

# An Evaluation on the impacts of Dry Zone Coastal Ground Water quality changes on sustainability of rural water supply (Kalpitiya Peninsula, Sri Lanka)

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## ARTICLE DETAILS

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## ABSTRACT

Due to the vast utilization and over exploitation, ground water has become a diminishing resource evident from the recent past in the dry zone coastal areas of the world. Forceful powers of both natural and anthropogenic directives have resulted accelerated ground water quality degradation causing fatal diseases and ground water stress as well. On this background the study focus on the main objective of appraising the impact of Dry Zone Coastal Ground Water Quality changes on the water supply for rural inhabitants in terms of spatial dissemination of ground water taking Kalpitiya Peninsula of Sri Lanka as the case study location. The significance of ground water usage in the context of demographic and economic conditions of the area was reviewed using secondary data. In order to appraise the level of ground water stress, a water quality index (WQI) was implemented referenced to the case study region determined on a basis of thirteen [13] physico-chemical parameters namely Electrical Conductivity, Total Dissolved Solids (mg/L), Chloride (mg/L), PH, Total alkalinity (TA), Total hardness (TH), Calcium, Magnesium, Sulphate, Fluoride, Turbidity in NTU, Total Iron in mg/L (as Fe) and Nitrate in mg/L (as N). Thirty four [34] sampling ground water extraction points were monitored covering July, 2014 for dry period & December, 2014 for wet period of Northeast monsoon. Groundwater appropriateness for domestic uses was appraised by using World Health Organization standards for water quality indicators. The results of this study reveals that unsuitable ground water quality (WQI value = 300<) can be observed in more than 75% land areas of the Kalpitiya peninsula according to the Inverse Distance Weightage Interpolation analysis. The highlighted areas depend on ground water as the major water source for the drinking and domestic purposes and also for the agricultural and fisheries industrial needs. This indicates that the Dry Zone Coastal Ground Water table is in constant stress of deprivation and the urban water supply immensely threatened. Accordingly the sustainability of dry zone coastal rural water supply is in a critical need of due attention from the policy makers, planners and users as well.

## 1. Introduction

It is evident that the most important and widely utilized water resource in Sri Lanka is the ground water, while being the most significant drinking water supply methodology for the country's population. According to the 'Joint Monitoring Program for water supply and sanitation' report of WHO/UNISEF, 2004, percentage of 22.4% urban population in Sri Lanka utilize groundwater as the drinking water source while 71.8% of rural population depends on ground water not only for the drinking purpose but also for agricultural and domestic necessities. Livelihood options of the dry zone coastal areas basically depend on the availability of ground water resources apart from being rural or urban. Most importantly, the rate of groundwater abstraction of coastal dry zone areas of Sri Lanka has significantly exceeded its' recharge rate, subsequently resulting critical degradation of the water quality in the recent past (Panabokke, 2007).

Apart from that fact, saltwater intrusion induced by the climate change derived scenarios such as the sea level rise is threatening the rare and exquisite ground water aquifers especially in the coastal dry zone areas. Due to these reasons the sustainability of water supply in dry zone coastal areas is facing a persistent question. Accordingly, as the most vital source of water, groundwater resource of the island requires higher attention momentarily with regarding its quality level on obligatory purposes. The quality level of ground water changes due to both natural and anthropogenic forces. Especially the

physico-chemical character of any groundwater expresses its quality level and consumption pattern (Sirajudeen & Vahith, 2014). Therefore developing useful methodologies in assessing the level of ground water quality is essential in order to minimize the level of water stress while enhancing the environmental and socio-economic sustainability. Hence this study focus on appraising the quality level of ground water resource compositing the most considerable chemical parameters indicating ground water quality. The quality of ground water was assessed by developing a Water Quality Index (WQI) utilizing total thirteen (13) parameters. The major objective of this paper is appraising the impact of Dry Zone Coastal Ground Water Quality changes on the water supply for rural inhabitants in terms of spatial dissemination of ground water.

## 2. Literature Review

The Coastal Environment is a very dynamic geomorphological system which is subjected to continual disturbances and changes over time and space (McGranahan et al., 2007). Coastal zones in the world have been changing intensely during the 20th century with the increasing populations, economies and urbanization globally. Today, below 10 meter low-elevation coastal zones of the world contain about 10% of the world population (McGranahan et al., 2007). With the rapid growth of population the demand for basic needs are continuously increasing. Specially, water has gained the position of the most valued resource in the whole universe as the most primary need of living beings.

Sri Lanka also facing these consequences as an island, with increased effects of climate change induced scenarios. It is estimated that Sri Lanka's ground water resources record as 78000 million m<sup>3</sup> per year (Nandalal, 2010). In the coastal areas of dry zone, population exceeding 80% use dug wells and tube wells as the drinking water sources especially in areas where pipe born water is very rare (Panabokke, 2007). Particularly the coastal dry zone areas where the major livelihood options are basically fisheries and agriculture of Sri Lanka depend on ground water. This accelerated utilization of groundwater cause water quality depreciation and subsequently has higher adverse effects on public health and hygiene (WHO, 2004) and on the sustainability of socio-economic characteristics of the built environment. Therefore developing methods on appraising and monitoring the level of water quality has gained sophisticated attention of various scholars in recent years.

