Hydrogeological Characterization and Spatiotemporal Variation of Groundwater Chemistry at Lakvijaya Coal-Fired Thermal Power Plant Area, Norochcholei, Sri Lanka

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Abstract: The Lakvijaya power station is the largest in Sri Lanka, and it is utilized groundwater for landscaping activities of its premises. The demand of 1,400 m3/day is extracted through a shallow well field existing within the premises, and the peripheral densely populated farmlands are also extensively abstracted groundwater from this highly vulnerable shallower coastal aquifer which is under threat of salinization by either seawater intrusion or upconning due to the influence of groundwater depletion with subsequent deterioration of water quality as well. The initial baseline assessment of hydrogeology and geochemical distribution was carried out in 2018, followed by quarterly assessment of groundwater level & water quality through an established groundwater monitoring network in 2019 and 2020. Biological Oxygen demand (BOD), Chemical Oxygen demand (COD), Dissolved oxygen (DO) and Physio-chemical parameters of Electrical Conductivity (EC), Total Hardness, Alkalinity, Total iron, Salinity, Total Dissolved Solids (TDS), F^-, NO_3^-, Ca^{2+}, Mg^{2+}, CO_3^{2-}, Cl^-, SO_4^{2-}, PO_4^{3-}, Na^+ and K^+ were tested during the process. The analysis have identified a correlation between the higher elevated levels of EC, Hardness, TDS, Mg^{2+}, Cl^-, Sulphate & Salinity distribution and zones where groundwater is being excessively utilized. Incipient level of seawater upconning or localized saliniazation is observed within these higher abstraction zones of inland farming areas including the Power plant area which inevitably demand the requirement of appropriate management. However, the groundwater quality within the power plant area is reflected progressive restoration after regulatory measures effect on the abstractions from 2019 as observed from the quality variations detected in 2020. The NO_3^- (20.0 -50.0 ppm) and PO_4^{3-} (2.1- 3.5 ppm) in groundwater are comparatively higher nearing permissible levels at the eastern flank of the study area where extensive farming is in operation. This may be attributed to infiltration of excessively used fertilizer within this high permeabile sandy soil. High COD and low DO levels were indicated the possibility of groundwater contamination by wastewater with high organic matter content. However, Low BOD reflecting the number of micro-organisms in the water is minimum.

Keywords: Water Quality, Groundwater, Salinization, Power Plant.

1. Introduction

Groundwater provides most freshwater. Monitoring and protecting groundwater is critical since it is dynamic and affected by irrigation, excessive abstraction, industrialisation, and urbanization (Qiu *et al*., 2021). Coal power plants release toxic effluent and other pollutants that can contaminate groundwater aquifers. Polluted groundwater harms humans (Qiu *et al*.,

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2021). Monitoring and assessing hydrochemistry changes in groundwater is critical for early contamination or modifications.

Sri Lanka's largest power plant is Lakvijaya. Quarterly, a groundwater monitoring network in the power plant's vicinity examines the hydrogeological situation and baseline hydro-geochemistry. The community and power station use shallow groundwater for agricultural, drinking, and beautification. Only power plant landscaping uses groundwater. The equilibrium between rainfall recharge and flood irrigation waters impacts this shallower sand aquifer's groundwater level and storage volumes. Drinking water is a global social and environmental issue. Groundwater conservation and management are issues with global development. Physical, chemical, and biological water qualities compared to standards (Verma, 2018). The primary objective of this study was hydrogeological and water quality assessment through long-term monitoring to identify the variation of water chemistry and possible contamination by power plant operations and groundwater abstractions by the well field within their land premises to peripheral area, providing the baseline condition and variations with time to facilitate sustained management of the resources by early preventive measures. Data for 2019–2020 are analyzed. Aquifer testing on the well field was done to estimate the safe yield and establish a pumping strategy to limit groundwater abstractions in 2019 at the power plant.

2. Study Area

The Lakvijaya power station is located near Panayadiya and Narakalliya, Kalpitiya DSD of Puttalam District. 160 km² Kalpitiya Peninsula borders the Indian Ocean and Puttalam lagoon. These populations rely on cash crop agriculture and shallow groundwater from the NS coastline that formed the Kalpitiya Peninsula.

