Hydrogeological Characterization and Spatiotemporal Variation of Groundwater Chemistry in and around the Lakvijaya Coal-fired Thermal Power Plant Area, Norochcholei, Sri Lanka

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Abstract

The Lakvijaya power station also known as the Norochcholei power station, is the largest power station in Sri Lanka. According to the Ceylon Electricity Board, the US$455 million first phase generates nearly 1.7 TWh of electricity annually; a significant amount when compared to Sri Lanka's total production of 11.5 TWh in 2011. Lakvijaya power plant is utilized groundwater for landscaping activities of its premises which is approximately 100 acres in extent. The daily water requirement of 100 m^3/day is extracted by means of shallow well field existed within the premises of power plant and the peripheral densely populated farmlands are also extensively abstracted groundwater from highly vulnerable shallower coastal aquifer which is under threat of salinization by sea water intrusion or upconning and depleting groundwater level and deterioration of groundwater chemistry.

The study was carried out to assess the initial baseline assessment of hydrogeology & geochemical distribution in year 2019 followed by subsequent quarterly water chemistry assessment through an established groundwater monitoring network within the area in year 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. The results have indicated a correlation of elevated levels of EC, Hardness, TDS, Mg^{2+}, Cl^-, Sulphate & Salinity distribution with the zones of high groundwater abstractions which reflected the incipient level of upconning at the inland farming areas while either seawater intrusion or upconning at the power plant area is also detected. The aquifer water chemistry at the power plant premises area is in natural restoration after being regulated abstractions from 2019 as observed from the variations of water chemistry in year 2020.

The NO_3^- (20 -50 ppm) , and PO_4^{3-} (2.1- 3.5 ppm) levels are comparatively higher, indicating near permissible levels of concentrations at the eastern inland flank where extensive farming practices are in operation. This may be attributed to extensive fertilizer application on the highly vulnerable sandy soil.

High COD level and low DO level indicated the groundwater contaminated by wastewater with high organic matter content. However, Low BOD means less oxygen is being removed from water, so the water is usually purer and the number of micro-organisms in the water is minimum.

Keywords: Water Quality, Groundwater, Thermal Power Plant, Norochcholei

1. Introduction

Groundwater is an essential component of the Earth's freshwater resources. Moreover, the escalating utilization of groundwater results in a decline in water levels as well as degradation of its quality (Qiu *et al*., 2021) since the groundwater resources are dynamic in nature and are affected by the factors such as an expansion of irrigation, excessive abstraction in use of Industrialization, and urbanization, hence supervision and conserving this important resource is essential (Chatterjee *et al*., 2010).

Due to the long-term activities of coal power generation processes, many toxic and harmful wastewater as well as other contaminants are produced and may enter groundwater aquifer through runoff and infiltration. Finally, consumption of contaminated groundwater can pose a threat to human health (Qiu *et al*., 2021). Therefore, it is vitally important that consistent, regular monitoring & assessment on the changes of hydrochemistry in groundwater of the area for immediate remediation in the event of any incipient stage contamination or changes observed.

The Lakvijaya power plant also known as the Norochcholei power plant, is the largest power station in Sri Lanka. The power station has established at the close vicinity to the coastal line at Norochcholei, Puttalam, on the southern end of the Kalpitiya Peninsula. The study is focused on the initial assessment of hydrogeological condition and baseline hydrogeochemistry with subsequent quarterly monitoring through an established groundwater monitoring network within the power plant premises and its peripheral area. The power plant is utilized the groundwater for landscaping activities of its premises which is approximately 100 acres in extent.

In the study area, shallow groundwater is mainly extracted for agricultural practices, drinking & domestic purposes by the community, and the power plant for landscaping activities. However, sea water is being utilized for cooling of boilers and discharge back to off shore area as per the stipulated guidelines. Presently, groundwater is only used for landscaping activities of the power plant. The fluctuation of groundwater level and the storage volumes of this shallower sand aquifer is mainly influenced by the balance between the rainfall recharge & flood irrigation waters with total abstractions for all aforesaid activities.

