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Groundwater Responses to Artificial Recharge of Rainwater in Kilinochchi District in Sri Lanka

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Abstract – *Groundwater is one of Sri Lanka's most precious natural resources. A large number of people depend on it for their sustenance with no expense to the State. When compared with surface water, groundwater is a hidden resource, which is more reliable and also less subject to the type of year-round variation as in the case with surface streams and rivers. However in Kilinochchi area the groundwater quality has deteriorated over the years due to various reasons. Further the water level in the well decreases and dries up during dry season. Since over 80% of the population depends on groundwater for domestic and irrigation purposes. This important to increase the water levels in the well and improve the quality. Rainwater harvesting is an age old technology to harvest rainwater from roof and store for domestic and other purposes. In this study rainwater harvested from the roof is diverted to the well to increase the well water level using two methods called direct method and overflow method. In direct method the harvested rainwater from the roof is diverted to the nearby well for artificial recharging. In overflow method the rainwater harvested from the roof is stored in tank and the overflow from the tank is diverted to the well. In total 11 wells were selected and artificial recharging was done either by direct or overflow method. Water levels were monitored in the wells as well as rainwater harvesting tanks. Further water quality parameters such as pH, EC and Total Dissolved Salts were measured in both well water and rainwater. According to the study results groundwater recharge is higher in wells in Madduvil Nadu GTMS, Periyakulam IyanarVidyalayam and Punnaineeravi GTMS because these wells were artificially recharged by direct method. Therefore direct method of artificial recharging using rainwater is effective in drought prone areas. Average recharge varies from 196mm to 301mm per year. Groundwater quality analysis showed that pH, EC and TDS were within the safe limit of 6.5-8.5, 1500 µS/cm and 500mg/L in Madduvil Nadu GTMS, Periyakulam IyanarVidyalayam and Punnaineeravi GTMS wells respectively. Other wells were not suitable for drinking purposes due to higher EC and TDS values. Rainwater harvesting tank water quality in all 11 well sites were within the safe limit. Therefore artificial recharging using rainwater does not pose any threat for well water quality. Therefore communities in this study site are advised use rainwater harvesting to increase the water levels in the wells and also to improve the well water quality.*

***Key words**: Groundwater, rainwater, quality, recharge*

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1 INTRODUCTION

Water is an essential and most important resource to sustain life humans. It forms 50 to 60% of body weight and plays an active role in all the vital processes of our body. Approximately 25% of the world's population has no access to clean and safe drinking water (Amarasinghe,*et al.*, 1999). Even though freshwater is available in most parts of the world, many of these water sources contaminated by natural means or through human activity. With the population boom and industry expansion, the demand for potable water is ever increasing, and freshwater supplies are being contaminated and scarce (Amarasinghe,*et al*., 1999). A satisfactory supply must be available to all humans and other lives on earth. Improving access to safe drinking-water can result in tangible benefits to health. Water plays a vital role in the development of communities since a reliable supply of water is an essential prerequisite for the establishment of a permanent community.

Unfortunately, the liquid, gas and solid wastes from such a community have a considerable potential for water pollution. Water shortage and water pollution cause four million deaths per year around the world; this means one person dies every eight seconds. The majority of the victims are infants under five years of age from Africa and the developing countries of Asia (Asian Development Bank, 2011).

Almost 80% of the rural populations in Sri Lanka rely on groundwater for their domestic needs because of its excellent natural quality and sustained availability throughout the year (Panapokke and Perera, 2005). Main towns in the dry zone of Sri Lanka such as Jaffna, Mullaitivu, Kilinochchi, Polonnaruwa, Anuradhapura, Batticaloa, Mannar, Puttalam, Vavuniya depend almost 90 % on the groundwater supply (Panabokke and Perera, 2005).The composition of groundwater naturally reflects the underlying geology, the residence time in the rock, the previous composition of the groundwater and in some instances, the flow path. Due to the slower movement of groundwater as compared to that of surface water, the composition of the groundwater shows a negligible variation with time for a given aquifer (Lerner et al 1990).

During monsoon/post-monsoon (*Maha* season) groundwater levels near to the ground surface as the recharge to the aquifer takes place during *Maha* season. During dry season (*Yala* season) groundwater level goes down due to abstraction, evapotranspiration and other losses such as seepage and percolation (De Silva and Rushton, 2007). Further it is aggravated when discharge rates are greater than there recharge rates. Seasonal fluctuation of groundwater is significantly correlated with precipitation, as is found that recharge into the groundwater system is considered entirely to be from rainfall infiltration and percolation (De Silva and Rushton, 2007).

Water quality refers to the physico-chemical and biological quality parameters of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or domestic purposes. Water quality is important because it directly affects the health of the people, animals and plants that drink or utilize the water for their survival. When water quality is compromised, its usage puts users at risk of developing health complications. Water quality standards are put in a place to ensure the efficient use of water for the designated purpose. Water quality analysis is to measure the required parameters of water following standard methods, to check whether they are in accordance with the standards. The qualities of groundwater resources vary naturally and widely depending on climate, season, and geology of bedrock as well as anthropogenic activities (De Silva and Rushton, 2007). In addition to the natural sources of constituents acquired by water during its interaction with atmosphere and rocks, various human activities such as industrial, sewage and domestic waste disposal, fertilizers, pesticides etc. also contribute to change the natural chemical constituents of water. Therefore, a regular check of its chemical quality is required for assessing its suitability for different purposes and for quantitatively for monitoring any future change. Over pumping of aquifers, discharge of toxic chemicals and contamination of water bodies with substance that promote algae growth are major cause for water quality degradation and also the pollution of the groundwater happens mostly due to percolation of pluvial water and the infiltration of contaminants through the soil under waste disposal sites(Humbarde, *et al*., 2014).

The environmental impact of human activity on the groundwater is considered as one of the major hazards. Rapid Urbanization and increased agricultural activities have resulted in the degradation of the quality of water. Unused fertilizers, pesticides, effluents discharged from industries and sewage water are the main contaminants of the groundwater. The chemical budget of major ions and heavy metals are important in determining the quality of groundwater. Total Dissolved Solids (TDS) values are considered important in determining the usage of water and groundwater with high TDS values are not suitable for both irrigation and drinking purposes (Rajasooriya, 2002).

1.1 Justification for the study

Wells in the schools, hospitals and primary health care units of the study area in Kilinochchi were holding less amount of little water during the dry season and some wells get completely dried during dry season. Further, the quality of the groundwater was not good because of the high concentration ofions in groundwater during dry season. The well water columns also showing quality variation due to the density effects, during the wet season the water quality parameters were nearly same at bottom and the surface of the well water but during the dry season, those parameters show significant variation between the bottom and surface of the well water. Bottom quality values were higher than the surface values mainly during dry season when wells hold little water (Saravanan,*et al*., 2014). Adding more water to the well water may improve the water quality. Rainwater is free water received which could be used effectively to artificially add water to these groundwater wells to improve the quantity as well as quality. Due to these reasons the wells in the study area especially schools, hospitals and primary health care units were in need for rainwater harvesting and means to artificially recharge the wells so that they could get more groundwater and better quality water during dry season. This research project was designed to study the groundwater responses to artificial recharge of rainwater in the study area for sustainable groundwater quantity and quality.

2 BACKGROUND OF THE STUDY AREA

The Killinochchi area is situated in the dry zones of Northern Sri Lanka on 9.3803° N, 80.3770° Ecoordinates. The total land area is approximately 1205 Km^2. The poverty level in this area is as high as 64 %, which is more than double for the national average (Asian Development Bank, 2011). The Killinochchi area, being at the center of the 26 years long devastating civil war (1983–2009), has seen major destruction of its irrigation facilities and water reservoirs. Hence, the poverty in the area can be mainly attributed to the war that resulted in the destruction of most of the infrastructure in the district. As the war displaced residents return to their villages, competition for the already scarce water resource is expected to grow sharply. According to the national census data, the population has quadrupled from 23,625 in 2009 to 112,875 in 2012.

2.1 Climate

There are two distinct seasons in the study area call *Maha* (wet) and *Yala*(dry) season. *Maha* is from October to February and receives rainfall from second inter-monsoon and north east monsoon to the northern and eastern regions of Sri Lanka. The average annual rainfall in dry zone is 1,800 mm per year. Most of the rainfall occurs during the *Maha* season, and January is the coolest month. The *Yala* (dry) season varies from May to September receives very less or no rain and May is the hottest month. Although rainfall amount is quite enough for this small area, because of temporal asymmetry and poor water resource management policies, there is water scarcity especially during the dry period (Mikunthan and De Silva, 2009).

2.2. Geology

Geology also plays major role in groundwater occurrence in the study area. PanKaj Kumar *et al* (2016) have conducted a detailed study on mapping of groundwater potential zones in Killinochchi area which is used for this study as the basis and their findings are directly used for this study. According to PanKaj Kumar *et al* (2016), the study area is occupied by five major features (Figure 1) as follows:

• Alluvial and lagoonal clay, silt, and sand
Alluvial is the depositional structure formed by running water from all different basins in Killinochchi area. Lagoons are bodies of water on the landward side of barrier islands near the coastal region. Both of these places contain finer sediments with grain size varying from clay to sand and poor sorting order. Area is consideredmoderately well for groundwater exploration.