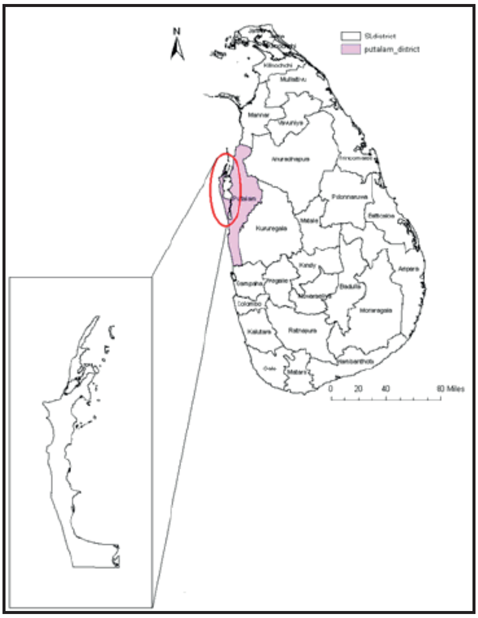

Fig. 01 - The regional view of Kalpitiya Peninsula

The North-western coast aquifer is shallow and features Quaternary sandy aquifer media (Jayasingha *et al.*, 2011). The topography is generally flat, except for prehistoric and monsoon-formed dunes. Palavi is the lagoon's southernmost land bridge. Unconsolidated sand offers a freshwater aquifer 6 to 9 m below MSL; it grades into sandstone. Clay-mixed mudstone occurs in sandstone. Underlying limestone unconformity. Kalpitiya's fossiliferous limestone is 60 m thick. Consistently hot. Average annual temperatures are 31ºC and 26ºC, with 950 mm to 1050 mm of rain.

3. Material and Methods

There are more than 75 tube wells existed within the power plant premises which are all shallower wells in the depth range merely of 4-10 meters. Out of these 75 numbers of existing wells, 15 numbers of wells and another 35 numbers of tube wells located outside peripheral area of the power plant were selected for initial sample collection. 20 numbers of tube wells within the premises were selected for aquifer testing. Groundwater levels were monitored on these water sources throughout the study.

3.1 Aquifer Testing

The pumping test were conducted out for 24 hours pumping with 95% recovery at chosen 20 tube wells. After the calibration test, 20 tube wells were pumped continuously. The nearest wells were taken as observation wells. Groundwater level of the pumping and observation wells were recorded over regular intervals to assess whether there is an influence on the surrounding environment.

3.2 Sample collection

Water sampling is the major activity of this study since it shows the area's baseline water chemistry and its fluctuation over time to detect the affects of abstractions on quality deterioration and aquifer depletion. Under conventional guidelines, 50 wells were sampled. First batch was obtained in October 2019, and second and third in August 2020 and December 2020 respectively. After initial sampling, the power plant established suggested abstraction levels. Despite regulations, tube wells in outlying areas are used for agriculture.

3.3 Groundwater Chemistry

Based on the initial baseline hydrogeological and water quality evaluation, the next two quarters of groundwater monitoring were assessed. Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), and Physio-chemical parameters such as color, temperature, turbidity, pH, Electrical Conductivity (EC), Total Hardness, Alkalinity, Total iron, Salinity, Total Dissolved Solids (TDS), NO^{3-}, Ca^{2+}, Mg^{2+}, $CO_3{}^{2-}$, Cl^-, $SO_4{}^{2-}$, and $PO_4{}^{3-}$ were analyzed in BOD, COD, and DO were measured within 24 hours using APHA 5210 B, 5220 D, and 4500 OG. Colors were measured by colorimetry (APHA - 2120: B 23rd Edition), pH was measured using an electrometer (APHA - 4500-H+: B 23rd Edition), EC was analyzed by a conductometer (APHA - 2510: B 23rd Edition), Total Hardness, Ca^{2+}, Mg^{2+}, were determined by EDTA titrimetric analysis, Alkalinity was determined by neutralization titration, $NO_3{}^-$ The water quality spatial distribution maps were created per parameter using ArcGIS 10.3 to determine the fluctuation of hydro-geochemistry across time and place.