The availability of fresh water for drinking is one of the most serious social and environmental issues at global level. The protection and managing of groundwater quality at appropriate levels are always a matter of concern with the present developing activities of the world. The water quality is the physical, chemical, and biological characteristics of water in relation to a set of standards. Water pollution may be defined as alteration of the physical, chemical, or biological properties of water (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 if any by the impact of 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 which facilitate sustained management of the resources by early preventive measures and mitigatory approach through appropriate planning in long term basis.

After a preliminary hydrogeological and water quality assessment, several chemical parameters were selected for the long-term monitoring process on quarterly basis which is in operation at present. This paper is focused on the analysis work carried out from the year 2019-2020. Beside water quality monitoring, aquifer testing on the well field was carried out to assess the safe yield and introduce of a pumping plan to regulate the groundwater abstractions in 2019 within the power plant premises.

2. Study Area

The Lakvijaya power plant is situated within the Grama Niladhari Divisions (GNDs) of Panayadiya and Narakalliya which belongs to Kalpitiya Divisional Secretariat Division (DSD) of Puttalam District. The land extent of Kalpitiya

Peninsula is 160 square kilometers which is bordered by the Indian ocean by west and Puttalam lagoon from east. The main economy of the community within these areas are cash crop farming with extensive use of groundwater from the shallower aquifer existed along N-S coastal stretch which have created the Kalpitiya Peninsula itself. The aquifer of the Northwestern coast of Sri Lanka is one of the highly productive unconfined coastal aquifers, and it is characterized by its shallow nature and sandy aquifer media derived from marine origin during the Quaternary age (Jayasingha *et al*., 2011). Generally, the area is highly characterized by flat topography except some slightly higher elevation mounds in the central part due to paleo dunes and some of the area in western margin due to recently developed dunes by monsoon winds. The southern end is connected to the main land at Palavi area where the lagoon ends. The entire peninsula is composed of fine to coarse coastal sands from successive aggradations processes of beach formation.

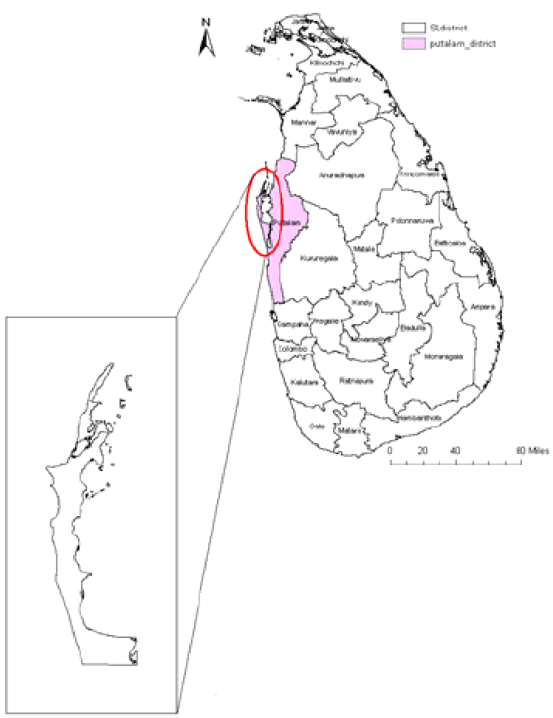

Figure 1 *The regional view of Kalpitiya Peninsula*

The horizon of unconsolidated sand provides an excellent perennial freshwater aquifer. These sands grade into a sandstone basement at a depth between 6 to 9 m from MSL. Within the sandstone, bed are patches of mudstone with complete mixing of clay. Below sandstone, a limestone bed forms an unconformity. The thickness of the clastic fossiliferous limestone is more than 60 m in the Kalpitiya peninsula.

The climate is characterized by high temperatures throughout the year. The average annual maximum and minimum temperatures are about 31 and 26^0 C, respectively and receives an average annual rainfall of 950 to 1050 mm.

