AN OVERALL HYDRO-GEOCHEMICAL APRRAISAL OF GROUNDWATER ALONG THE EASTERN FRINGE OF CHILIKA LAGOON, ODISHA, INDIA, DURING PRE-MONSOON SESSION, 2018

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By

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CERTIFICATE FROM THE SUPERVISOR

This is to certify that **Sri Shubham Dutta (Exam Roll No. MGEO194024)** has worked under my guidance on the topic **'An Overall Hydro-geochemical Appraisal of Groundwater along the Eastern Fringe of Chilika Lagoon, Orissa, India, during Pre-monsoon Session -2018'**, in the Department of Geological Sciences.

He has completed his work with due sincerity, which is being submitted herewith as a thesis towards the partial fulfillment of his **M.Sc. Degree Examination in Applied Geology (2019)** of **Jadavpur University.**

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ABSTRACT

Groundwater is perennial storage of water which is credited by recharging and debited through drafts or well capture. About 80% of people in India live in villages and mostly depend upon wells for domestic uses and agriculture because of non-availability of surface water bodies. Climatic anomalies, uplift/down drift and excess draft have been depleted or contaminated the ground water. Groundwater is easy to extract, a cheap source, self-rechargeable and well protected from contaminants. Hence it is the best choice for drinking water, domestic, irrigation and industrial purposes. Irrigation is the largest user of ground water in underdeveloped country like India, today. Overexploitation of groundwater for the requirement of agricultural yield to its utmost maximum quantity as led by prolific growth of population and extensive inhabitation in past few decades, encroachment of unfavourable coastal areas became a common practice. This unplanned expansion of inhabitation and thereby agriculture, not only hampering the natural ecosystem, but also imparting a deep-routed problem in overall geo-hydrological scenario of the area. Overpumping resulted in rapid acceleration to seawater ingress, and thereby degrading the overall quality of groundwater. Optimum storage capacity of the underground reservoirs is also deteriorating. The villages around the Chilika lagoon, Odisha, facing an infrequent problem relating to the same issue of excess rate of groundwater pumping, because of the excess salinity of available surface water and it is expected with time this issue will become more acute. In the present study an attempt has been made to evaluate the major physicochemical parameters of groundwater from dug-wells and tube-wells along the eastern fringe of Chilika Lagoon, Puri district, Odisha, India, during pre-monsoon season of 2018. Investigations were carried out to get an overall scenario on seawater ingress and the effect of that in regard to the suitability of groundwater towards domestic and irrigation purposes. Anthropological interventions and growth of agriculture in the newly formed island were also taken into account for the overall ground water status of the studied area. A length of 50 km from Bramhagiri to Malud was studied in the present work along the eastern fringe of the lagoon.

Keywords: Groundwater, drinking, irrigation, seawater-ingress, Chilika, dug-well, tube-well

Table of Contents

Contents — Page No.

List of Figures

List of Tables

Chapter 1

Introduction

Chapter 1: Introduction

1.1 Introduction

Groundwater is the major source of freshwater in many parts of the world for meeting the requirements of domestic and agricultural purposes. It may obtain from aquifers, fractured crystalline bedrocks are also a good source of fresh water.

In rural regions, where well managed surface water acquisition and transportation systems and related infrastructures are not available, groundwater serves as prime source of drinking, domestic and agricultural purposes. Ground water is a perennial water bank which is credited by recharging and debited through drafts or well capture. As the population of the Earth is growing at a faster rate and so is the demand of food and urbanization, in such a situation extraction of groundwater is increasing at faster rate to meet the demands of people. In the places of intense urbanization, surface runoff due to rain does not get the enough opportunity to percolate downward to enrich the groundwater reserve. Also the use of chemical fertilizer for irrigation, generally phosphates and nitrates percolate downward as a solute with percolating water. The areas with nearby coasts face more problem. Chilika Lagoon and six blocks around could not use surface flow for water logging, salinity intrusion and back water. As the depletion of ground water goes on at a high rate, there form small cone of depressions of the nearby wells that in turn produces a large cone of depression. So the intrusion of saline water into the fresh water is the common phenomenon around the Chilika region. Recharging and discharging rates to aquifers are difficult to access and available surface water is sometimes inadequate and inappropriate to meet the demand.

In the present study an attempt has been made to evaluate the major physical and chemical geo-hydrological parameters of groundwater (dug and tube well water) during pre-monsoon, along the eastern fringe of Chilika Lagoon, in the Krushnaprasad and Bramhagiri block of Puri district, Odisha. Investigations were also done to get an overall scenario on seawater ingress and the effect of that in regard to the suitability of groundwater towards domestic and irrigation purposes. Anthropological interventions and growth of agriculture in the newly formed island were also taken into account for the overall ground water status of the studied area. A length of 50 km from Bramhagiri to Malud was studied in the present work along the eastern fringe of the lagoon.