4. Results and Discussion

4.1 Groundwater level

The power plant and pheripheral area are 4.5 meters above sea level. Since the study area is flat, groundwater levels vary from 0.5-5.00 m below ground level (mbgl). Continuous pumping in the farmlands made static groundwater level monitoring challenging. Despite massive abstractions, groundwater levels tend to stabilize with a low drop of 0.3-0.5 m during pumpings due to the highly permeable and fertile coastal sandy aquifer. Increased electrical conductivity (EC) at high abstraction sites. The groundwater level hasn't dropped significantly. This implies that sea water intrusion is the sole

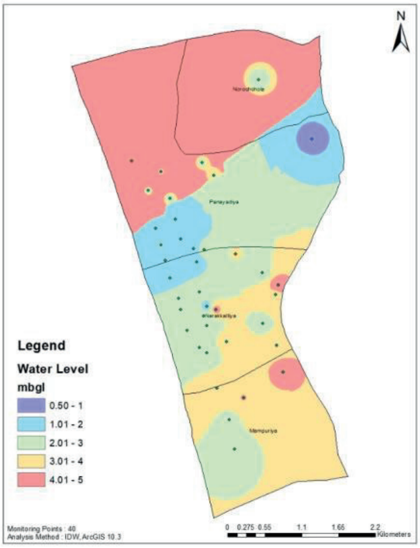

Fig. 02 - Groundwater Elevation Map of the study area

possibility, as there are no other groundwater recharge sources save direct precipitation into this isolated coastal aquifer floating on a high-salinity water body. Seawater incursion or upconning cause uncontrolled abstractions.

4.2 Aquifer Testing Results

Regional hydrogeological flow regime suggested groundwater moved towards the sea from the interior, creating a hydraulic head gradient between the sea and inland freshwater aquifer, allowing for bigger groundwater extraction. When considering sea water intrusion or upconing, aquifer testing must evaluate safe well field abstraction quantities. Since the aquifer contains sand, its permeability and storage properties are good (Fogg, 1986), leading in little depletion despite high discharge rates. Even at 400 lpm, the highest drawdown at Lakvijaya Power Plant was 1-3 cm, and 95% recovery took less than a minute. All wells test positive. Salinity and electrical conductivity of groundwater did not alter throughout pumping. Despite this aquifer's high output, just 60% of its maximum capacity was recommended, with rest periods.

This sandy aquifer tube well field is used for gardening. Due to sandy soil and aquifer, much of the extracted groundwater infiltrates back into the aquifer, decreasing the impact (Heiss *et al.*, 2014). Parallel pumping from these well fields is not recommended because wells are close (10-15 meters) and reaching the same aquifer is unacceptable (Harvey *et al.*, 1994). Groundwater abstraction amounts and pattern were determined to minimize long-term influence on this fragile aquifer.

4.3 Chemical Test Results

The results of initial hydrogeological and water quality assessment followed by the quarterly monitoring suggests considerable quality improvement in groundwater as evidenced in some chemical parameters were exhibited lower values with time. This is due to regulated abstractions in the power plant. During monitoring, the groundwater chemistry of agricultural fields' periphery deteriorated.

4.3.1 Electrical conductivity (EC), Total Dissolved Solids (TDS) and Salinity

EC predicts groundwater quality whereas TDS measures dissolved minerals to demonstrate salinity. Conductivity depends on dissolved minerals and temperature. EC and TDS reflect total dissolved solids (TDS) or the early examination, ranged from 318

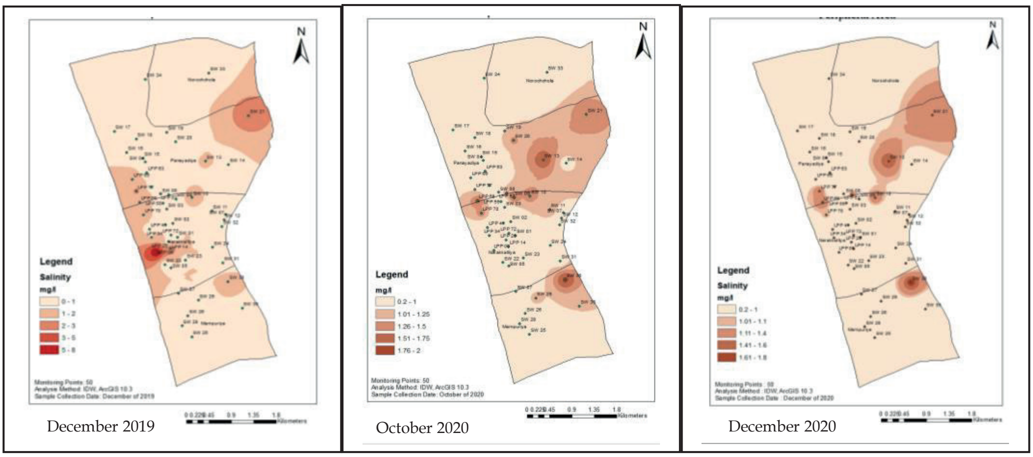

Fig. 03 - Variation of the Electrical Conductivity of the groundwater in the study area