3. Material and Methods

There are more than 75 tube wells existed within the power plant premises (Fig.2) 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 Performance Testing

The pumping test were carried out for 24 hours pumping with 95% recovery at selected 20 tube wells. Selected 20 tube wells were pumped at a constant rate after the calibration test performed. The closest wells were taken as observation wells. Groundwater level of the pumping & observation wells were measured during regular intervals to identify whether there is an impact on the surrounding environment.

3.2. Sample collection

Water sampling is the main activity of this study since it reveals the water chemistry of the area which reflects the baseline condition and its variation over time to identify the influences by the abstractions on quality deterioration as well as depletion of aquifer storage. The sampling was carried out from 50 nos. of wells under standard guideline & procedures. Initial sampling batch was collected in October 2019 and second & third sampling batches were carried out in August 2020 and December 2020 respectively. After initial sampling, it was introduced the abstractions at recommended levels within the power plant premises. Despite this is under regulation, the tube wells at peripheral area are still utilized without proper control for agricultural activities.

CO_3^{2-}, Cl^-, SO_4^{2-}, and PO_4^{3-} were analyzed in the initial assessment. BOD, COD and DO were measured by the methods APHA 5210 B, APHA 5220 D and APHA 4500 OG respectively within 24 hours' period. Colors were measured by colorimetry (APHA - 2120: B 23rd Edition), pH were measured using Electrometer (APHA - 4500-H+: B 23rd Edition), EC were analyzed by conductometer (APHA - 2510: B 23rd Edition), Total Hardness, Ca^{2+}, Mg^{2+}, were determined by EDTA titrimetric analysis, Alkalinity were

Figure 2 *Google map view of the study area in and around the Norochchelei Power plant with monitoring locations*

3.3. Assessment of Groundwater Chemistry

Monitoring physio-chemical parameters of groundwater for next two quarters were selected based on the initial baseline hydrogeological and water quality assessment. 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+},

determined by neutralization titration, NO_3^-, SO_4^{2-}, and PO_4^{3-} were determined by colorimetry and Cl^- were analyzed by Titrimetric – Silver Nitrate Method.

The water quality spatial distribution maps were prepared per each parameter from the analysis results with the use of ArcGIS 10.3 to identify the variation of hydro-geochemistry of the area over time and space.

4. Results and Discussion

4.1. Groundwater level

Elevation of the study area has been measured as 4.5 meters above sea level. Since the topography of the study area is flat, elevation of the groundwater levels does not vary in a wide range and it varies in between 0.5 -5.00 mbsl. Monitoring of static groundwater level in the area was in difficult due to continous pumping throughout the farming lands. The aquifer is highly permeable and therefore the groundwater yiled is highly productive where the community tend to pump with high capacity submesible pumps without consdiering the consequences of contamination by sea water mixing.

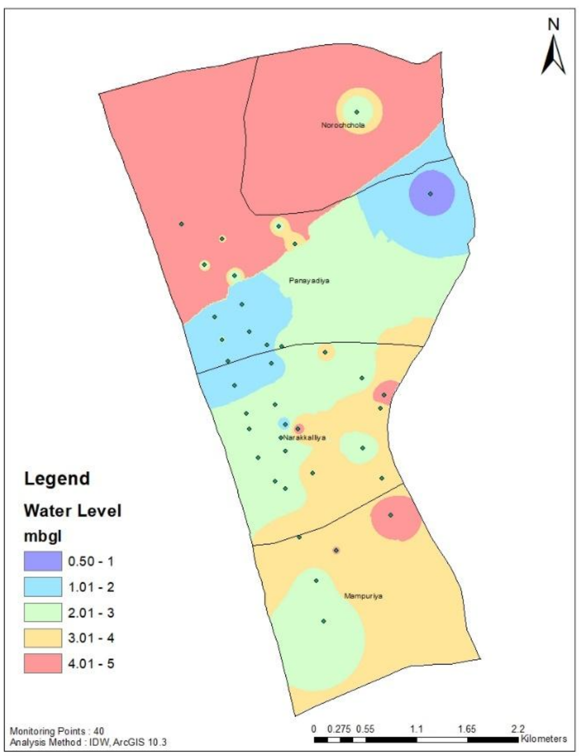

Figure 3 *Groundwater Elevation Map of the study area*

Considering the increased of Electrical Conductivity of the area with no decline of groundwater level of the area despite the high abstraction leads to infer that sea water intrution is the only possibility considering there is no any other recharge of groundwater into this aquifer from any outside storage since this coastal aquifer is isolated and floating on the high saline underneath.

