An assessment of groundwater quality of shallow tube wells using physio-chemical parameters at three villages of Kalpitiya peninsula of Sri Lanka

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Abstract— Coastal sand aquifer is the sole freshwater resource available in the Kalpitiya peninsula of Sri Lanka, where coconut plantation was prominent till 1970. Since then, intensive agricultural practices have been carried out using synthetic chemicals. This assessment aims to quantity the groundwater quality (n=33) of selected three villages where agriculture is the prominent activity by using shallow tube-wells for irrigation, in comparison with two prominent seasons, namely rainy and drought in 2020. Samples were collected using standard methods and tested through an accredited laboratory. The overall result reveals that there is no significant groundwater quality deviation with respect to the drought and rainy season of 2020; however, a third shallow tube-wells (n=11) WQI was above 50, which means poor to very poor groundwater quality, those wells are not suitable for direct human consumption. In contrast, a two-third tube-well WQI was below 50 means good groundwater quality with respect to the assessed physio-chemical parameters, which means the groundwater quality of respective shallow wells are not being affected by external pollutants.

Index Terms— Groundwater quality, physio-chemical parameters, Water Quality Index, Kalpitiya peninsula, Shallow tube-wells, drought and rainy season.

1 INTRODUCTION

Groundwater is one of earth's most vital renewable and/or non-renewable and widely distributed resources (Harshan et al., 2016). The quality of water is a vital concern for mankind since it is directly linked with human welfare. The per capita total water availability in Sri Lanka is estimated at around 2800 cubic meters per year, which suggests that Sri Lanka is adequately endowed with water resources for daily requirements by 2025 (Panabokke, 2007). Sri Lanka's groundwater reserves have been distributed within six main types of aquifers (karstic, coastal, deep confined, lateritic, alluvial, and shallow regolith) (Panabokke and Perera, 2005).

The Northwest coast of Sri Lanka, where Kalpitiya has located, consists of the shallow aquifer (coastal spits and bars), which has the thinner lense of freshwater, and it is more easily subjected to depletion or eutrophication since the associated beach sand consists of fine sand particles and wash deposits permits excellent perennial freshwater aquifer. (ref Panabokke). Re-charge is by direct infiltration from both rainfall and returns irrigation flows. Prior to the introduction of irrigated agriculture, groundwater flow under the peninsula would have been to the sea and the lagoon. A thin freshwater lens occurs in the sand and is present at depths of 1 – 3 m over most of the peninsula with the highest groundwater levels in monsoonal wet periods, and this can decline down to 4 – 6 m during extended dry periods and as a result of groundwater lens overexploitation. (ref)

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Though the volume of freshwater in these aquifers usually expands during the rainy season and contracts during the dry season with fluctuating brackish and saline boundaries. So, over-extraction from these freshwater lenses results in the coning or entering of the underlying brackish water into the freshwater (Panabokke and Perera, 2005).

Further, the quality of water plays a prominent role in promoting both the standard of agricultural production and human health. On the other hand, agriculture is the dominant livelihood of the population of the Kalpitiya peninsula. Until the late 1970s, the Peninsula agriculture was based essentially on coconut plantations and some tobacco crops. However, taking advantage of a relatively fresh groundwater reservoir at shallow depth and of the well-drained and aerated soil, settlers started intensive and diversified cultivation of cash crops in the early 1980s. People extract the groundwater from the shallow tube wells for their agricultural activities (Lawrence and Kuruppuarachchi, 1986).

A study carried out by Samanmali et al. to assess the groundwater quality in the entire Kalpitiya peninsula says that the average pH values were recorded between 6.8 and 8.5 mg/L, Average Electrical Conductivity (EC) was recorded between 103 µS/cm – 33016 µS/cm within these three months (October and January 2014), and average Electrical Conductivity levels were greater than the 750 µS/cm exceeding Sri Lankan standards. Thus, it is apparent that groundwater in the area could not be recommended for domestic consumption, at least during the dry season. Changing climate resulting in less rainfall and sea-level rise will aggravate the problem (D. Samanmali et al., 2014).

In this context, three villages (Mampuriya, Narakkalliya, and Panayadiya) of Kalpitiya were selected to assess the groundwater quality by using the Water Quality Index (WQI) of selected shallow tube wells using a random sampling method.