Quality of water is a foremost feature in defining the level of wellbeing of the general public. Thus Water quality management is vital for human welfare. Therefore measuring level of ground water contamination is very important. Usually the water quality is defined in terms of the chemical and physical characteristics which presence in the water and all the dissolved and particulate organic and inorganic mater in the water includein the appraisal (UNEP/WHO, 1996). Electrical conductivity, pH, Dissolved oxygen, Temperature, and more other parameters that determine the water quality can be measured both in-situ and lab testing methodologies (Sirajudeen & Vahith, 2014). The major features of water quality monitoring can be defined as in-situ measurements, water sample collection and analysis, the appraisal of the analytical outcomes, and the recording of the results (UNEP/WHO, 1996). In this, the Water Quality Index (WQI) is considered as an effective tool of appraising contamination level of water which follows the major features of water quality monitoring (Chugh et al., 2014). Water Quality Index (WQI) is a very significant and communicative method in assessing the level of water quality worldwide. This concept was firstly developed by Hortan in 1965 and then further developed by many interested scholars. WQI is considered as one of the most advance and effective gears to indicate facts on the quality of water to the apprehensive water users and policy makers (Singh & Hussian, 2016). It can be well-defined as a method of evaluation replicating the compound impact of different water quality parameters because the WQI is a mathematical equation utilized to convert huge number of water quality statistics into a sole number representing the level of water quality in a more comprehensive manner. Chugh et al, 2014 defined Water Quality Index as "a rating reflecting the composite influence of different water quality parameters on overall quality of water". This method effectively summarizes huge amounts of water quality data in very simple terminologies such as 'good', 'excellent', 'Bad', 'Worse' etc.. This can significantly transfer the message of the appraisal from policy level to general public in a very effective manner (Al-shujairi, 2013).

The focal determination of developing a WQI is to convert a complex set of water quality data into coherent and useable information in a way even a layman can know the status of the particular water source. WQI targets at giving a sole value to

the water quality of a water source by converting the conditions of the considered list of parameters in a sample into a solitary value, which in turn delivers a wide-ranging explanation of the quality of water and its appropriateness for various purposes specially as drinking (Bora and Goswami, 2016). Therefore developing Water Quality Index (WQI) is vastly considered as a major principle for classification of water which is based on the utilization of standard parameters for characterizing water ( Mophin-Kani & Murugesan 2011). Chugh et al., 2014 explains that organizations such as World Health Organization, Environmental Protection Agency of USA, European Union Environmental departments, Agencies of Australia, Bureau of Indian Standards, Canada, and Indian Council of Medical Research are giving extensive devotion in standardizing the reference values of commonly considered water quality parameters in developing Water Quality Indexes. This indicates the level of importance in determining the water quality especially in areas with water stress such as the coastal dry zone of Sri Lanka.

### 3. Material and Methods

#### 3.1. Study Area

Kalpitiya peninsula is located in the Dry zone climatic region of North Western coastal belt of Sri Lanka, between 79° 40' Eastern Longitude and 7° 50'– 8° 30' Northern latitudes. The area belongs to the administrative boundaries of North Western province and Puttalam district. According to the Department of Census and Statistics of Sri Lanka 2011 records, 98,470 of total population in the area further distribute as 49,397 male population and 49,136 female population. The multi-cultural and multi-ethnic population of the area comprised with Sinhalese, Tamils, Burgher and Muslims. Kalpitiya peninsula records 500 -600 mm average annual rainfall mainly from the North East monsoon between December and February. October, November and December months usually record the annual highest rainfall values in every year. The ground water lens of the area mainly recharged by the North-Eastern monsoon period and the ground water table includes in the Coastal Sand aquifer. Maximum of 31oC to minimum of 27oC average annual temperature values record in the area. Due to this high temperature, humidity and evaporation is very high in this area. Altitudes of most parts of the peninsula do not exceed 10 meter elevation level as a result of being a coastal split.

#### 3.2. Methodology

The chemical characteristics of ground water were tested using both field testing and lab testing methodologies. Under 'field testing' thirty four (34) sampling wells were tested for Electrical Conductivity, pH and Salinity field measurements which were collected in situ. The Eutech's Cyber Scan CD650 Waterproof Handheld multipara meter was used for the well data collection processes. Total Dissolved Solids (mg/L), Chloride (mg/L) ,pH, Total alkalinity (TA), Total hardness (TH), Calcium, Magnesium, Sulphate , Fluoride ,Turbidity in NTU, Total Iron in mg/L (as Fe) and Nitrate in mg/L (as N) tested on chemical analysis under the lab testing for the thirty four (34) sampling locations. Data collections were done two times covering both wet and dry seasons of the area on July, 2014 for dry period & December, 2014 for wet period of Northeastern monsoon. Using the collected data a Water Quality Index (WQI)

was developed to appraise the ground water table's suitability as drinking water.