4.2. Aquifer Performance Testing Results

Regional hydrogeological flow regime of the area indicated that the groundwater flow towards the sea from the inland thus creating a hydraulic head gradient between sea and the inland freshwater aquifer which enables groundwater abstraction feasible at a higher level. However, when it considering the water quality due to possible sea water intrusion or up coning, the abstraction volumes of the well field estimated carefully with the analysis of pumping tests data. Since the aquifer medium is off sand, the permeability and the storage are very high (Fogg, 1986), resulting negligible levels of drawdown in all the wells where test pumping was carried out despite the discharge rates were selected at high levels 400 liters per minutes (lpm). The maximum drawdown encountered during these all pumping was merely 1-3 cm only and during the phase of recovery, more than 95% recovery was observed within less than a minute due to the high permeability of the aquifer even discharge rate was more than 400 lpm. Since same drawdown and rate of recovery being observed, all the well abstractions were recommended the discharge 6 hours per day with 150 lpm rate and should be kept 2 hours non-pumping period every after 2 hours of pumping.

These tube wells are located in a highly pores sand aquifer, further groundwater abstraction is needed only for landscaping activities. Therefore, it can be assumed, much water will infiltrate again into the same aquifer lowering the impact to the sandy aquifer (Heiss *et al*., 2014). When all those tube wells are pumped at the same time which are located closer to each other, they are tapping groundwater from the same aquifer which is not suitable (Harvey *et al*., 1994). Therefore, it should strictly follow the above recommendations, and groundwater should be abstracted only from the recommended tube wells to lower the impact to the aquifer and next quarterly monitoring process.

4.3. Chemical Test Results

According to the obtained results of initial hydrogeological and water quality assessment and quarterly monitoring assessments, some parameters obtained significant quality improvement of groundwater within the recommended well field area of the power plant premises. However, the groundwater chemistry of the peripheral area of the agricultural lands illustrated deterioration of groundwater quality during the period under monitoring.

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

The EC is a most adequate indicator to assess groundwater quality and TDS is the concentration of all dissolved minerals in the water, which indicates the general nature of salinity of water. Conductivity of water is proportional to its dissolved mineral matter content and varies directly with the temperature changes. EC and TDS of water signify the amount of total dissolved solids (TDS) or salinity present in it, which in turn shows the total inorganic contaminants of water. The EC of groundwater of the study area varied from 318 µS/cm to 13,000 µS/cm in preliminary assessment, in the next two quarters of October 2020 and December 2020 show significant reduction and EC values of the area varied from 315 µS/cm to 4,500 µS/cm and 250 µS/cm to 3,000 µS/cm respectively (Fig.4). The concentration of total salt content in groundwaters, obtained in terms of electrical conductivity (EC), is considered as the important parameter for judging the suitability. Sri Lanka Standards Institution (SLS) guidelines classification for EC have been generally used in literature (Mahagamage *et al*., 2019). According to SLS guidelines, drinking water with an EC of 750 µS/cm -1,500 µS/cm causes no risk to human health, According to WHO classification, EC of more than 3,500 µS/cm adversely affect human health. However, the higher EC above 1500 uS/cm is indicated scattered manner which reflects the groundwater abstraction is high and water wells have gone deeper to facilitate more pumping in those areas. These patchy areas have dominantly occurred on the west to Lakvijaya Power plant towards inland where agricultural farming practices are heavily in operation.

Figure 5 indicates the salinity variation of the area and shows relative nature with the EC variation. The range of Salinity decreased from preliminary assessment to the final quarter of December 2020 and respectively varied from 0 to 8.0 ppm, 0.2 ppm to 2.0 ppm, and 0.2 ppm to 1.8 ppm.