The water quality index aims at giving a single value to the water quality of a source, reducing a great number of parameters into a simpler expression, and enabling easy interpretation of monitoring data (Bharti and Katyal, 2001). The water quality index (WQI) has emerged as a central way to convey water quality information to policymakers and the general public and is regularly used for regulatory impact analysis. It is a compound indicator that aggregates information from several water quality parameters (Walsh and Wheeler, 2012). The purpose of this assessment is to provide an overview of the existing groundwater quality of the selected three villages using the standard WQI recommended for water quality.

2 Statement of the Research Problem

In the Kalpitiya peninsula majority of the land is being under cultivation which uses groundwater intensively for irrigation as this is the only water source. The groundwater level is largely fluctuating with the prominent seasonal variation; These aquifers are re-charged mainly during the 3-4 months of rain in the wet 'maha' season (October to January), and water in these aquifers then gets collected in the form of a freshwater 'lens' floating above the denser saline water. The volume of freshwater in these aquifers usually expands during the rainy season and contracts during the dry season (June to August) with fluctuating brackish and saline boundaries. Due to the very permeable nature of the sandy soil and the essentially flat topography, the part of the rainfall, which is not evapotranspiration, essentially infiltrates into the subsoil. (Panabokke and Perera, 2005). The fresh groundwater table has the profile of a thin lens reaching an elevation of about 2 meters above sea level in the centre of the peninsula. (Lawrence et al., 1986). With reference to the above facts, it has been observed many frequent flood events during intensive rainfall of maha season; due to this, the groundwater table reached above the mean sea level. On the other hand, during the dry season, the groundwater table is between 3-4 meters below ground level.

In this context, it is essential to assess the groundwater quality with the seasonal variation to provide an overview of the quality using WQI value derived from selected physio-chemical parameters of water because of the significant fluctuation of groundwater table with the season.

3 Objective of the Research

The main objective of this study is to identify the groundwater quality by developing WQI using selected physio-chemical parameters of drinking water in selected shallow tube wells of three villages in the Kalpitiya peninsula with reference to two seasons.

4 Material and Methodology

4.1 Study area

Kalpitiya is a low-lying sand peninsula on the northwest coast of Sri Lanka, and it covers a total land area of about 160sq km. It was located between 79° 40'– 79° 50' Easting longitude and 8° 20' – 8° 90' Northern latitude. Figure 1 shows the map of the study area. Geographically it is bordered by the Indian Ocean from one side and Puttalam lagoon from inland. Coconut land, sand dunes, scrubland, and agro cultivated lands are the mainland cover in the Kalpitiya peninsula [4]. Coconut and agricultural fields are the main two land-use sectors in this area. The climate is characterized by average annual rainfall between 500 – 600 mm from the North-East monsoon between October and January. The average annual temperature of the Kalpitaya is a maximum of 31^{o}C to a minimum of 27^{o}C. (rewrite)

Table 1

Village name	Population	Land area (Acres) (2018)	Cultivated area (Acres) (2018)	Number of samples
Mampuriya	2922	875	563	11
Narakalliya	1860	875	340	11
Panayadiya	2680	1750	586	11

The below figure shows the study area.

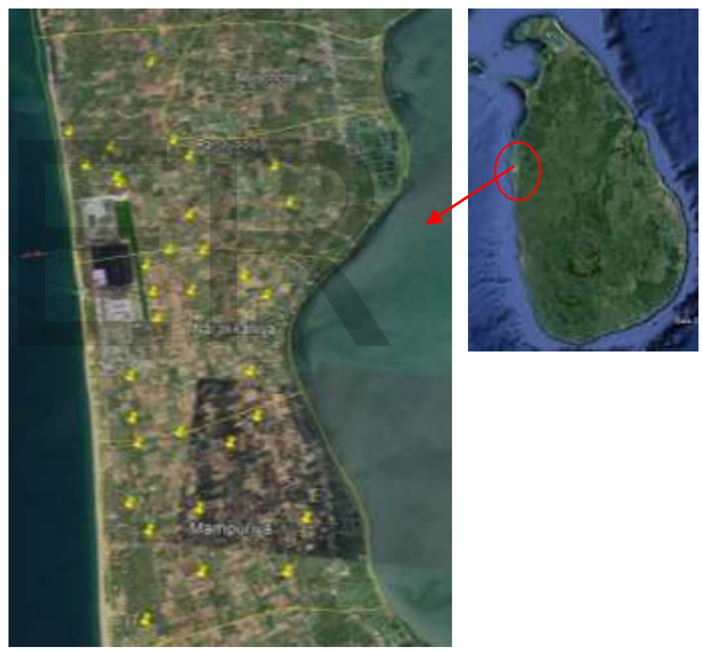

Figure 1; Sampling location of three villages in Kalpitiya

4.2 Sampling size

At the initial stage of the study, a preliminary study was carried out to have a general idea regarding the study area and distribution pattern of the tube wells within this area. Accordingly, 33 shallow tube wells within the selected three villages were selected based on the total number of existing shallow tube-well found in each village. Each tube well was nominated with specific numbers. The drought period samples were collected from May to June, and the rainy period samples were collected from December to January. The average measured groundwater table was 2.5 m and 0.9m, respectively.