The following methodology was utilized in order to generate Arc GIS raster layers which were then used in developing a Water Quality Index (WQI) to appraise Dry Zone Coastal Ground Water Quality.

$$W_i = w_i / \sum w_i \quad \text{equation 01}$$

Where  $W_i$  is the relative weight and  $w_i$  is weight of each parameter which was given considering their apparent effects (1 to 5 being most important) on the relative significance in the overall quality of water for drinking purposes. The number of parameters is considered as value for 'n' and 'i' was considered as the  $i$ th sample location.

The equation 02.1 was utilized to calculate the quality rating of each parameter.

$$Q_i = (C_i / S_i) \times 100 \quad \text{equation 02.1}$$

Distinctly, the quality rating for pH and DO ( $Q_{pH}$ ,  $Q_{DO}$ ) was calculated using,

$$Q_i = (C_i - V_i / S_i - V_i) \times 100 \quad \text{equation 02.2}$$

Where,  $Q_i$  = the quality rating,  $C_i$  = value of the water quality parameter gained from the laboratory analysis results,  $S_i$  = value of the water quality parameter attained from recommended World Health Organization standards,  $V_i$  = the ideal value which is considered as 7.0 for pH and 14.6 for DO in precedent studies as identified in the literature review.

For finding the WQI, the sub-indices ( $S_{li}$ ) were first calculated for each parameter, and then used to compute the WQI as in the following equations.

$$S_{li} = W_i Q_i \quad \text{equation 03}$$

$$WQI = \sum S_{li} \quad \text{equation 04}$$

The figured WQI values were categorized as following.

1. <50 =Excellent
2. 50 - 100 = Good
3. 100 - 200 = Poor
4. 200 - 300= Very poor
5. >300 = Unsuitable

Spatial deviation of WQI values were analyzed applying inverse distance weighted (IDW) interpolation method in Arc GIS 10.3 interface. The World Health Organization standards permissible in Drinking Water (2004) used for each parameter and the relative weights calculated are described in table 01.

**Table-1**  
**The standards and relative weights for considered parameters of WQI**

	Parameters	WHO, 2004	Weight	Relative Weight
		$S_i$	$W$	relative weight ( $W_i$ )
1	EC $\mu$ s/cm	250	3	0.08
2	TDS mg/L	1000	5	0.13
3	Cl- mg/L	250	3	0.08
4	PH	8.5	3	0.08
5	Total alkalinity (TA)	200	2	0.05
6	Total hardness (TH)	300	2	0.05
7	Calcium (mg/L)	75	2	0.05
8	Magnesium (mg/L)	30	2	0.05
9	Sulphate (mg/L)	200	3	0.08
10	Fluoride (mg/L)	1	5	0.13
11	Turbidity in NTU	5	2	0.05
12	Total Iron in mg/L (as Fe)	0.3	2	0.05
13	Nitrate in mg/L (as N)	45	5	0.13
			39	1

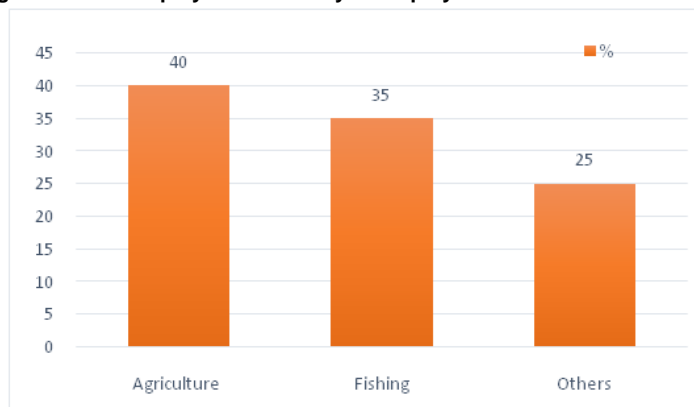
Sources: Compiled by authors using WHO

The necessity of Ground water for the livelihood options of population living in the coastal dry zone of Sri Lanka was established using 2013 Socio, economic statistical database of the Divisional Secretariat of Kalpitiya DS Division. The collected secondary data were analyzed by developing graphs and relevant maps and then compared with the Water Quality Index results.

**4. Results and Discussion**

The Employment diversity of the Kalpitiya area displays high priority on agriculture and fisheries making the income-generating pattern of the people of this area mainly depending on these two major sectors. Lagoon and Marine fisheries sectors and prawn cultivations are highly active in the area being very important economic sectors and agriculture is the other most important income source. Especially the Agriculture sector which is 40% (according to 2013 statistics of Kalpitiya Divisional Secretariat) dominate being very highly productive in mass scale vegetables and fruits cultivation.

Figure.01: The Employment diversity of Kalpitiya Divisional Secretariat area



Source: Source: Kalpitiya Divisional Secretariat, 2013

The area is considered as rich and fertile which grows both upcountry and low country vegetables and fruits without any variation in season in large quantities. The seasonal fruit and vegetable crops such as Carrot, Beet-root, Papaya, Grape fruit, Watermelons, Chilies, Lady’s Fingers and etc. which are cultivated in vast land extends are provided with additional water supply using underground pipe lines. Therefore the main land uses of the area are seasonal crop cultivations and coconut cultivations. Due to the less amount of rainfall receiving and no rivers available these livelihood options depends on the Shallow aquifer on coastal spits and bar type described as a “compound spill” (Panabokke, C. R., 2007). This groundwater aquifer recharge only with the seasonal rainfall therefore the area suffers with a constant water stress. For the additional water required for mass scale cultivations the water is pumped from large agro wells dug in the farm lands extracting the ground water in mass scale.