• Chamockitic biotic gneiss:
Charnockite represents a conformable intrusive igneous rock which with biotite gneiss was subjected to high-grade metamorphism. Charnockite and surrounding gneiss have layer structure composed of melanocratic and leucocratic parts. Mineralogically, melanocratic parts consist of hornblende and biotite in gneiss, and ortho pyroxene addedincharnockite. Leucocratic parts are composed of biotite and colorless minerals in gneiss, while biotite is absent in charnockite.

• Jaffna limestone:
Jaffna limestone is typically a compact, hard, partly crystalline rock formed in the early Miocene age. The limestone 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. The limestone is an important aquifer, and, together with thin sand layers, forms an extensive cover providing a source of drinking water and irrigation across the area.

• Red earth, red, and brown sand:
They are the sand stone with the mineral composition of quartz and/or feldspar. In the study area, it is of red and brown colored. These rock formations usually allow easy percolation of water and other fluids and are porous enough to store large quantities, making them valuable aquifer.

• Undifferentiated Vijayan gneiss with trend lines:
They are mainly granitic rocks composed of garnet and feldspar with very low porosity. They are considered as poor aquifers zones.

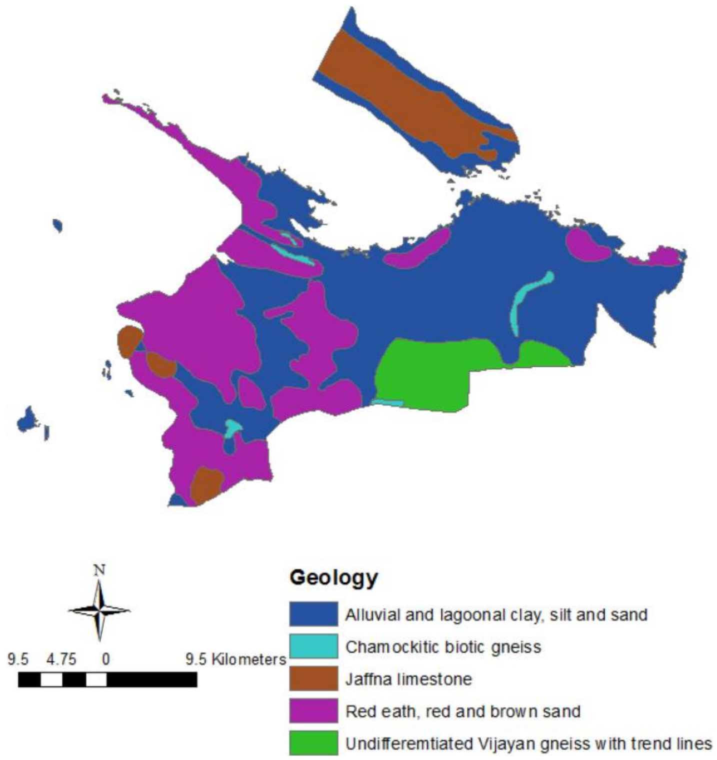

Fig. 1. Geology of the Kilinochchi area (Source Kumar, *et al.*, 2016)

2.3. Soil type

Soil is an important factor for delineating the groundwater potential zones. The climate, physiography and geology characterize soil and play an important role in groundwater recharge and runoff. The water holding capacity of the area depends upon the soil types and their permeability. According to the analysis of the soil type by PankajKumar *et al.* (2016) the study area is predominantly covered by four main soil types, namely, soil classes Immature brown loams (dry zone); reddish brown earths; regosolic alluvial soil; and solodised solonetz and solonchaks (Figure 2). According to their influence on groundwater occurrence, regosolic alluvial soil is considered as very good, whereas reddish brown earths are being considered as moderately better than other soil types.

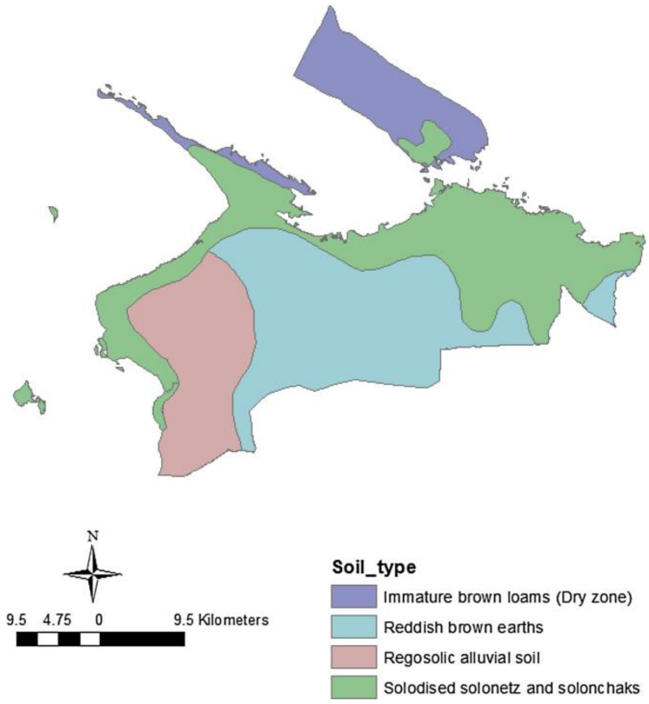

Fig. 2.Soil type of the Kilinochchi area (Source: PankajKumar,*et al.*, 2016).

2.4. Groundwater potential zones

According to Pankaj Kumar *et al.* (2016) soil is an important factor for delineating the groundwater potential zones. The climate, physiography, and geology characterize soil and play an important role in groundwater recharge and runoff. The water holding capacity of the area depends upon the soil types and their permeability. The analysis of the soil type reveals that the study area is predominantly covered by four main soil types, namely, soil classes Immature brown loams (dry zone); reddish brown earths; regosolic alluvial soil; and solodised solonetz and solonchaks (Figure 3). According to their influence on groundwater occurrence, regosolic alluvial soil is considered as very good, whereas reddish brown earths are being considered as moderately better than other soil types (Pankaj Kumar,*et al.*, 2016).

According to Pankaj Kumar *et al.* (2016), the groundwater potential zonation was prepared by overlaying cumulative weight assigned to all the five thematic layers, viz., geomorphology, geology, slope, soil, and land-use/land-cover maps, using the weighted overlay methods in spatial analysis tool of Arc GIS 10.2. Through the weighted overlay analysis process, knowledge-based ranking and weightage of different class for each thematic layer has been given based on their contribution toward groundwater potentiality/development. Based on calculation, groundwater potential index (GWPI) for the study area ranges from 0.06 to 0.30 with a standard deviation of 0.04. Then, natural-break classification scheme using Jenk’s optimization method was applied for mapping

(Jenks, 1967). The GWPI was grouped into four classes: good, moderate, poor, and very poor. All the thematic layers were converted into raster format and overlaid in Arc/Info; and the resultant composite coverage was classified into four groundwater potential zones, such as good (5.3 % of the area), moderate (61.9 % of the area), poor (26.6 % of the area), and very poor (6.2 % of area) (Figure 3). The maximum area (61.9 % of the total area) is characterized by moderate groundwater potential zone.

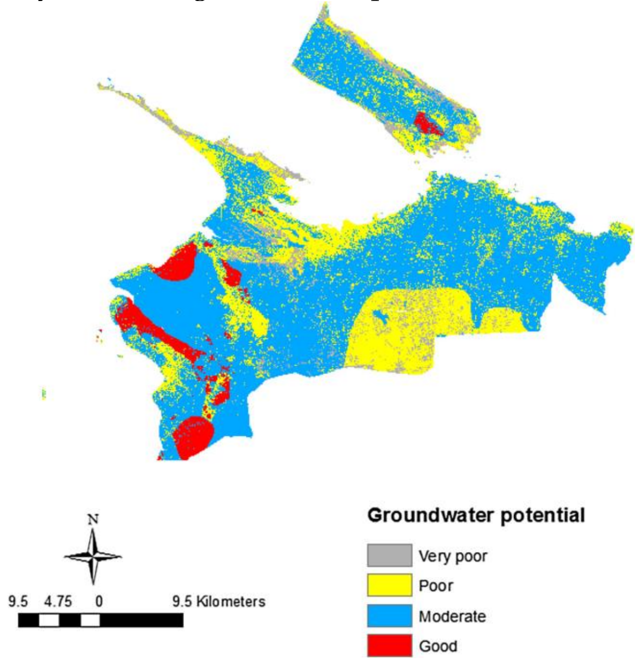

Fig. 3. Groundwater Potential of the Kilinochchi area
Source: Pankaj Kumar *et al.*, (2016)

Further PankajKumar *et al*. (2016) found that the excellent groundwater potential zone is concentrated in the south–western and north–western regions of the study area due to its almost flat terrain nature like alluvial plains with the distribution of limestone and dense forest land with high infiltration ability.