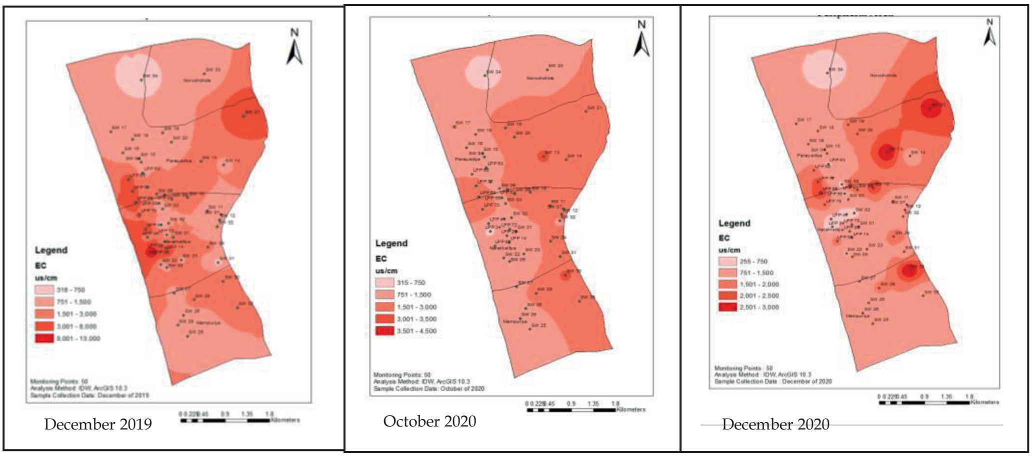

Fig. 04 - Variation of the Salinity of the groundwater in the study area

to 13,000 uS/cm. EC values ranged from 315 uS/cm to 4,500 uS/cm between October 2020 and December 2020. (Fig.3). Total salt concentration in groundwater, measured by EC, is an important feature. EC of 750 uS/cm - 1,500 uS/cm provides no harm to human health, per SLS. According to the WHO, EC over 3,500 uS/cm is harmful. EC over 1500 uS/cm is distributed (Fig.03), which coincides with low groundwater levels.

These patchy areas are mostly found east of Lakvijaya Power Plant, where agricultural cultivation is prevalent. The salinity decreased from the initial evaluation to the fourth quarter of December 2020, ranging from 0.0-8.0 ppm, 0.2-2.0 ppm, and 0.2-1.8 ppm due to regulated pumping of the well field.

From the baseline assessment, TDS in groundwater has decreased. It's 150-7,000 ppm, 155-2,000 ppm , and 126-1,500 ppm. WHO allows 500 ppm TDS in groundwater and 2,000 ppm is the maximum (Verma, 2018). 1,000-3000 ppm TDS is salty groundwater (Verma, 2018). The area's groundwater is mostly non-saline. High TDS (above 1200 ppm) in drinking water tastes bad to humans (Verma, 2018).

Irrigation can affect the growth of TDS in groundwater in several ways, especially in dry locations. As irrigation water evaporates or is absorbed by plants, dissolved salts seep into groundwater. Saltwater can harm the power plant and neighboring agricultural areas due to previous groundwater depletion. Under permitted pumping rate, EC, Salinity, and TDS improved near the power plant.

4.3.2 Total hardness, Calcium and magnesium

Most groundwater hardness is caused by limestone, sedimentary rock, and calcium-bearing minerals (Cloutier *et al.*, 2008). Chemical and mining wastewater or excessive lime application in agricultural regions can harden groundwater locally. Over pumping might also deplete the limestone aquifer. Overabstraction may cause hard groundwater in December 2019. Table 1 shows how these values have declined over time. According to WHO guidelines, the permitted amounts of Hardness, Ca^{2+}, and Mg^{2+} in drinking water are 250 ppm 100 ppm, and 30 ppm (if SO_4^{2-} = 250 ppm) – 150 ppm (if SO_4^{2-} 250 ppm). The control of groundwater abstractions from the well field within the power station improved total hardness, Ca^{2+}, and Mg^{2+} levels in groundwater compared to the peripheral agricultural region where heavy abstraction is still practiced.