Figure 02 (Annex 1) illustrates the principle source of drinking water of households in the study area according to the Census and Statistics data of 2012. It indicates that apart from being rural or urban, the population of the area totally depends

on the available ground water resources applying added more pressure on the shallow ground water table of the Kalpitiya peninsula. Figure 03 (Annex 02) illustrates the pattern of ground water stress the area is struggling to face with the continuous and excessive water demand.

In order to evaluate the impacts of Dry Zone Coastal Ground Water quality changes a Water Quality Index was developed. WQI values obtained to assess the overall quality of ground water in the study area point out minimum 10.80 to maximum 2013.54 during month of July and minimum 36.27 to maximum 1499.27 during month of December. In the month of July only 12% of the Ground water sampling locations indicate excellent water quality and it decreases down to 6% in December. But the Water quality level of index value between 50 -100 which indicate good quality reported as 35% in July but 38% in December. Also the reported poor quality locations in July were 24% but it has increased to 29% in December and the 9% very poor quality locations in July has increased to 12% in December. Yet the locations with Unsuitable water quality which was 21% in July has been decreased in to 15% in December.

Table-2  
Number of locations and Percentages of reported WQI values

WQI Index value	Data Set 1 - July 2014	Data Set 2 - December 2014	Data Set 1 - July 2014 %	Data Set 2 - December 2014 %
Excellent	4	2	12%	6%
Good	12	13	35%	38%
Poor	8	10	24%	29%
Very Poor	3	4	9%	12%
Unsuitable	7	5	21%	15%

Sources: Compiled by authors, 2017

Accordingly 53% ground water sampling points in July and 56% in December are not in suitable standards to be used as drinking water as illustrated in figure 04 (Annex 3).

The December to February months of Northeast monsoon season is when the Kalpitiya peninsula receives high rainfall annually. Data Set two represents the month of December where averagely high rainfall occurs to the area. Conversely, July is the month of driest period when the lesser rainfall occurs during the Southwest monsoon of May to September. Data set

one of month July represent this season. Using the two data sets of sampling locations, GN wise spatial variation of WQI values were analyzed applying inverse distance weighted (IDW) interpolation method in GIS. According to the IDW interpolation analysis unsuitable ground water quality (WQI = 301< ) can be observed in more than 75% land areas of Annawasala, Kandakuli, Kudawa, Pudukudirippuwa, Kurinjipitiya, Palliwasalthure, Musalpitiya, Mudalappaliya, Palakudawa, Thalavila East, Norochcholea, Panayadiya and Alankudawa GN areas in month of July, 2014. In December 2014,

Mudalappalliya, Palakudawa, Norochcholea and Musalpitiya GN areas record unsuitable ground water quality (WQI = >301) which can be observed in more than 75% land areas. Accordingly the ground water of Mudalappalliya, Palakudawa, Norochcholea and Musalpitiya GN areas is unsuitable for drinking purpose in both Dry and Wet seasons of Kalpitiya area. In July, only Mukkuthoduwa, Palasola, Andan Kanniya and Ettale GN areas represent fair ground water quality (WQI = <101). All the other areas can be observed with poor (WQI = 101-200), very poor (WQI = 201-300) or unsuitable (WQI = >301) ground water quality. In December Nawakkadu, Daluwa, Thethapola, Nirmalapura, Viruthodai, Mukkuthoduwa, Palasola, Andan Kanniya and Ettale GN areas can be observed with fair ground water quality (WQI = <101). Other entire area more than 80% represents poor (WQI = 101-200) and very poor (WQI = 201-300) ground water quality.

Accordingly only Mukkuthoduwa, Palasola, Andan Kanniya and Ettale GN areas have good water quality in both Dry and Wet seasons and among them only Mukkuthoduwa represent excellent (WQI = <50) ground water quality in both Dry and Wet seasons figure 05 (Annex 4). Compared with the ground water changes, it is visible the same GN areas where the shallow water table is highly changing and the mass scale vegetable, coconut and fruit agriculture is popular face the worst water quality changes too. This evaluation on the impacts of Dry Zone Coastal Ground Water quality changes gives evident that water supply for the rural inhabitants will become impossible via the available ground water sources in near future.

Accordingly the sustainability of rural water supply is in question and consequently Kalpitiya peninsula can be named as an area with a highly contaminated ground water table. Further the results of this appraisal indicate the dry zone coastal areas of Sri Lanka is in a threaten situation regarding the visibly existent drinking water stress. If necessary precautions were not taken immediately, this tragic situation will be the common scenario of other areas of coastal belt as well adversely impacting on the population in socio-economic and environmental aspects. Therefore the dry zone coastal areas of the country are in need of immediate attention of policy level and planning intervention in order to prevent the subsequent impacts be a burden to the inhabitants.