2.5. Groundwater Quality

Mahagamage *et al.* (2017) reported that the rural population in the Kilinochchi District area depends mostly on groundwater sources as the area does not get treated water. Majority of the population in the district are farmers. Mahagamage *et al.* (2017) conducted the study to determine the ground water quality along with pathogenic contamination status of groundwater in Kilinochchi area. In this study thirty wells were sampled in April 2017 and water temperatures, Dissolved Oxygen (DO), pH, conductivity, Total Dissolved Solids (TDS), salinity were measured at the site itself using standard meters. N-NO3-, N-NO2-, N-NH3, Total Phosphate (TP), Chemical Oxygen Demand (COD) and total hardness were measured by the standard spectrophotometric and titrimetric methods. Total coliform and fecal coliform count were obtained from membrane filtration methods. *Salmonalla* sp. and *Shigella* sp. were identified using WHO standard methods. The ground water pH varied between 4.30 to 8.40 whereas DO was between 1.13 mg/l to 9.18 mg/l. Water TDS, salinity and conductivity ranged between 38 to 5569 mg/l, 27to 3978 mg/l, 60 to 8840µs/cm respectively. It was found that most of the wells exceeded the values given by Sri Lankan Standard Institution (SLSI) for drinking water standard.N-NO3-, N-NO2-, N-NH3 concentration ranged between <1.00 to17.56 mg/l, <1.00 to 2.50 µg/l and <1.00 to 21.51 µg/l respectively.TP, COD and total hardness ranged between 47.67 to 191.42 µg/l,12.81 to 420.90 mg/l and 62.0 to 796 mg/l. Almost all ground water samples exceeded SLSI drinking water standard for COD (10 mg/L). Thirty seven percent of samples exceeded SLSI drinking water standard for total hardness (250 mg/l) as well. Sixty percent of samples were contaminated with total coliform whereas 47%of samples were contaminated with fecal coliform bacteria. Interestingly 37% of samples were positive for *Salmonalla*sp. and one groundwater source was contaminated with *Shigella* sp. The result of the present study revealed that 50% of ground water sources were not within the SLSI drinking water quality standards. Microbial contamination with *Salmonalla* sp. shows that continuous monitoring is essential to safeguard ground water consumers and take action accordingly. Therefore, Mahagamage*et al.* (2017) recommended prior treatment is a must before consumption of groundwater for drinking purposes.

3 METHODOLOGY

In total eleven wells in schools and primary medical care units (PMCU) were selected randomly for this study in order to improve the groundwater quantity through artificial recharge using rainwater and quality of water (Figure 4). All these wells were categorized in four groups based on the well depth (Table 1). Shallow wells are in less than 4m depth, Medium depth wells are in 4m-5.5 m depth and deep wells are in 5.5 m to 7m depth (Mikunthan and De Silva, 2009). Deepest well is having the depth of more than 7m. The maximum depth of the well in the study area is 10.4 m and the minimum depth is 4m. All the wells are in 2-3m diameter except one with less than 2 m diameter.

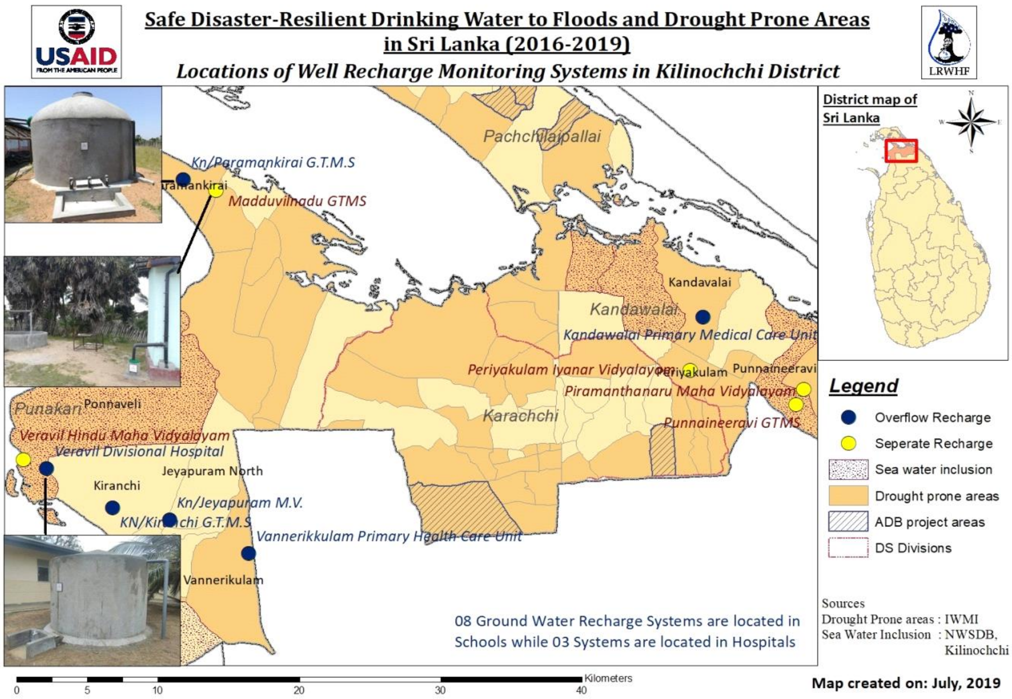

Fig.4. Sampling locations in the Kilinochchi area

Pankaj Kumar et al (2016)'s study finding in the Kilinochchi area is used as the base for this study as there is no need to redo the same process. Geology of the wells also varies in nature. According to Pankaj Kumar *et al*. (2016) geology demarcation of six wells are in Red earth, red and brown sand which usually allow easy percolation of water and other fluids and are porous enough to store large quantities, making them valuable aquifers. However, according to Pankaj Kumar *et al*. (2016) these wells are located in moderate groundwater potential zone. Other 5 wells are located in Alluvial and lagoonal clay, silt, and sand these wells also classified as moderate groundwater potential by Pankaj Kumar *et al*. (2016). Table 2 shows the location of the well and possible aquifer type and groundwater potential zone. As these wells are in moderate groundwater potential zone, these wells are mostly dried during dry season or hold less water in the bottom of the well making its unavailable for domestic or other uses. Because of the above reasons these wells were selected for this artificial recharging by rainwater harvesting project.

There were two methods of artificially recharging the wells. When the wells are near to the House/Building rainwater harvested from the roof is directly diverted to the wells. This is called "direct recharging method". When wells located far away from the roof the rainwater from the roof is collected into the rainwater harvesting tank and the over flow of the rainwater harvesting tank was diverted to the well. This is called "Overflow recharge method". These methods were selected based on the location of well and rainwater harvesting tank and rainwater capturing roof (De Silva and Ariyananda, 2020).

Table 1 Well details in the study area

Well Name	DSD/GND	Well No	Well Depth (m)	Well Diameter (m)
Shallow Wells > 4m depth				
Madduvill Nadu GTMS	Poonakari	1	4.1	2.36
Paramankirai GTMS	Poonakari	2	4	2.03
Kallaru Tamil Vidyalayam	Kandawallai	4	4.06	
Medium Depth Wells 4m-5.5m depth				
PeriyakulamIyanarVidiyalayam	Karachchi	3	5.2	1.3
Kandawallai PMCU	Kandawallai	6	4.52	3.07
Veravil Divisional Hospital	Poonakari	10	5.1	3.05
Veravil Hindu MahaVidyalayam	Poonakari	11	5.1	2.6
Deep Wells 5.5m-7m				
Vannerikkulam PMCU	Karachchi	7	5.7	2.14
Piramanthanaru M.V.	Kandawallai	8	5.95	2
Punnaineeravi GTMS	Kandawallai	5	6.2	2.14
Deepest Well >7m				
Jeyapuram M.V.	Poonakari	9	10.4	2.64

Table 2. Geological information and artificial recharging methods of selected wells

Well Name	DSD/GND	Well No	Aquifer type	Artificial recharging method
Madduvill Nadu GTMS	Poonakari	1	Red earth, red and brown sand	Direct
Paramankirai GTMS	Poonakari	2	Red earth, red and brown sand	Overflow
PeriyakulamIyanarVidiyalayam	Karachchi	3	Alluvial Lagoonal Clay, sand	Direct
Kallaru Tamil Vidyalayam	Kandawallai	4	Alluvial Lagoonal Clay, sand	Overflow
Punnaineeravi GTMS	Kandawallai	5	Alluvial Lagoonal Clay, sand	Direct
Kandawallai PMCU	Kandawallai	6	Alluvial Lagoonal Clay, sand	Overflow
Vannerikkulam PMCU	Karachchi	7	Red earth, red and Brown sand	Overflow
Piramanthanaru M.V.	Kandawallai	8	Alluvial Lagoonal Clay, sand	Direct
Jeyapuram M.V.	Poonakari	9	Red earth, red and brown sand	Overflow
Veravil Divisional Hospital	Poonakari	10	Red earth, red and brown sand	Over flow but no water
Veravil Hindu Maha Vidyalayam	Poonakari	11	Red earth, red and brown sand	Overflow but no recharge

Well water levels below ground level (m) and water level in the rainwater harvesting tanks were monitored from May 2017 to May 2019 on weekly basis. Further well and rainwater harvesting tank water quality was also measured in weekly basis. Measured quality parameters were pH, Electrical Conductivity (µS/cm) and Total Dissolved Solids (mg/L).