4.3 Sampling technique

GPS coordinates of each tube well were recorded using Explorist

510 Version 6.04 MAGELLAN GPS Tracker instrument. Samples were collected following standard procedures and guidelines. Approximately two sample bottles with the volume of 500 ml and another sample bottle with the volume of 02 liters were carefully filled from extracted water from each tube well separately. A sample bottle of 500 ml was added 2.5 ml of HNO_3 (65 % analytical grade) at the sampling site, and all the bottles were sealed without trapping air bubbles. Water samples were analyzed at the accredited laboratory.

Electrical Conductivity (EC), pH, Turbidity, Sodium (Na), Chloride (Cl), Total Hardness, Total Alkalinity, Salinity, Total Dissolved Solids (TDS), were analyzed using relevant instruments and titrimetric methods and Chromium (Cr), Arsenic (As), Cadmium (Cd), Barium (Ba) and Lead (Pb) in water samples using ICP-MS. Standard procedures were followed for the analysis of each parameter of the water samples, as mentioned below in table 2.

Table 2

No	Parameter	Unit	Methodology
01	Temperature	^0C	No
02	Turbidity	NTU	APHA-2130:B 22nd Edition
03	pH at 25 $^OC \pm 2\ ^OC$		APHA-4500-H+:B 22nd Edition
04	Electrical Conductivity	$\mu S\ cm^{-1}$	APHA-2510:B 22nd Edition
05	Total Hardness (as $CaCO_3$)	$mg\ L^{-1}$	APHA-2340:C 22nd Edition
06	Total Alkalinity	$mg\ L^{-1}$	APHA-2320:B 22nd Edition
07	Total Dissolved Solids	$mg\ L^{-1}$	Calculated
08	Chloride (as Cl)	$mg\ L^{-1}$	APHA-4500-Cl:B 22nd Edition
09	Sodium	$mg\ L^{-1}$	APHA – 3500: Na:B
10	Salinity	Ppt	APHA-2520:B 22nd Edition
11	Chromium (as Cr)	$\mu g\ /\ L^{-1}$	USEPA 200.8
12	Barium	$\mu g\ /\ L^{-1}$	USEPA 200.8
13	Arsenic (as As)	$\mu g\ /\ L^{-1}$	USEPA 200.8
14	Cadmium (as Cd)	$\mu g\ /\ L^{-1}$	USEPA 200.8
15	Lead (as Pb)	$\mu g\ /\ L^{-1}$	USEPA 200.8

Table 2 below shows the Sri Lankan Standard (SLS 614: 2013) recommended for drinking water quality.

Table 3

Parameter	Unit	SLS
Temperature	^0C	No
pH	-	6.5-8.5 (at 25ºC + 2 ºC)
Turbidity	NTU(max)ppm	2
Electrical conductivity(EC)	µS/cm	750-3500
Total dissolved Solid(TDS)	ppm	500
Sodium	(as Na) ppm	200
Chloride	(as Cl) ppm	250
Total hardness (as $CaCO_3$),	ppm	100-300
Total Alkalinity	ppm	200
Salinity	ppt	No
Cadmium	(as Cd) ppb	3
Lead	(as Pb) ppb	10
Arsenic	(as As) ppb	10
Chromium	(as Cr) ppb	50
Barium	(as Ba) ppb	No

4.4 Calculation of WQI

Weighted arithmetic index (Khwakaram, 2012) was used to calculate the Water Quality Index (WQI). In this method, different water quality parameters are multiplied by a weighted factor and are then aggregated using simple arithmetic mean (Ravi,2016). By using the following equation calculated the rating scale of Qi for individual parameters;

Qi = [(Vactual-Videal) / (Vstandared - Videal) *100

Where,

Qi – Quality rating if the ith parameter for a total n water quality parameters.
V actual – Actual value of the water quality parameter obtained from the analysis.
V ideal – Ideal value that quality parameter obtained from the standard tables.
(V ideal for pH = 7 and for the other parameters, it equals 0).
V standard – recommended standard of the water quality parameter

The relative weight is calculated by using the following equation;

Wi = I/Si

Where,

Wi – relative (unit) to for the nth parameter
Si – Standard permissible value for an n^{th} parameter
I – Proportionality constant

The Wi (relative wright) to various parameters are inversely proportional to the recommended standards.