## 5. Conclusion

Ground water is the most substantial method of potable and agricultural water supply especially in the rural areas of dry zone coastal belt in Sri Lanka. Over exploitation and vast utilization of ground water has led to accelerate the rate of ground water diminishing apparent from the recent past. Hastened exploitation of groundwater has caused water quality downgrading which consequently begun to cause higher adverse effects on public health and hygiene. Therefore this study focused on appraising the quality level of ground water

resource compositing the most considerable chemical parameters indicating ground water quality which is the main water source in the case study area of Kalpitiya Peninsula.

The major objective of this paper is appraising the impact of Dry Zone Coastal Ground Water Quality changes on the water supply for rural inhabitants in terms of spatial dissemination of ground water. The quality of ground water was assessed by developing a Water Quality Index (WQI) utilizing total thirteen (13) parameters taking the World Health Organization chemical parameter standards 2004 as the base. Thirty four (34) selected sampling wells were tested using both field testing and lab testing methodologies. Tested Parameters were Electrical conductivity, Total Dissolved Solids (mg/L), Chloride (mg/L), pH, Total alkalinity (TA), Total hardness (TH), Calcium, Magnesium, Sulphate, Fluoride, Turbidity in NTU, Total Iron in mg/L (as Fe) and Nitrate in mg/L (as N). Sub-indices for each parameter were calculated and then all the sub-indices were composited together to develop the Water Quality Index (WQI). Spatial deviation of WQI values were analyzed applying inverse distance weighted (IDW) interpolation method in Arc GIS 10.3 interface. According to the analysis 53% ground water sampling points in July and 56% in December are not in appropriate standards to be used as potable water. The IDW application indicates the ground water of Mudalappalliya, Palakudawa, Norochcholea and Musalpitiya GN areas is unsuitable for drinking purpose in both Dry and Wet seasons of Kalpitiya area. Only Mukkuthoduwa, Palasola, Andan Kanniya and Ettale GN areas have good water quality in both Dry and Wet seasons and among them only Mukkuthoduwa represent excellent (WQI = <50) ground water quality in both Dry and Wet seasons. More than 80% of the peninsula indicate adversely contaminated ground water table according to the appraisal indicating the possible threatening scenarios in dry zone coastal regions of the country. Linked with the ground water changes, it is evident with the WQI calculations that the same GN areas where the shallow water table is highly changing and the mass scale vegetable, coconut and fruit agriculture is popular are the areas which facing to the worst water quality changes too. Consequently the dry zone coastal areas of the country are in need of instant consideration of policy level and planning intervention in order to avoid the subsequent impacts on the basic demand for water of coastal population.

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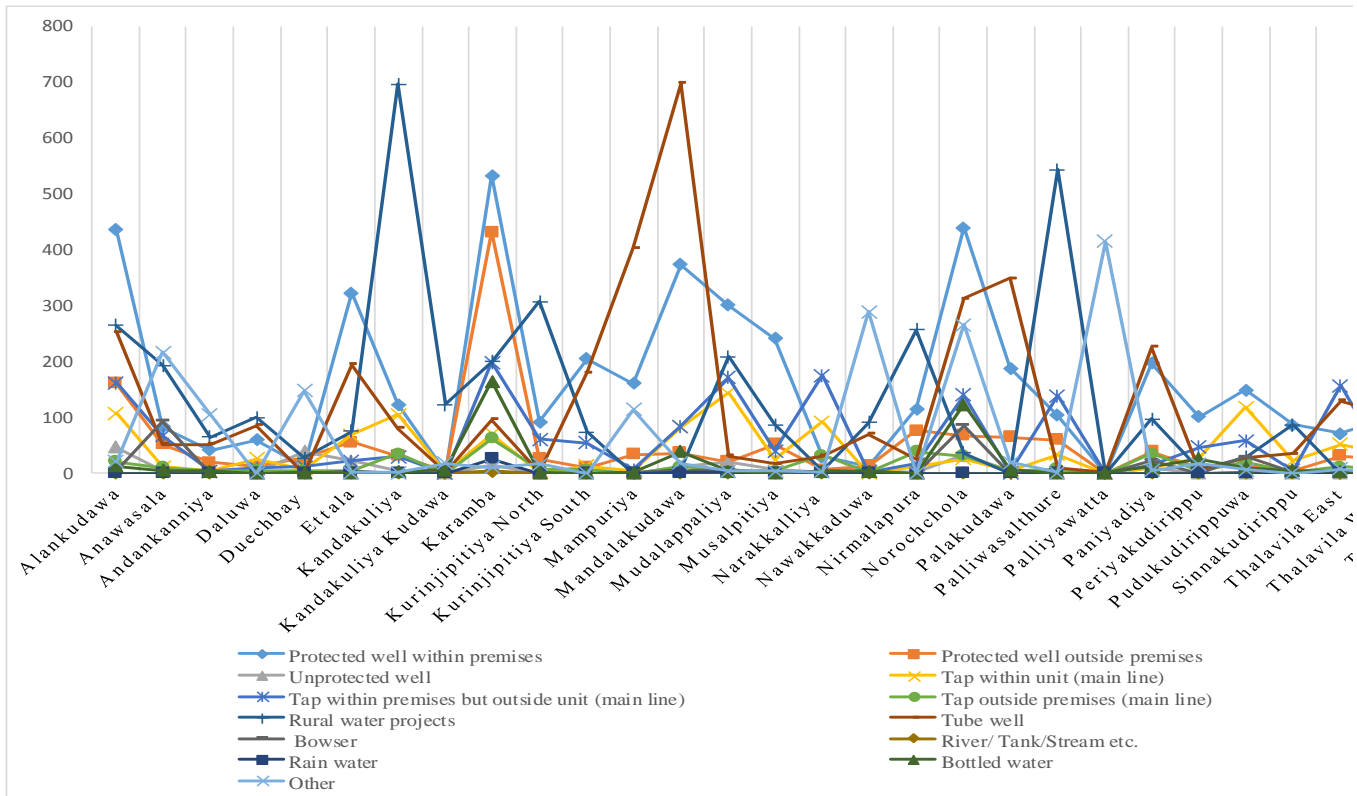
## References