4 RESULTS AND DISCUSSION

4.1 Artificial groundwater recharge

4.1.1. Effect of Method of artificial recharge on shallow well water level

Paramkirai GTMS and Madduvill Nadu GTMS wells are located in red earth, red brown sand areas. Both the wells were artificially recharged by rainwater. But the Madduvil Nadu GTMS was rechargedby direct method from 15/11/2017 to 31/5/2019 (one and half year) (Figure 5). Paramankirai GTMS well was artificially recharged by the overflow method from 15/11/2017 to 31/05/2019 (Figure 6). Therefore, the total amount of water applied for artificially recharging the well in Madduvil Nadu GTMS is higher than that of the Paramankirai GTMS. As the result the well water level increased almost near to the ground surface (0.3mbgl) at Madduvil Nadu GTMS facilitating the availability of groundwater during the dry season.

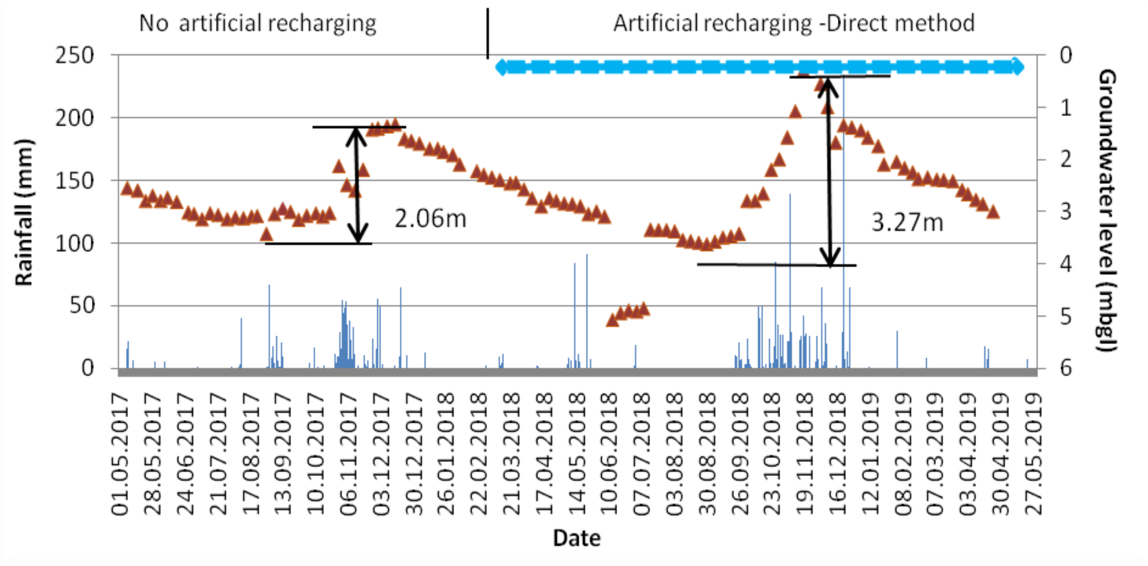

Fig. 5. Rainfall pattern and groundwater levels variation of in Madduvil Nadu GTMS well due to direct method of artificial recharging.

The groundwater level rise observed in well water level in Madduvil Nadu GTMS due to direct recharge was 3.27m in the year 2018 and it was 1.21m higher than the non recharging year of 2017. Whereas the groundwater level rise observed in the well water level in Paramankirai GTMS was 2.76m during 2018 and it was 0.56m higher than the non recharging year of 2017 (Figure 6). However, the rainfall received during May 2017 to April 2018 was only 1067.5 mm, whereas the rainfall received during May 2018 to April 2019 was 1744.3 mm. Even though there was higher rainfall in 2018, the wells showed difference in groundwater level rise based on the method of artificial recharging. It proves that the direct recharge (rainwater harvested in the roof to well) method was effective to have better recharge. It showed the artificial recharge by direct method is better than overflow method to achieve increase the well water level inthe drought prone areas in Kilinochchi.

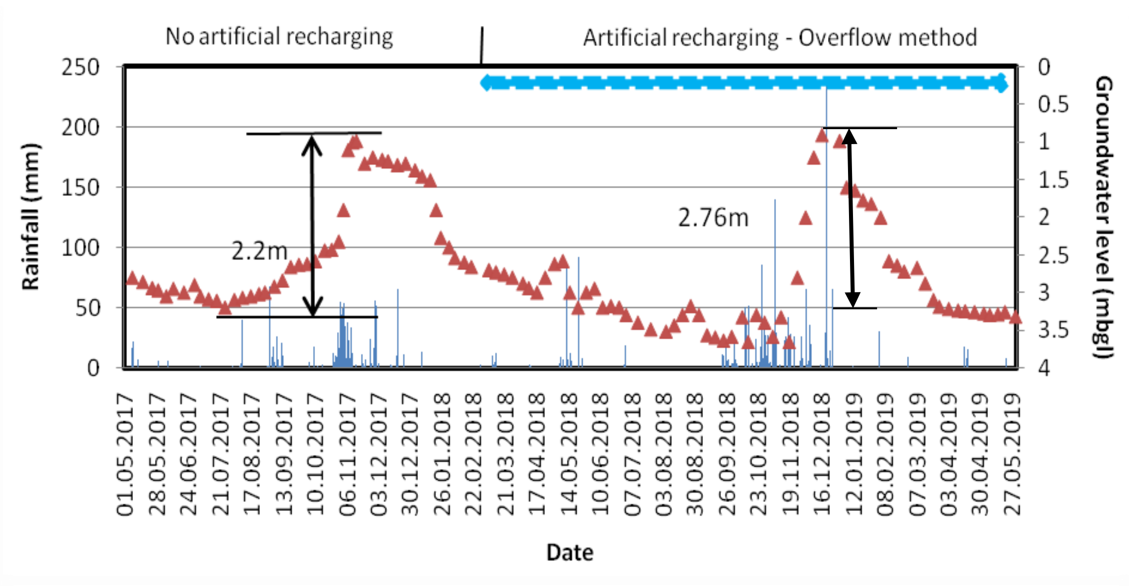

Fig. 6. Rainfall pattern and groundwater level variation in Paramankirai GTMS due to overflow method of artificial recharge

4.1.2 Effect of Method of artificial recharge on Medium Depth well water level

Both wells in Periyakulam Iyanar Vidiyalayam and Kandawallai PMCU are located in Alluvial and lagoonal clay, silt, and sand in medium depth in (4.0-5.5m). PeriyakulumIyanarVidyalam well was recharged by direct method from 18/11/2017 to 31/5/2019 (Figure 7). But Kandawalai PMCU was artificially recharged by overflow method from 22/12/2017 to 31/5 /2019.In both wells there was an increment in recharge when artificially recharged the wells by rainwater. Due to artificial recharge in both wells the well water level was maintained near to the ground level (<1mbgl) during dry season.

According to the groundwater level rise calculation PeriyakulamIyanarVidyalayam has higher groundwater level rise (4.33m) compared to Kandawalai PMCU well where the groundwater level rise was only 3.41m. It shows that the artificial recharging by direct method is more efficient method than the overflow method. It may be due to the fact that in the overflow methodthe quantity of rain water was not adequate to increase the well water level.

Both Veravil divisional Hospital and Veravil Hindu M.V wells are located in Red earth, red, and brown sand. Both these wells are medium depth (4.0-5.5m). However these wells were not successfully artificially recharge by overflow method during study period. Therefore groundwater level rise observed in the well for Veravil Divisional Hospital and Veravil Hindu M.V was 3.0 m and 3.2 m respectively.

However, the rainfall received during May 2017 to April 2018 was only 1067.5 mm. whereas the rainfall received during May 2018 to April 2019 was 1744.3 mm. Even though there was higher rainfall in 2018, the wells showed difference in groundwater recharge based on the method of artificial recharging. Wells in Veravil Divisional Hospital and Veravil Hindu M.V showed the lowest recharge because there was no artificial recharge to these two wells. Among the two methods of artificial recharging wells rainwater direct method was the effective method to have better recharge. Therefore artificial recharge by direct method is better than overflow method to achieve higher recharge in drought prone areas in Kilinochchi.