In the study TDS of groundwater of the area varied from 150 ppm to 7,000 ppm in the preliminary assessment, Within the October 2020 sampling batch, TDS varied from 155 ppm to 2,000 ppm and from 126 ppm to 1,500 ppm variations of TDS indicated in December 2020 sampling batch. According to WHO the acceptable level of TDS in groundwater for drinking purposes is 500 ppm and the extreme permissible limit is 2,000 ppm (Verma, 2018). The groundwater with TDS 1,000-3,000 ppm is considered slightly saline (Verma, 2018). So, the groundwater of the study area falls in the class of non-saline to slightly saline. The presence of high levels of TDS (above 1200 ppm) in drinking water generally tastes wise unacceptable for human beings (Verma, 2018).

This heavy Irrigation can influence the increase of TDS in groundwater in several ways, particularly in arid regions. When irrigation water evaporates or is taken up by plants, it leaves the dissolved salts it contained in the soil and accumulated which gradually infiltrate into groundwater. Previously, groundwater abstraction of the area within the power plant premises and the peripheral agricultural area was high and seawater influence is possible in the area. Under recommended pumping rate, The EC, Salinity and TDS were positively improved within the area of the power plant premises.

4.3.2. Total hardness, calcium (Ca^{2+}) and magnesium (Mg^{2+})

Water hardness in most groundwater is naturally occurring from weathering of limestone, sedimentary rock and calcium bearing minerals (Cloutier *et al*., 2008). Hardness can occur locally in groundwater from chemical and mining industry effluent or inordinate application of lime to the soil in agricultural areas. As well as over pumping may cause the abstraction of ground water from the underneath limestone aquifer. Over abstraction and chemicals discharged by the Power Plant may result high hardness in groundwater detected during December 2019. In the same way, those values have been reasonably dropped with the time as shown in the Table 1. According to the WHO guideline, the permissible levels of drinking water for Hardness, Ca^{2+} and Mg^{2+} were 250 ppm, 100 ppm and 30 – 150 ppm accordingly. It was observed that restricting the abstraction from the tube wells within the power plant premises, beneficially affected on total hardness, Ca^{2+} and Mg^{2+} concentration of groundwater compared to the peripheral agricultural area with high abstraction practices.

4.3.3. Chloride (Cl^-) and Sulphate (SO_4^{2-})

Average values of Sulphate and Chloride variation pattern in Table 1 is almost identical of