1. Al-shujairi, S.O.H., (2013). Develop and Apply Water Quality Index to Evaluate Water Quality of Tigris and Euphrates Rivers in Iraq, 3, pp.2119–2126.
2. Bora, M. & Goswami, D.C., (2016). Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India. Applied Water Science. Available at: <http://link.springer.com/10.1007/s13201-016-0451-y>.
3. Census and Statistics data (2012), Department of Census and Statistics as retrieved on <http://www.statistics.gov.lk/>

4. Chugh, P. et al., (2014). On Water Quality Standards and Water Quality Indices. International Journal of Science and Research (IJSR), 3(8), pp.1–3. UNEP/WHO(1996) Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes; Edited by Jamie Bartram and Richard Ballance Published on behalf of United Nations Environment Programme and the World Health Organization © 1996 ISBN 0 419 22320 7 (Hbk) 0 419 21730 4 (Pbk)
5. Horton, R. K. (1965). An index number system for rating water quality. Journal of Water Pollution Control Federation, 37,300–305.
6. McGranahan, G.,Balk, D., B. Anderson., (2007), The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and Urbanization, International Institute for Environment and Development (IIED), Vol 19(1): 17–37.
7. Mophin-Kani K. & Murugesan A.G. (2011)Assessment of River Water Quality Using Macroinvertebrate Organisms as Pollution Indicators of Tamirabarani River Basin, Tamil Nadu, India, ISSN: 2224-7777(Online)
8. Nandalal, K.D.W., (2010) Groundwater Resources; Proceedings of the National Forum on 'Water Research Identification of Gaps and Priorities', Colombo, Sri Lanka. September, 16-17, 2010. Published by National Science Foundation, Sri Lanka; (pg 99-117)ISBN:978-955-590-109-3, Retrieved on <http://slwater.iwmi.org/sites/default/files/DocumentRoot/H043233.pdf#page=106>
9. Panabokke, C.R., (2007), Groundwater conditions in Sri Lanka ; Published by National Science Foundation of Sri Lanka: ISBN 978-955-590-079-9, Retrieved on <http://dl.nsf.ac.lk/bitstream/handle/1/5392/NA333.pdf?sequence=2&isAllowed=y>
10. Singh, S. & Hussian, A. (2016), Water quality index development for groundwater quality assessment of Greater Noida sub basin, Uttar Pradesh, India, Cogent Engineering (2016), 3: 1177155., <http://dx.doi.org/10.1080/23311916.2016.1177155>
11. Sirajudeen J. and Abdul Vahith R. (2014) Applications of water quality index for Groundwater quality assessment on Tamil Nadu and Pondicherry, India Journal of Environmental Research And Development Vol. 8 No. 3, January-March 2014 (Pg; 443) Department of Chemistry, Jamal Mohamed College (Autonomous), Tiruchirappalli, Tamil Nadu (INDIA)
12. World Health Organization (WHO) (2014), World Health Statistics, ISBN 978 92 4 156471 7 ISBN 978 92 4 069267 1 (PDF) (NLM classification: WA 900.1); Retrieved on [http://apps.who.int/iris/bitstream/10665/112738/1/9789240692671\\_eng.pdf](http://apps.who.int/iris/bitstream/10665/112738/1/9789240692671_eng.pdf)
13. WHO/UNISEF Joint Monitoring Program for water supply and sanitation (July 2004); Coverage Estimates of Improved Drinking Water. wssinfo.org
14. WHO (World Health Organization)(2004), Guidelines for Drinking Water Quality, 3rd Edition, WHO, Geneva, 2004.