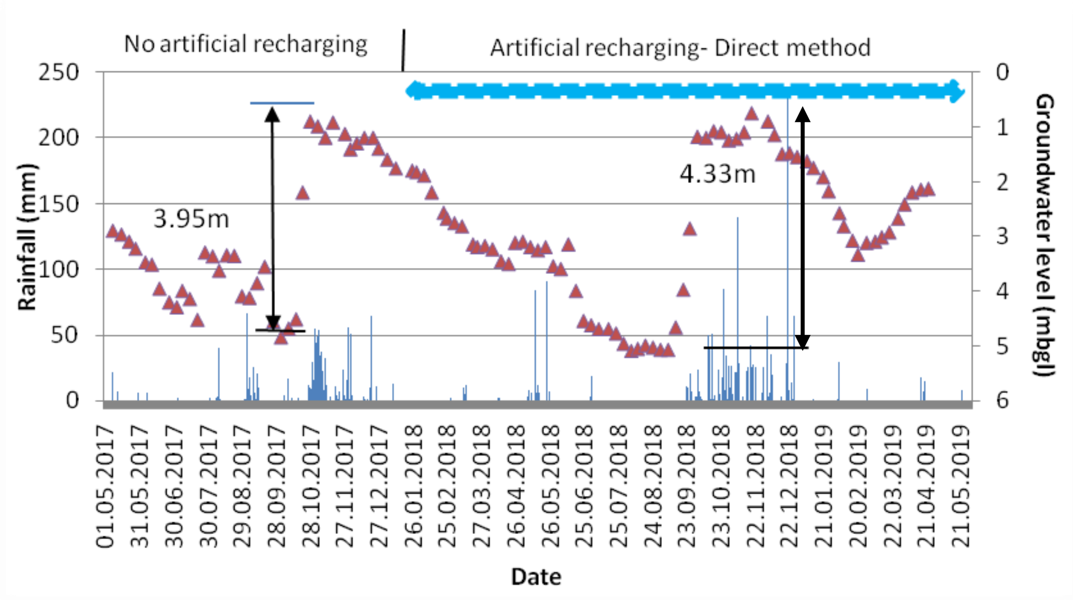

Fig. 7. Rainfall pattern and groundwater level variation in PeriyakulumIyanarVidyalayam due to direct method of artificial recharge

4.1.3. Effect of Method of artificial recharge on Deeper Depth well water level

Wells in Punnaineeravi GTMS, Piramanthanaru M.V and Vannerikkulam PMCU are in deep wells category having the well depth of 5.5m -7m depth (Table 1). Punnaineravi GTMS well and Piramanthanaru M.V were in Alluvial lagoonal Clay and sand, whereas Vannerikulam PMCU well is located in Red Earth red Brown sand. However both these aquifers were classified as moderate potential for groundwater. When considered the artificial recharging method, Punnainveeravi GTMS and Piramanthanaru M.V well were artificially recharged by direct method whereas Vannerikulam PMCU well was artificially recharged by overflow method. Even though the rainfall received during May 2017 to April 2018 was only 1067.5 mm and rainfall received during May 2018 to April 2019 was 1744.3 mm, method of artificial recharging played a major role in well water table rise during the year 2018. Accordingly Punnainveeravi GTMS well showed 5.02 m rise in groundwater level (Figure 8) whereas Vannerikulam PMCU well showed only 4.92 m. It showed that that the direct method is effective than the overflow method of artificial recharging in drought prone areas in Kilinochchi.

4.1.4. Effect of Method of artificial recharge on deepest well water level

Well in Jeyapuram M.V is the deepest well with 10.4m depth and this well is located in Red earth, red and brown sand. This well was artificially recharged with overflow of rainwater harvesting tank and from 19/05/2018 to 31/05/2019. However, there was only a 2.84 m rise in groundwater level (Figure 9). This may be due to the reason that artificial recharging is not effective in deepest well of 10m depth.

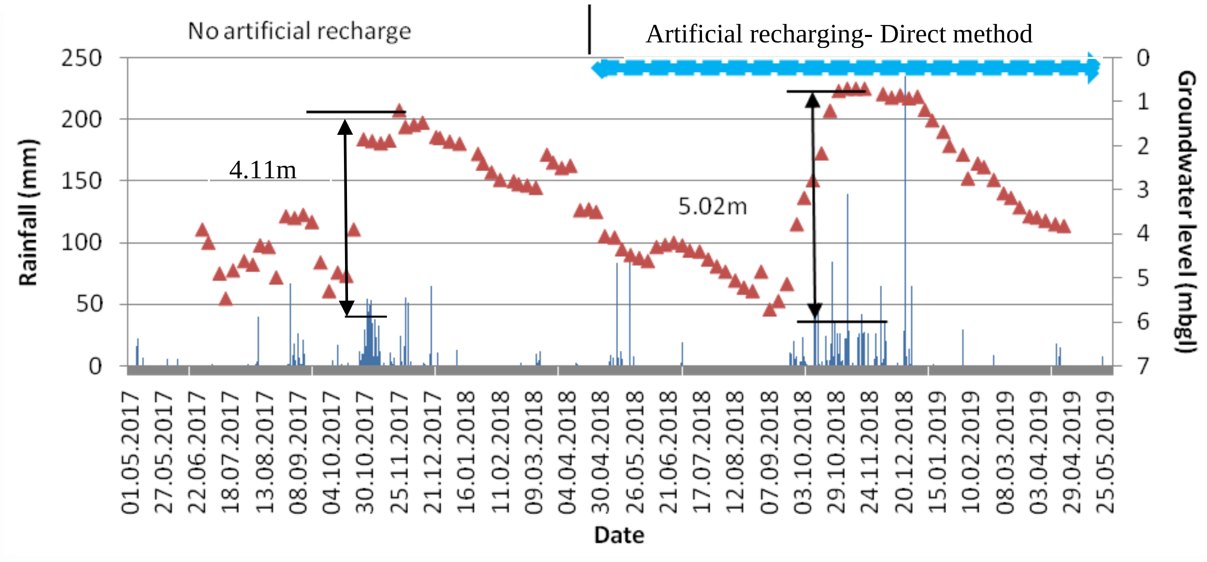

Fig. 8 : Rainfall pattern and groundwater level variation in Punnaineeravi GTMS due to direct method of artificial recharge.

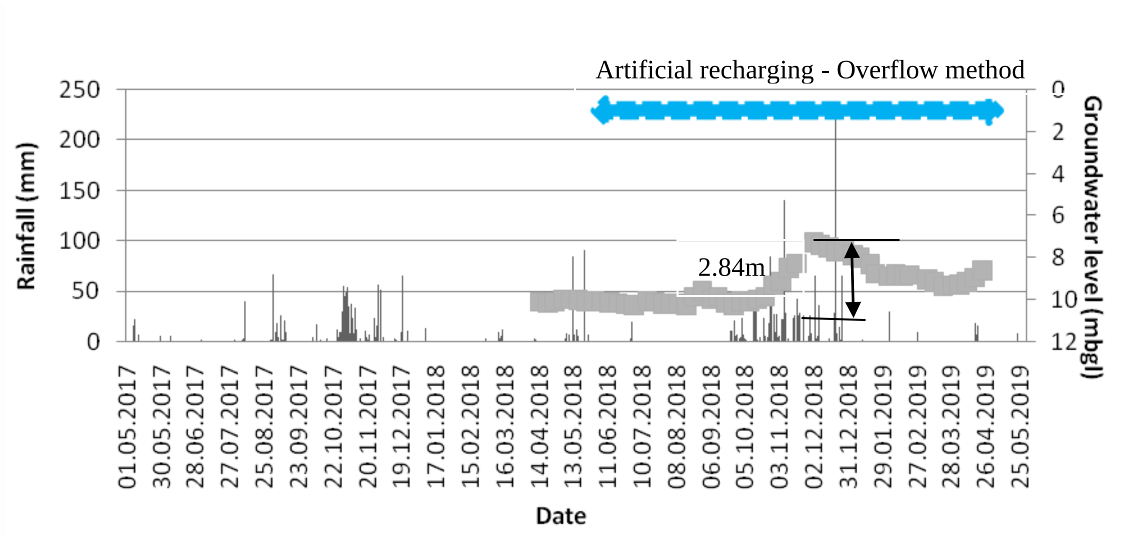

Fig.9: Rainfall pattern and groundwater level variation in Jeyapuram M.V due to overflow method of artificial recharge

Table 3 shows the recharge took place in each location during the year 2017 and 2018. Year 2017 was before artificial recharging by rainwater and 2018 was after the artificial recharging by rainwater harvesting either by direct or overflow method. Recharge during 2018 was higher than that in 2017 mainly due to the impact of artificial recharging. Even within 2018, direct method of artificial recharging contributed to the higher recharge than the overflow method of artificial recharging. It may be due to the fact that direct recharge contributes higher volume of rainwater whereas the overflow takes place only when the tank is full and when there is overflow. Therefore overflow recharging contributed to the limited volume of rainwater for artificial recharging. To calculate the recharge, water table rise in the groundwater level and the specific yield of the aquifer based on the literature (De Silva and Rushton, 2007; Mikunthan and De Silva 2012, Mikunthan and De Silva 2009; Kumar, et al., 2016) was used.