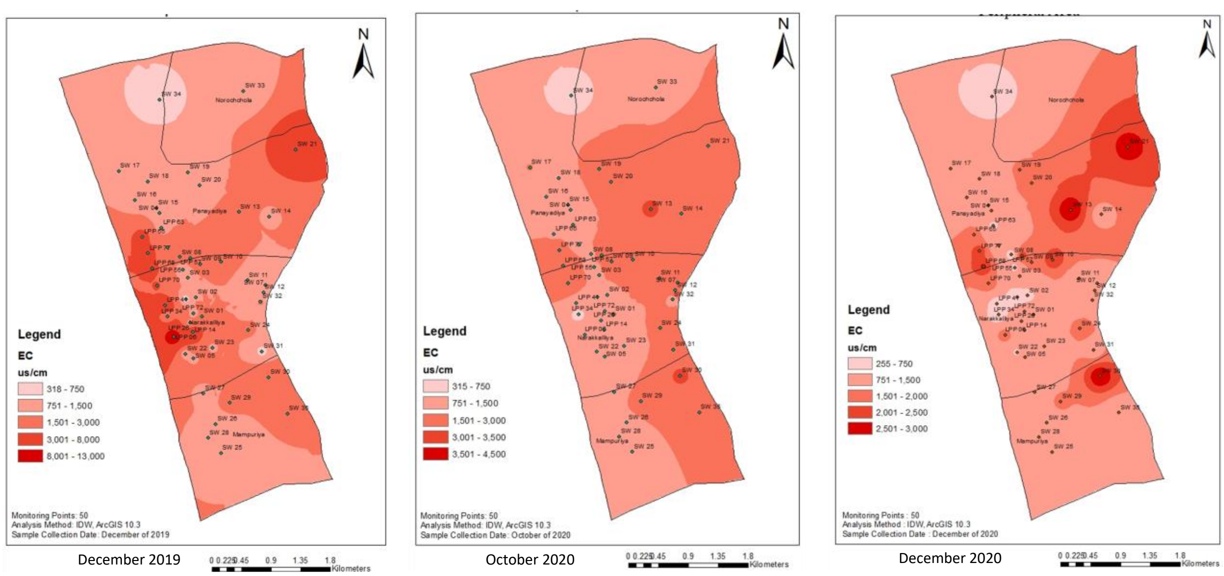

Figure 4 Variation of the Electrical Conductivity of the groundwater in the study area

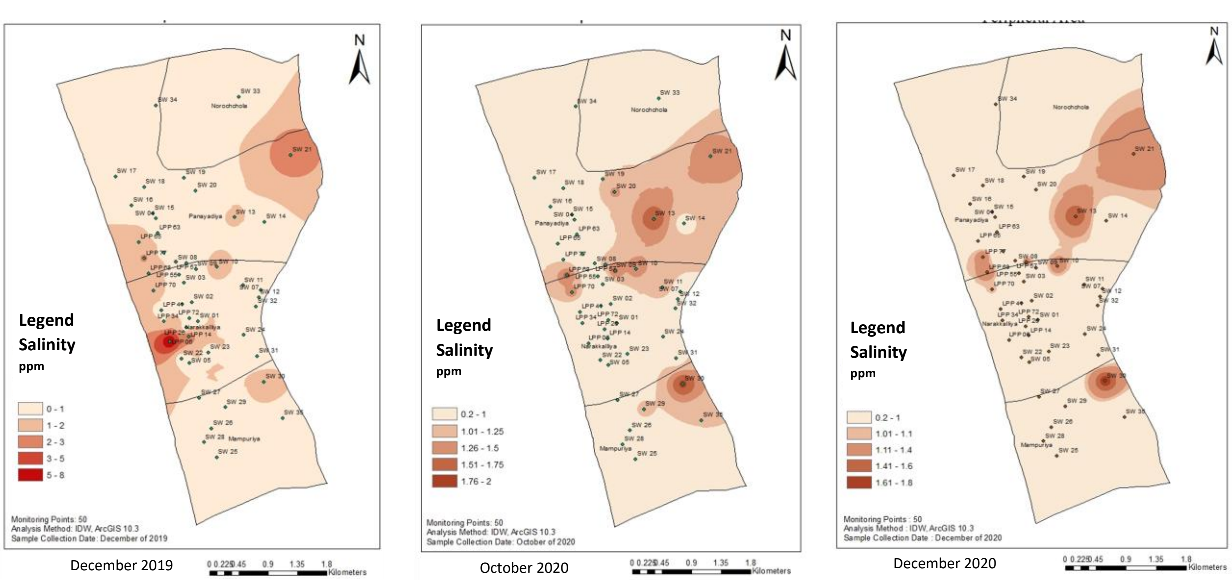

Figure 5 Variation of the Salinity of the groundwater in the study area

the study area. This may be attributed to high groundwater abstraction resulting gradual salinization which increases the chloride levels. Further, the one possibility of high Sulphate and Chloride at power plant area may also be off seeping of utilized sea water in the process for boiler operations before release back onto sea. Permissible level of both Sulphate and Chloride for drinking water is 250 ppm. However, high concentration of Sulphate may also arise in shallow, unconfined aquifers that acquire big inputs of sulphate from atmospheric deposition, fertilizer use and land utility of animal wastes. Observing the heavy farming activities are folding in peripheral regions and considering the quantity of fertilizer being put to the ground, those excessive sulphate values may be occurred but the concentric isolated patch of high SO_4^{2-} level at power plant area is difficult to reason out other than resulting by salinization influences.

The average concentrations of Total Iron, Fluoride, NO_3^- and PO_4^{3-} of the study area were identified as adjacent to their permissible levels of 0.30 ppm, 1.0 ppm, 50.0 ppm and 2.0 ppm. However, it is being indicated higher NO_3^-, and PO_4^{3-} concentrations in groundwater where extensive farming are being carried out. This may be a result of using concentrated fertilizers to a higher extent.