Annex 01

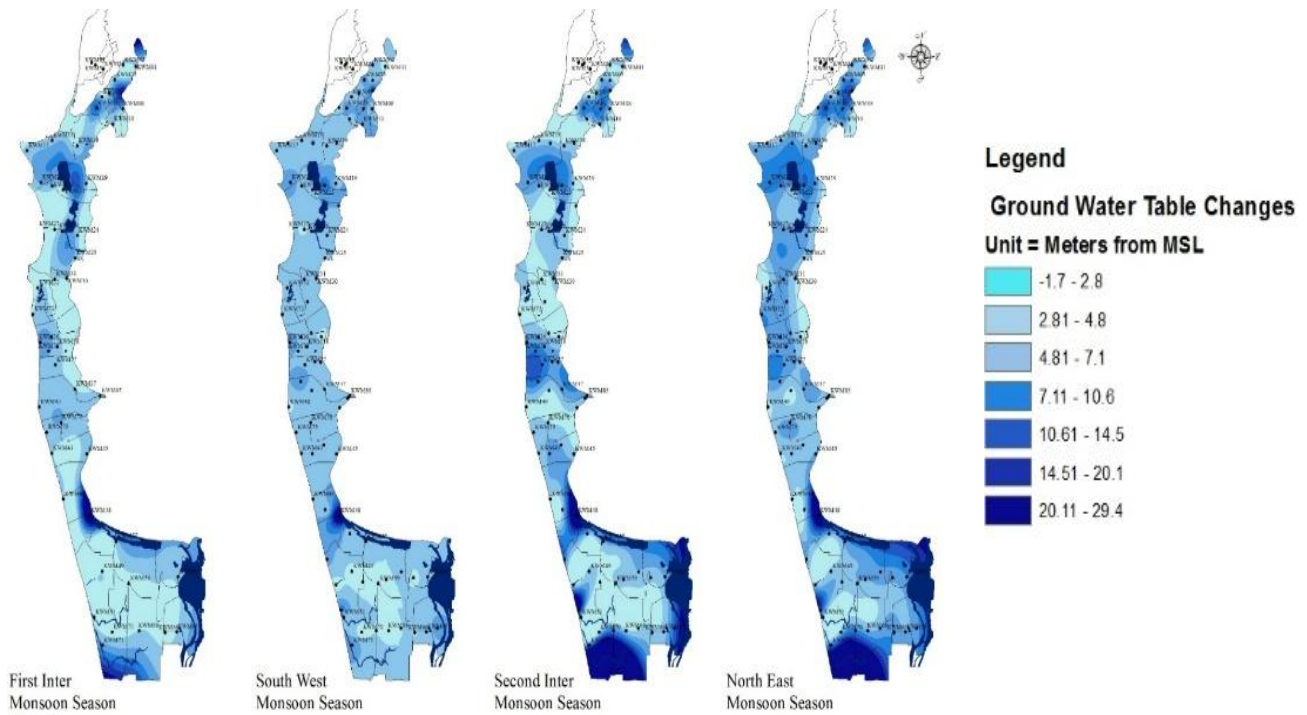
Figure.02: The principle source of drinking water of households in the Kalpitiya Divisional Secretariat area



Source: Prepared by authors using the data of Department of Census and Statistics, Sri Lanka, 2012

Annex 02

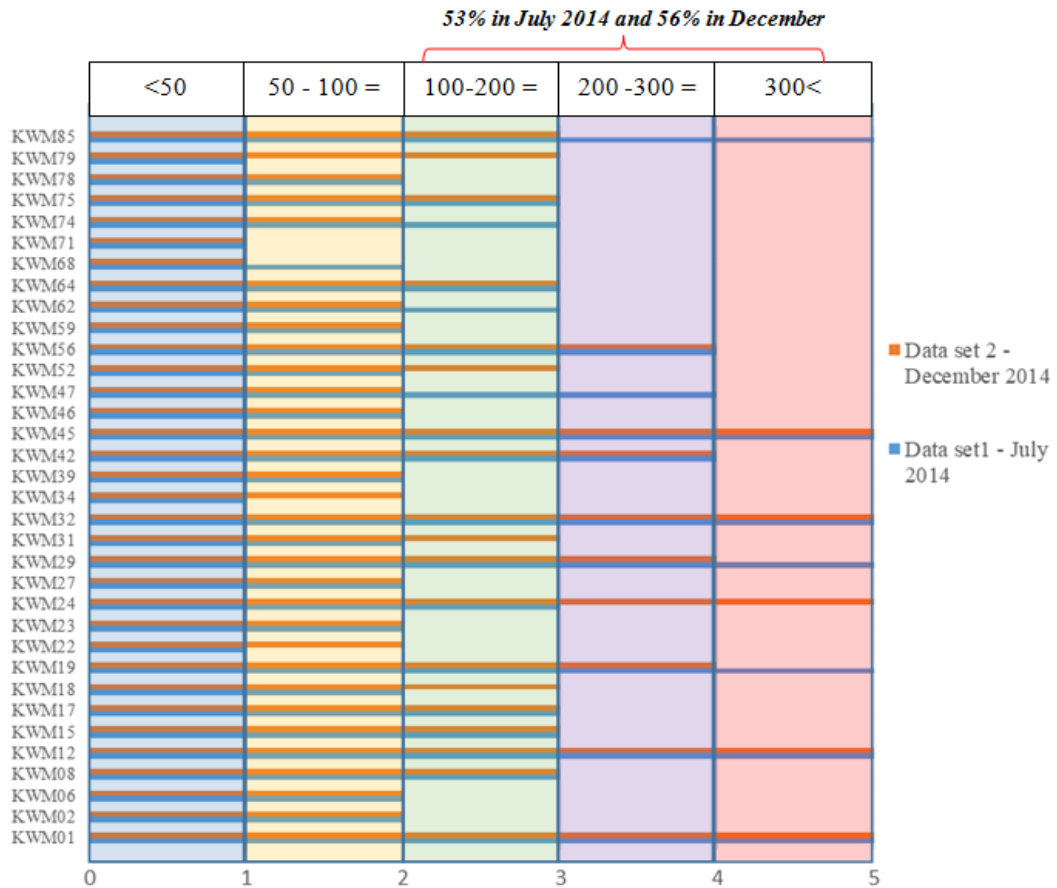
Figure.03: Ground water table fluctuations with the seasonal climate pattern