4.3.3 Chloride and Sulphate

Sulphate and Chloride averages match the research area (Table 1). High groundwater abstraction causes gradual salinization, increasing chloride and Sulphate levels. Due to controlled pumping, the elevated levels of cl and so4 in groundwater diminish in the next two monitoring analyses. Sulphate and chloride are both 250 ppm in drinking water. However, substantial concentrations of Sulphate may also emerge in shallow, unconfined aquifers that receive large inputs of sulphate from atmospheric deposition. Despite heavy farming activity in the adjacent agricultural areas, Cl or SO_4 are identified only at near-permissible levels. High SO_4^{2-} levels in a power plant area are hard to explain without salinization.The fertilizer use and land use of animal wastes research area's average concentrations of Total Iron, Fluoride, NO_3^- and PO_4^{3-} were around their acceptable ranges of 0.30 ppm, 1.0 ppm, 50.0 ppm and 2.0 ppm.

4.4 Biological Parameters

Seasonal changes in DO levels are seen. Microbial activity are depleting DO in the water. Water can contain 4-7 ppm dissolved oxygen. Below 4 ppm DO is harmful. Groundwater with heavy cultivation has increased NO_3^- and PO_4^{3-} concentrations. This may be caused by overusing concentrated fertilizers. Higher COD values reflect more oxidizable organic matter, lowering DO. Reduced DO can affect aquatic organisms by causing anaerobic conditions (Lokhande *et al.*, 2011). BOD measures the oxygen microorganisms absorb during aerobic breakdown. Power plant and peripheral water sources rarely have BOD.

Table 1 - Average variations of chemical and biological parameters of groundwaters in and around the power plant premises of the monitoring periods (*ND- Not Detected*)

Chemical Parameters	Area Inside the Power Plant Premises (mg/l)			Area Outside the Power Plant Premises (mg/l)		
	October 2019	October 2020	December 2020	October 2019	October 2020	December 2020
Total Hardness	982.00	442.67	314.00	506.83	636.79	635.00
Alkalinity	152.00	250.50	268.00	146.00	190.70	179.00
TDS	1408.00	585.40	550.00	697.00	758.90	681.00
Ca^{2+}	133.00	108.73	92.30	93.00	181.60	186.00
Mg^{2+}	159.00	41.93	32.30	65.60	41.83	42.70
Total Fe	0.01	ND	0.05	0.02	ND	0.11
Cl^{-}	691.00	253.90	326.00	180.00	236.90	269.00
SO_4^{2-}	218.00	137.30	129.00	147.00	300.30	259.00
F^{-}	0.35	0.34	0.62	0.45	0.88	0.82
NO_3^{-}	9.38	2.94	4.99	62.60	25.69	30.40
PO_4^{3-}	0.04	0.22	0.37	1.29	0.78	1.35
Na^{+}	515.00	178.00	173.00	89.10	128.10	113.00
K+	23.00	19.18	12.30	244.00	45.03	38.20
DO	2.63	2.63	4.81	3.92	3.92	5.20
BOD	2.10	2.10	0	2.53	2.53	0.10
COD	8.33	8.33	52.20	18.20	18.22	22.70

5. Conclusion and Recommendation

Some water quality metrics including EC, TDS Salinity, Total hardness, Ca^{2+}, and Mg^{2+} concentrations in groundwater with same distribution and temporal volatility in 2019-2020 is attributed to probable seawater intrusion by up conning when groundwater abstraction is substantial. EC, Hardness, and SO_4^{2-} all exceeded their permitted thresholds for drinking. High amounts of Cl^{-} and SO_4^{2-} in groundwater around the power station may have originated from unregulated withdrawals and decreased after the ground water extraction technique. Total Fe, F^{-}, NO_3^{-}, and PO_4^{3-} were WHO-safe. Low BOD eliminates less oxygen from water, making it purer and less microbiological.Therefore,groundwater quality is fairly good for drinking, although pre-treatment is needed to reduce EC, salinity, and sulphate. Excessive unregulated abstractions in high agricultural regions have suggested incipient salinization in fresh groundwaters with high levels of EC, Salinity, Hardness, and Sulphate in scattered and patchy quality distribution maps.The installation of well field abstraction regulations has improved the water chemistry and groundwater level of the aquifer around the power station. The groundwater chemistry and distributed groundwater depletion of agricultural fields show qualitative and quantitative aquifer deterioration. Long-term groundwater management through a participatory approach involving all user groups is the most effective and efficient way to protect this productive but fragile aquifer against sea water intrusion and other anthropogenic influences.

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