The **WQI** is,

WQI = ΣQiWi / ΣWi

Where **Qi** – Quality rating, **Wi** – Relative (unit) weight

The WQI is categorized into five groups to describe the level of groundwater quality from 0 to 100.

WQI	Description
Excellent	0-25
Good	26-50
Poor	51-75
Very poor	76-100
Unsafe	above 100

5 Results and Interpretations

5.1 Seasonal variation of WQIs

The seasonal variation of WQI is presented in fig 2 below.

Figure 2; WQI of all shallow wells during rainy and drought season in three villages

Fig 2 shows that only one (well No 33) WQI value less than 25 means the groundwater quality of this well is in excellent condition during both seasons. Additionally, another shallow tube well (well No 17) shows excellent groundwater quality during the rainy season only, whereas twenty-five (25) shallow tube wells show WQI between 26-50 during the rainy season and twenty-one (21) during drought season. However, during the rainy season, eleven shallow tube wells (11) and four (04) shallow tube wells during drought season have average WQI values between 51 to 75. Additionally, only one shallow tube well (01) WQI value was 80 during the rainy season, and another shallow tube well shows WQI of more than 100 in both seasons (well No 32). Further, among these shallow wells, a third (11 shallow wells) were ranked above WQI 50 during drought season, whereas six samples were during the rainy season. It means the groundwater quality of such shallow wells was poor to very poor.

Nevertheless, Average WQI of all shallow wells comparatively higher in drought season. Further, above two-thirds of total shallow tube-well samples (22 out of 33) show good to excellent water quality irrespective of the seasons. However, the WQI differences in both seasons were insignificant except in some shallow tube wells; those were well numbers 14, 15, and 16.

5.2 Village WQI comparison

The below three figures show the WQI value of all three villages considered.

Figure 3; WQI of Mampuriya village

Fig;3 shows that the Mampuriya village found only three occasions (27%) exceeding the WQI 50. In contrast, all other shallow tube-wells WQI during both seasons within the range between 25 to 50 means good groundwater quality.

Figure 4; WQI of Narakkalliya village

Only six shallow (55%) tube-wells WQI value below 50 means good water quality, whereas nine shallow tube-wells WQI values are greater in drought season compared to the rainy season. However, the observed maximum WQI value was 65 in this village.

Figure 5; WQI of Panaiadiya village

Eight shallow wells (72%) WQI were below 50 in both seasons means good groundwater quality, whereas two wells were between WQI 50 to 60, which means poor quality, and one well exceeds the WQI 100 in both seasons categorized as very poor water quality.

6 Conclusion

Interestingly the lowest WQI (17) and highest WQI (113) were observed at Pannaiyadiya, which may be due to the influence of the land use pattern of the surroundings. Further, it can be concluded that the seasonal influence of the groundwater quality of shallow tube wells is less significant among these considered villages. However, around two-thirds of the shallow wells water quality is in good condition (WQI below 50). On the other hand, one-third of the shallow tube-wells water quality is not suitable for direct human consumption in all three villages.

7 Discussion

According to the obtained results from this study area, the following recommendations could be derived considering the cultivation pattern, geological characteristics, and climatic variation;

A proper pumping procedure and fertilizer usage application shall be implemented by the relevant government authority to prevent seawater intrusion and to contaminate the soil and groundwater from the excess usage of fertilizers.

Conventional treatment for the groundwater may not be adequate to meet the SLS standard for drinking water quality. Hence, advanced treatment systems such as Reverse Osmosis (RO) shall be installed to purify the groundwater to archive SLS standards.

Considering the increasing level of local demand on the vegetable market that drives the farmers to apply excess fertilizer usage might directly contaminate the groundwater because the soil condition and groundwater levels are many potentials to instantly permit the irrigation infiltration to the groundwater.

Finally, this study has some limitations to assess all potential parameters with the timeline to monitor the changes in groundwater quality, so the effort to do the continuous groundwater quality monitoring and groundwater pumping pattern would be necessary to implement to safeguard the groundwater quality of this area.

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