detailed investigations are required to characterize the fresh groundwater resources in the study area with practises of rainwater harvesting using roof catchments and improved ground catchments to re-initiate sustainable water management and ecological stability at a post-war context. A vital need to explore the possibilities for sufficient fresh water supplies to the island too is a prime requirement.

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REFERENCES

Arumugam, S. (1970). Development of ground water and its exploitation in the Jaffna Peninsula, Transactions of the Institute of Engineers, Ceylon, 1: 31-62.

Cooray, P.G. (1984). An introduction to the geology of Sri Lanka (Ceylon). 2nd rev. ed. Colombo: National Museums of Sri Lanka. xix, 340.

EU (2014). European and National Drinking Water quality. Department of Regional Development. Northern Ireland Environment Agency.

Gunesekaram, T. (1983). Ground water contamination and case studies in Jaffna Peninsula, Sri Lanka. Jaffna: Global Engineering Technology Services.

Hidayathulla, M.S.M. and Karunaratna, G.R.R. (2013). Assessment of groundwater quality in shallow aquifers in Jaffna Peninsula. Proceedings to 29th Technical sessions of Geological Society of Sri Lanka, Colombo, pp.109-113.

Joshua,W.D., Thushyanthy, M. and Nanthagoban, N. (2013). Seasonal variation of water table and groundwater quality of the Karst aquifer of the Jaffna Peninsula-Sri Lanka. *Journal of the National Science Foundation Sri Lanka*, 41 (1): 3-12.

Katz, B.G., Coplen, T.B., Bullen, T.D. and Davis, J. Hal. (1997). Use of chemical and isotopic tracers to characterize the interactions between ground water and surface water in mantled Karst, *Ground Water*, 35 (6): 1014–28.

Gallucci, Maria. (2016). Global warming and water scarcity could cause economies to shrink by mid-century: World Bank report, International Business Times: April 05.

Molle, F., Shah, T. and Barker, R. (2003). The groundswell of pumps: multilevel impacts of a silent revolution.. (Paper prepared for the ICID-Asia Meeting, Taiwan), 18p

Nandakumar, V. (1983). Natural environment and ground water in the Jaffna Peninsula, Sri Lanka, *Climatological Notes*, 33: 155-164.

Panabokke, C.R. (2007). Groundwater conditions in Sri Lanka: a geomorphic perspective. Colombo: National Science Foundation of Sri Lanka.

Divisional Secretary Office. (2011). Profile Velanai - 2011. Velani: Divisional Secretary Office.

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

Shah, T., Roy, A.D., Qureshi, A.S. and Wang, J. (2003). Sustaining Asia's groundwater boom: an overview of issues and evidence. *Natural Resources Forum*, 27: 130-40.

Pungudutivu.org. (2008). Water tank donation. Available from: <http://www.pungudutivu.org water-tank-donation>. [Accessed on 03/11/2013].