Table 3.Recharge in groundwater wells from artificial recharging by direct method or Overflow method

Well Name	DSD/GND	Well No	Recharge 2017 (mm)	Recharge 2018 (mm)
Madduvill Nadu GTMS*	Poonakari	1	124	196
Paramankirai GTMS**	Poonakari	2	132	166
PeriyakulamIyanarVidiyalayam*	Karachchi	3	237	260
Punnaineeravi GTMS*	Kandawallai	5	-	301
Kandawallai PMCU**	Kandawallai	6	-	205
Vannerikkulam PMCU**	Karachchi	7	-	295
Jeyapuram M.V.**	Poonakari	9	-	170
Veravil Divisional Hospital	Poonakari	10	-	180
Veravil Hindu MahaVidyalayam	Poonakari	11	-	192

*Direct Method **Overflow method

4.2 Water quality

4.2.1 Well water Quality

- *pH*

pH is one of the important water quality parameters that describes groundwater quality, since pH largely controls the amount of chemicals form of organic and inorganic compounds in groundwater (Mahagamage *et al.*, 2016). pH of the well water is within the safe limit for drinking water is 6.5 to 8.5 (SLSI, 2016) in deepest well (Jeyapuram M.V) except during no rainfall period during January to May 2019. Among the deep wells Punnaineeravi GTMS and Vannerikulum PMCU wells were recordedpH within 6.5 to 8.5. But Piramanthanaaru well was having higher pH of 8.5 during rainless period from March to September 2018 and March to May 2019. However pH didn't exceed 10 in these wells. Among the medium depth wells, PeriyakulamIyanarVidyalam, Vervil Hindu M.V and Veravil DH well water were within the safe limit of pH 6.5-8.5. But Kandawallai PMCU well water was above the safe limit of 8.5 during rain less period. However the pH was below 10 in all wells. Among shallow depth wells Kallar Tamil Vidyalam well water was measured pH less than 6.5, which is unsuitable to drinking purposes. Other wells in Madduvil Nadu GTMS and Paramankirai GTMS well water was below pH 10 and most of time the pH is within the safe limit for drinking water (Figure 10).

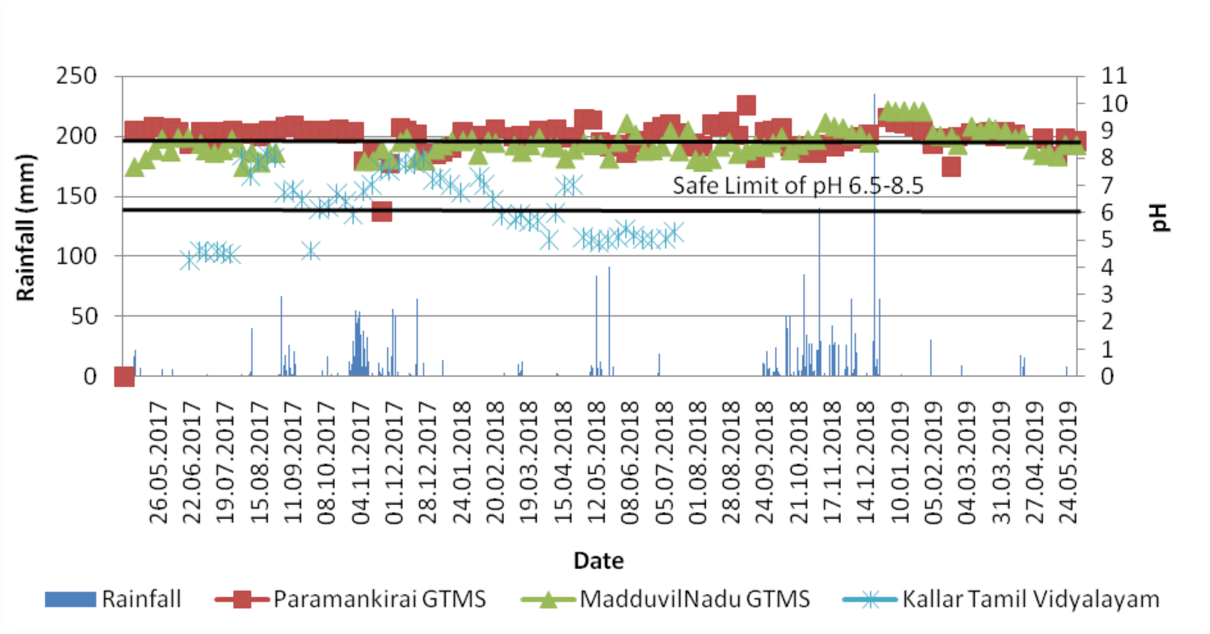

Fig.10. Temporal variation of pH of shallow depth well water in the study area

- *Electrical Conductivity(µS/cm)*

EC comprises the inorganic salts and organic matter that are dissolved in water(Mahagamage*et al.*,2019).Electrical conductivity of the deepest well water was above safe limit of 1500 µS/cm, higher as 2250 µS/cm during dry period from March to October 2018 and below the safe limit during October 2018 to May 2019 after *Maha* season rains. This is due to the dilution of well water during rainy season (Mikunthan and De Silva, 2008). Among deep wells electrical conductivity of Pirmanthanaaru MV well water is below the safe limit throughout the study period. However,Vannerikulam and Punnaineeravi GTMS well water were always above the safe limit (Figure 11). Electrical conductivity of Vannerikulam PMCU well water was almost 9500µS/cm during the study period and electrical conductivity of Punnaineeravi GTMS well water reached 4000µS/cm making this well water unsuitable for domestic purposes. This may be due to the higher ion concentration in deep well water.

Among the medium depth wells, electrical conductivity of PeriyakulamIyanarVidyalayam well water was below the safe limit of 1500µS/cm during the study period. Electrical conductivity of Kandawallai PMCU well water was above the safe limit (up to 2500µS/cm during the study period except for a short period during December 2018 to February 2019 due to dilution after *Maha* season rains. Electrical conductivity of Veravil Hindu M.V well water was above the safe limit throughout the study period and it was nearly 6500µS/cm and this well water is unsuitable for domestic purposes.

Among the shallow depth wells electrical conductivity of Maduvil Nadu GTMS well water was below the safe limit of 1500µS/cm throughout the study period (Figure 11). Electrical conductivity of Kallar Tamil Vidyalam well water quality was below the safe limit from September 2017 to May 2018 but during the other period the electrical conductivity was above the safe limit of about 3500µS/cm which makes the well water unsuitable for domestic purposes.

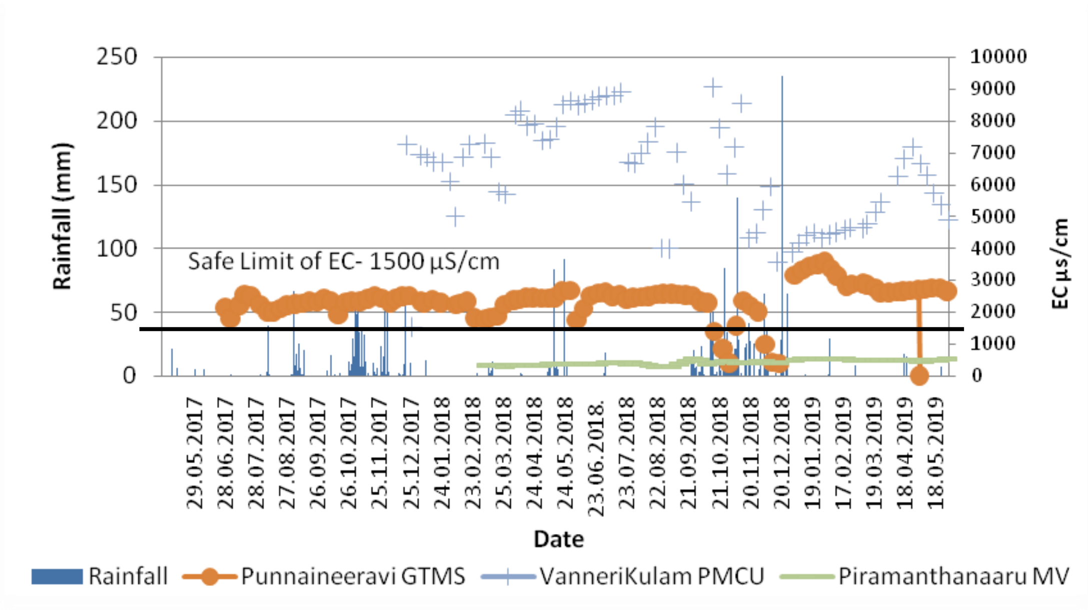

Fig. 11. Temporal variation of electrical conductivity (µS/cm) in deep wells water in the study area