Source: Prepared by Author, 2016: Using Geographical Information System.

Annex 03

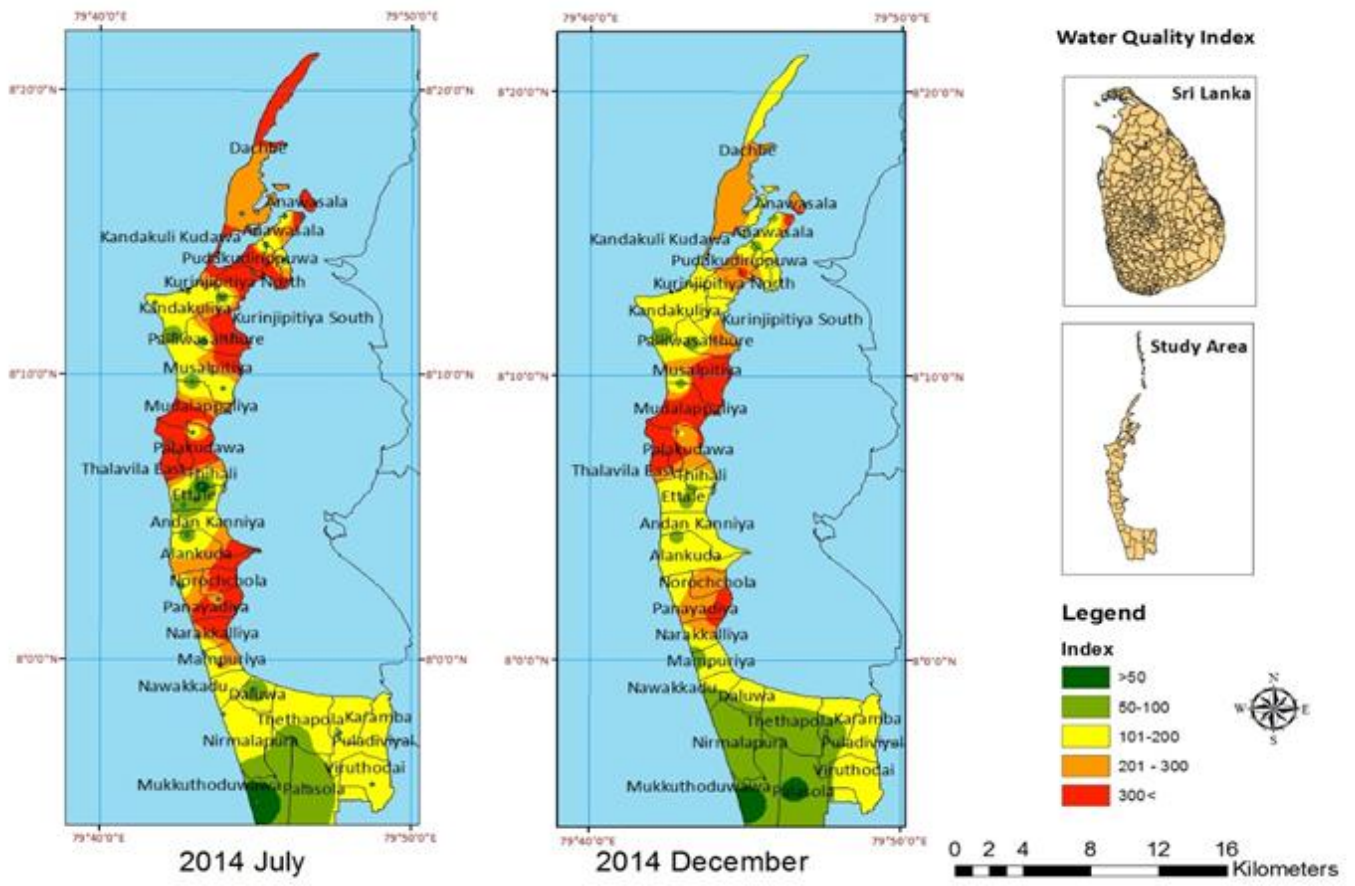
Figure 04: WQI values distribution according to sample location in the two periods



Sources: Compiled by authors, 2017

Annex 04

Figure.05: Water Quality Index values level – GN wise spatial distribution in Kalpitiya Peninsula



Source: compiled by authors, 2017