Table 1 Average variations of chemical and biological parameters of groundwater from 15 numbers of tube wells within power plant premises and from 35 numbers of tube wells in peripheral area with respect to the sampling batches

Chemical Parameters	Area Inside the Power plant Premises (ppm)			Area Outside the Power plant Premises (ppm)		
	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	2.1	0	2.53	2.53	0.10
COD	8.33	8.33	52.20	18.20	18.22	22.70

ND- Not Detected

4.4. Biological Parameters

Measured biological parameters were Dissolved Oxygen (DO), Chemical Oxygen Demand (COD) and Biochemical oxygen demand (BOD).

All aquatic animals need DO to survive. Low levels of oxygen (hypoxia) or no oxygen levels (anoxia) can occur when excess organic materials, such as large algal blooms, are decomposed by microorganisms. During this decomposition process, DO in the water is consumed. Low oxygen levels often occur in the bottom of the water column and affect organisms that live in the sediments (Chapelle et al., 2012). In some water bodies, DO levels fluctuate periodically, seasonally, and even as part of the natural daily ecology of the aquatic resource. As DO levels drop, some sensitive animals may move away, decline in health, or even die. Permissible limit of dissolved oxygen in water is 4-7 ppm. It is extremely harmful to drink water with DO level below 4 ppm (Lokhande *et al*., 2011).

COD is a measurement of the oxygen required to oxidize soluble and particulate organic matter in water. COD can be measured in real-time with COD sensors to improve wastewater process control and plant efficiency. COD is an important water quality parameter because it provides an index to assess the effect discharged wastewater will have on the receiving environment. Higher COD levels mean a greater amount of oxidizable organic material in the sample, which will reduce DO levels. A reduction in DO can lead to anaerobic conditions, which is deleterious to higher aquatic life forms (Lokhande *et al*., 2011).

BOD represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic (oxygen is present) conditions at a specified temperature. Certain environmental stresses (hot summer temperatures) and other human-induced factors (introduction of excess fertilizers to a water body) can lessen the amount of dissolved oxygen in a water body, resulting in stresses on the local aquatic life. One water analysis that is utilized in order to better understand the effect of bacteria and other microorganisms on the amount of oxygen they consume as they decompose organic matter under aerobic (oxygen is present) is the measure of BOD. However, BOD is not detected mostly at water sources in the power plant and the peripheral area.

5. Conclusion and Recommendation

From the results obtained from present study, it is concluded that some water quality parameters like EC, TDS Salinity, Total hardness, Ca^{2+}, and Mg^{2+}, concentrations in groundwater with identical distribution and temporal variation of the area during the monitoring period from 2019 to 2020 is a result of seawater intrusion by up conning process where the groundwater abstraction is high. Some parameters were deviated within vast range from their permisible levels for drinking purposes. The Cl^- and SO_4^{2-} concentration variations may be affected by off seeping of utilized sea water in the process for boiler operations before release back onto sea. However, Total Fe, F^-, NO_3^-, and PO_4^{3-} were adjacent to permissible limits of WHO standards. Low BOD means less oxygen is being removed from water, so the water is usually purer and the number of micro-organisms in the water is minimum. High levels of COD indicate that wastewater with high amounts of organic matter is mixed with groundwater. Therefore, groundwater quality is moderately suitable for drinking purposes and the pretreatment required before consumption. The groundwater may be used for the irrigation purposes but before that proper study should be conducted to ensure that the soil fertility as well as the crop production will not be harmed by contaminated groundwater. Prevention is the best method to protect the environment from contamination. Therefore, monitoring of groundwater abstraction through the establishment of a flowmeter system on the well field is recommended. Aditionally, the awareness and provide of necessory guidelines on the use of groundwater resources of the area to the community about these changes in groundwater of their territory specially to the farming community is beneficial in the long run to sustain this productive and highly vulnerable aquifer to sea water intrusion and other all possible contmaniations by anthropogenic activities.

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