- *Total Dissolved Solids (mg/L)*

Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water (SLSI, 2016). Acceptable safe limit of TDS is 500mg/L (SLSI, 2016). Among the wells in the study area only PeriyakulamIyanarVidyalam (Figure 12), Maduvil Nadu GTMS and Piramanthanaaru MV wells are having Total Dissolved Solids less than 500mg/L which is the safe limit. All the others wells water is having higher TDS values above 500mg/L. Deepest well in Jeyapuram MV is having TDS value of about 1120mg/L except during the rainy season from October 2018 to April 2019. During rainy season the TDS value is within the safe limit of 500mg/L. TDS value of the well water in Paramankirai GTMS, was above the safe limit. Lowest and highest TDS value obtained in Paramankirai GTMS during the study period was 1170mg/L (September 2019) and 6490mg/L (November 2019) which makes the well unsuitable for domestic purposes. TDS value of the well water is Kanadawallai PMCU was above the safe limit of 500mg/L and the lowest and highest TDS values obtained was 538 mg/L (Dec 2018) and 1386 mg/L (August 2018) respectively. TDS values decreased during *Maha* season rains in December due to dilution of the well water due to recharge. TDS value of the well water in Veravil DH was well above the safe limit of 500mg/L. The lowest and highest TDS observed in Veravil DH well water was 2781mg/L (January 2019) and 8856mg/L (March 2019) respectively which makes this well water unsuitable for drinking purposes. TDS in Vannarikulam PMCU well water was well above the safe limit of 500mg/L throughout the study period. The lowest and highest TDS values in Vannarikulam PMCU were 1770 mg/L and 7730mg/L respectively. TDS value of well water in Veravil Hindu M.V was above the safe limit throughout the study period and the lowest and highest TDS values observed in Veravil Hindu M.V well were 1113mg/L and 2918mg/L respectively. TDS value of the well water in Punnaineerai GTMS was above the safe limit of 500mg/L throughout the study period except in December 2018 TDS value came down to 200mg/L only for a short period due to *Maha* season rains and dilution of water in the well. The lowest and highest TDS values observed in this well was 200 mg/L and 1714mg/L respectively. It showed only three wells namely PeriyakulamIyanarVidyalam, Maduvil Nadu GTMS and Piramanthanaaru MV in the study area are having TDS value below 500mg/L of safe limit throughout the study period and suitable for drinking purposes. It may be these wells have higher recharge which dilutes the concentration of ions in the well water.

These harmful minerals accumulate because the body cannot excrete or utilize them. In most instances, TDS in your drinking water will not present a health problem but it's important to note, should TDS levels exceed 500mg/L, the drinking water can be considered unfit for human consumption (SLSI, 2016). It is recommended that people with kidney problem should drink pure water having TDS level below 100 mg/L for better recovery. There are ways to remove TDS through Reverse Osmosis (R.O.) Reverse Osmosis removes TDS by forcing the water, under pressure, through a synthetic membrane; distillation (Mahagamage, et al., 2016). The process involves boiling water to produce water vapor and deionisation (DI). But RO water doesn't have many of the essential nutrients you need for your health. Higher TDS value in about 70% of the study area is a concern as most of the rural communities suffer from Chronis Kidney Disease(Mahagamage, et al., 2016).

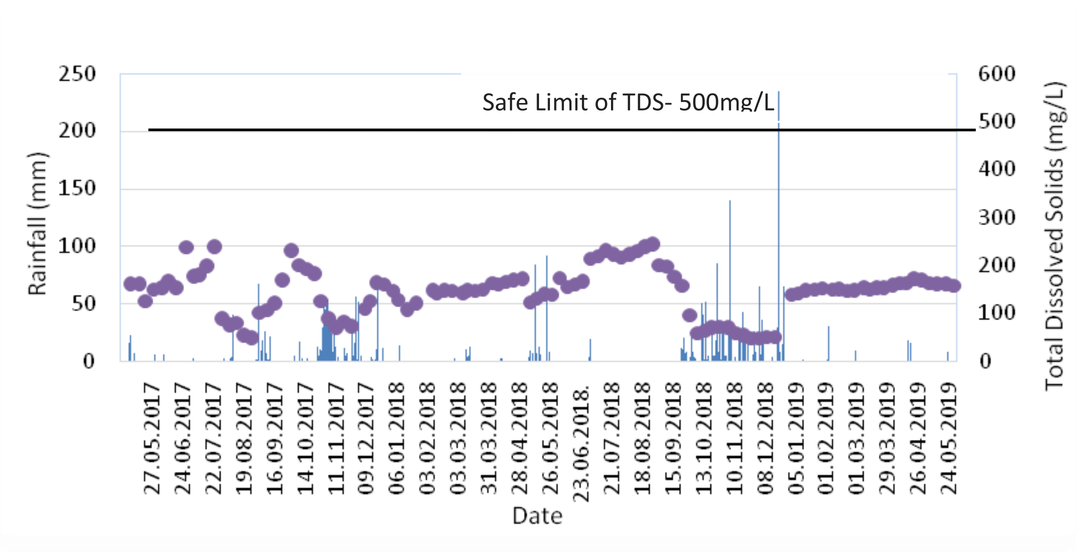

Fig.12. Temporal variation of Total Dissolved Solids (mg/L) in PeriyakulamIyanarVidyalayam well.

4.2.2. Rainwater Harvesting Tank water quality

- *pH*

The pH of pure water is 7. In general, water with a pH lower than 7 is considered acidic, and with a pH greater than 7 is considered basic. The normal range for pH in surface watersystems is 6.5 to 8.5, and the pH range for groundwater systems is between 6 and

8.5. In the study area pH of all the rainwater harvesting tank water in all locations were above the safe limit of 6.5-8.5 (Figure 13). According to Weidman,*et al.,* (2016) the higher pH or alkaline water can help slow the aging process, regulate your body's pH level by neutralizing the acid in the body, increases energy levels, extra hydrating than other water and prevent chronic diseases like cancer because alkaline water is suggested as containing antioxidants to extensively hydrate and filter out free radicals in your body. Normal drinking water generally has a neutral pHof 7. Alkaline water typically has a pH of 8 or 9.When you have kidney disease, it's more difficult for your kidneys to remove acid from your blood. Because of that, a high-alkaline diet, one that is low in acidic foods, may help people with kidney disease to balance their pH levels (Weidman *et al.* 2016).Further the reason for high pH levels in the Rain water Tank is due to cement dissolving of the Ferro cement tank when they are newly constructed. It will be reduced with time when the tank is used continuously. Therefore the pH in the Rainwater Harvesting Tank water quality is not a serious matter.

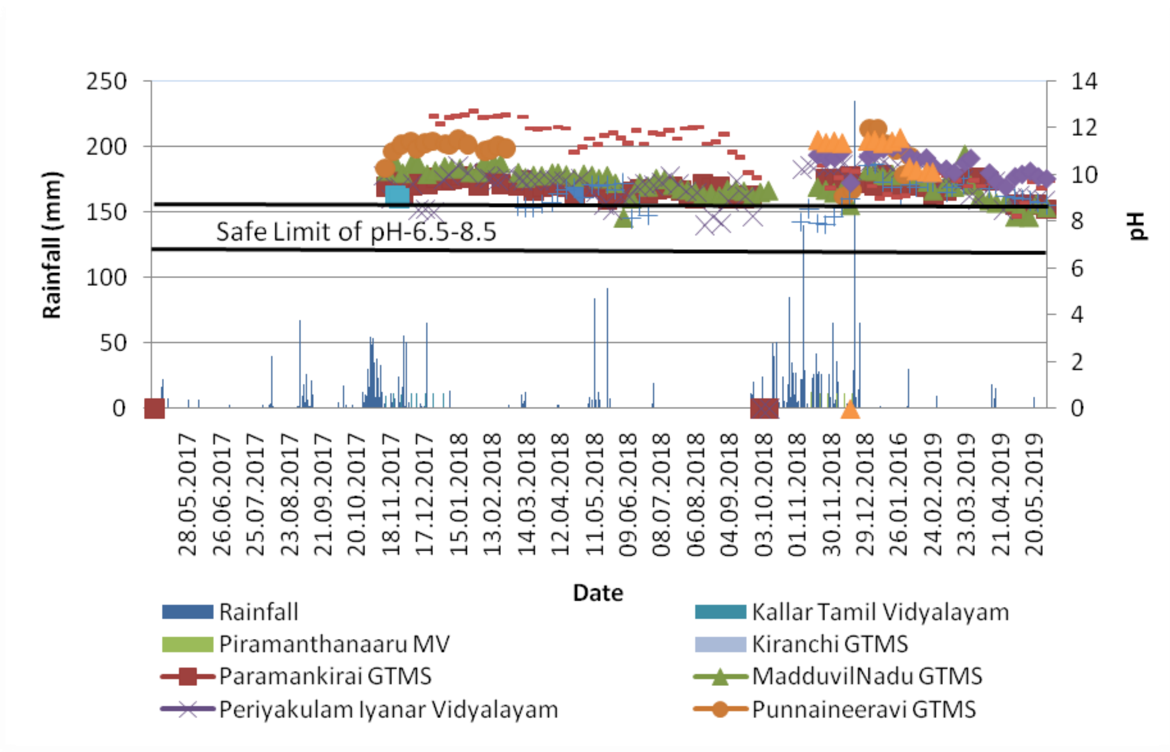

Fig. 13. Temporal variation of pH in water in the rainwater harvested tank

- *Electrical Conductivity (µS/cm)*

An electrical current result from the motion of electrically charged particles in response to forces that act on them from an applied electric field. Within most solid materials a current arise from the flow of electrons, which is called electronic conduction. In all conductors, semiconductors, and many insulated materials only electronic conduction exists, and the electrical conductivity is strongly dependent on the number of electrons available to participate to the conduction process. Most metals are extremely good conductors of electricity, because of the large number of free electrons that can be excited in an empty and available energy state (Meride and Ayenew 2016).

Electrical conductivity in all the rainwater harvesting tank water in all locations was within the safe limit of 1500 µS/cm (Figure 14). Therefore, the rainwater harvesting tank water quality is better than the well water quality of the study area. Some locations have higher EC values, and it may be due to cement dissolving of the Ferro cement tank when they are newly constructed.

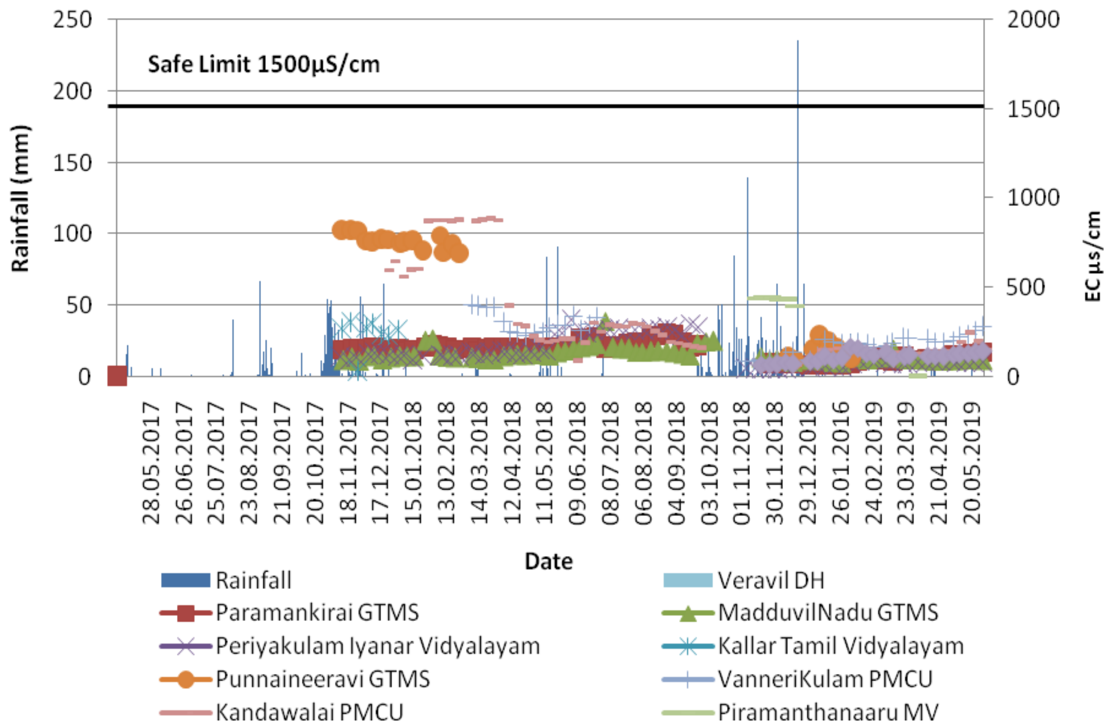

Fig. 14. Temporal variation of Electrical Conductivity in rainwater harvesting tank water

- *Total Dissolved Solids (mg/L)*

Total dissolved solids (TDS) is a measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized, or micro-granular (colloidal sol) suspended form (Meride and Ayenew, 2016). Generally, the operational definition is that the solids must be small enough to survive filtration through a filter with 2-micrometer (nominal size, or smaller) pores. Total dissolved solids are normally discussed only for freshwater systems, as salinity includes some of the ions constituting the definition of TDS. Although TDS is not generally considered a primary pollutant, it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants (Meride and Ayenew, 2016). The United States has established a secondary water quality standard of 500 mg/L to provide for palatability of drinking water. According to the results obtained in the TDS of Rainwater Harvesting tank water in all locations are within the safe limit (Figure 15). It shows that the Rainwater harvested water is in better quality than the groundwater well water quality in the study area. Some locations have higher TDS values, and it may be due to cement dissolving of the Ferro cement tank when they are newly constructed.

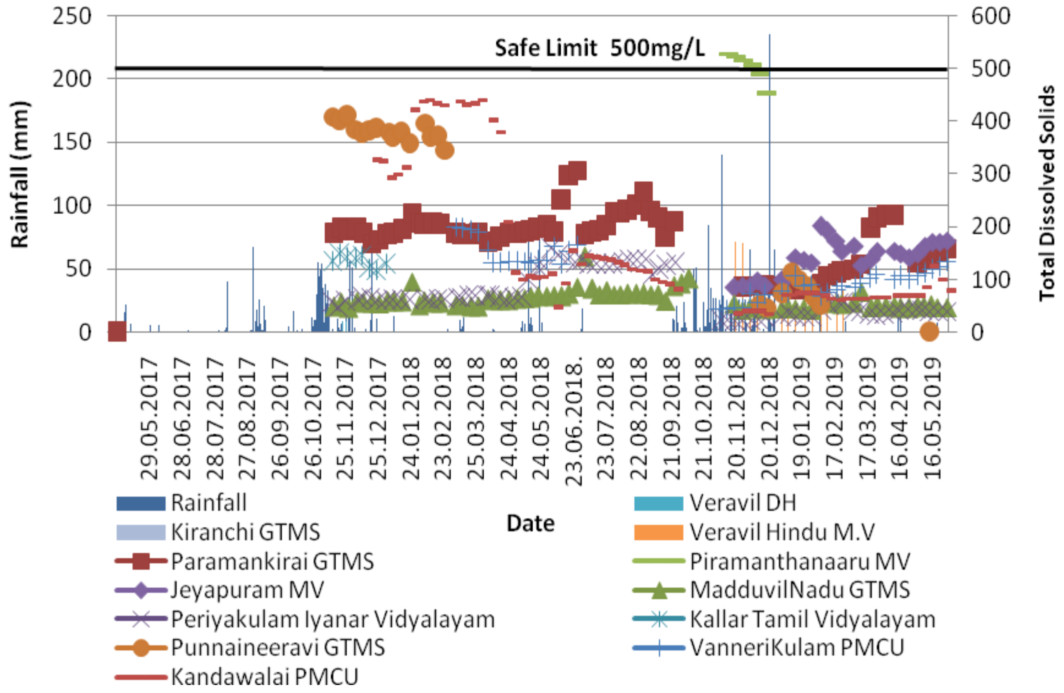

Fig. 15. Temporal variation of Total Soluble Solids *(mg/L)* in rainwater harvesting tank water

5 CONCLUSIONS AND RECOMMENDATIONS

This study proves that rainwater harvesting and using the rainwater harvested during wet season to recharge the groundwater wells is an appropriate methodology to keep the well water levels high during dry period. If the rainwater is not harvested, most of the water would have lost as runoff and not contributed to groundwater recharge effectively.

This study used two method of rainwater harvesting to recharge the groundwater wells. First method is to divert the water harvested on the roof straight to the groundwater wells (Direct method). Second method is to store the rainwater harvested in roof to the Rainwater Harvesting tank and the overflow of the rainwater from the rainwater harvesting tank is diverted to the groundwater wells for artificial recharging (Overflow method). According to the study results groundwater recharge is higher in wells in Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Punnaineeravi GTMS which were artificially recharged by direct method. Therefore direct method of artificial recharging using rainwater is effective in drought prone areas. Average recharge varies from 196mm to 301mm per year.

Groundwater quality analysis showed that pH of the well water was within the safe limit of 6-8.5 for drinking water; only in Madduvil Nadu GTMS, PeriyakulamIyanar

Vidyalayam and Punnaineeravi GTMS wells. Electrical conductivity in well water was within the safe limit of 1500 µS/cm only in wells in Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Piramanthanaaru M.V. TDS was within the safe limits of 500mg/L in wells of Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Piramanthanaaru M.V. Groundwater sourcesin Madduvil Nadu GTMS, PeriyakulamIyanar Vidyalayam and Punnaineeravi GTMS are having higher recharge compared to the other wells , therefore, the well water quality is improved due to the dilution process.

Rainwater harvesting tank water quality in all study locations were within the safe limit of 1500 µS/cm of electrical conductivity and 500mg/L total soluble solids. But pH was in higher side of 9-10 even though the safe limit is 6.5-8.5. Therefore, rainwater harvested water quality is superior to the groundwater quality in the study area. Therefore, artificial recharging using rainwater harvested water is not posing any threats to groundwater quality. Artificial recharging of groundwater wells by harvested rainwater is improving the water quality of the groundwater.

Therefore this study results recommends the following:

- Introduce rainwater harvesting tank in all households in the Kiliniochchi area.
- Use the rainwater harvested water drinking purposes as the groundwater quality is inferior to the harvested rainwater.
- Introduce direct method of artificial recharge the groundwater using harvested rainwater from the roof as much as possible.

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