1.2 Objective of the present study

The area lies in eastern coastal tract where salinity prevails in phreatic as well as in deeper aquifer. In Krushnaprasad, Brahmagiri etc. salinity hazard is widespread. In Puri district 19480 ha (7.3%) is affected with salinity and 15192ha (5.72%) is waterlogged. In 2006, crop of 1606 villages of 232 gram-panchayat was submerged (submergence more than 50%) due to flood. Total area affected was 58,465 ha which covers 22 % of the total area. Wetlands, especially the coastal lagoons are susceptible to rapid environmental alterations under the influence of natural and manmade events. As all the newly developed villages are located in those areas which are virtually separated by lagoon water and the installation of pipelines for supplying treated saline water is not possible the nearby subsurface water is the only source of fresh water. Therefore water is being pumped continuously from numbers of nearby dug and tube wells. And thus the salinity hazard takes place in these areas with the formation of larger cone of depression. High concentration of some chemical constituents are harmful for the human. Recognition of poor quality aquifers are necessary for the living. The overall objective of the present study is quantify the following relevant issues

I. Major physical, geo-hydrological parameters of ground water of this area in pre-monsoon session.
II. Chemical characterizations of the pre-monsoon ground water of the area.
III. A comprehensive comparison between dug and tube well water of the two blocks i.e. Krushnaprasad and Bramhigiri.

1.3 Literature Review

Hydro-geological surveys, water quality study and draft of GW were conducted in the Mahanadi delta since the year 1950, initially by the Ground Water Division of Geological Survey of India (Bhatnagar et al. 1970) and later by the Central Ground Water Board (Radhakrishna et al., 1976, Chakladar,1981; Srivastabet. al. 2013,2014) have reported factors responsible for the GWT fluctuation in a specific morphologic environment and prediction of future water depth by artificial neural network model. The results were that Meso-scale impacts of depletion in GWT shall affect MSL. It is assessed that globally the groundwater drawl has increased from 312 to 734km^3 and recharged from 126 to 283 km^3 between 1960 to 2000 (Wada Y. et al 2010). Their report specifies one third of world's ground water has been drawn without recharge. However Ground Water Table in the south Mahanadi delta in an average 2-5m observed in 2013 and trend is rising as per Central Ground Water Board MOWR, GOI. The yield of sediment in the catchment of river Mahanadi is of order 200-400tons/km^2 high in India (Meijerink, 1982-83). In coastal areas there is no change in GWT due to salinity intrusion (Jha et al 2008). Average seasonal water level fluctuation in the area is 2.2m, average discharge is 35.37lps, and drawdown is of 10.44m. The ground water development in coastal Odisha has increased from 23% in 1999 to 43% in 2009. The type of soil for possibilities of having aquifers should be sandy loam, clayey loam, gravel, sand of all types and fractured rocks. Groundwater is vanishing fast from the world and India is among the worst hit, shows data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites (NASA 2015). Dash et al. 2015 have made the hydro-geological studies of Chandanpur, a coastal area of Puri district in Odisha. They have reported GW quality is brackish which is fairly poor for domestic and moderately hard for agricultural use. The yield of sediment in the catchment of river Mahanadi is of order 200-400 tons/km^2 high in India (Meijerink, 1982-83). In peninsular India there is deep circulation of ground.

Chapter 2

Study Area

Chapter 2: Study Area

2.1 General

Chilika Lagoon, the largest brackish water lagoon in Asia, along the Indian east coast that spreads across 1100 square-km(approximately) area. The geomorphology, water quality of the lake had undergone significant changes over the years under the influence of natural events, like shifting lagoon inlet, silting up of the outer channel and others. Due to the strong dynamics of the inlets, associated to a strong long shore current and littoral drift of the Bay of Bengal towards north, as the incoming wave deflect towards north due to 'Coriolis force', the inlet migrate in the north-east direction. This region falls under Mahanadi river basin and the main drainage is formed by river Daya. As the there is an influx of marine water in the Chilika lagoon, so the area around the fringe of the Chilika lagoon is affected by intrusion of saline water.

2.2 Location of the Area

The present area study, situated between the latitude 19°28′–19°54′ N and longitude 85°05′–85°38′ E,Odisha, along the east coast of India. Figure 2.1 reveals a schematic map of the studied area.

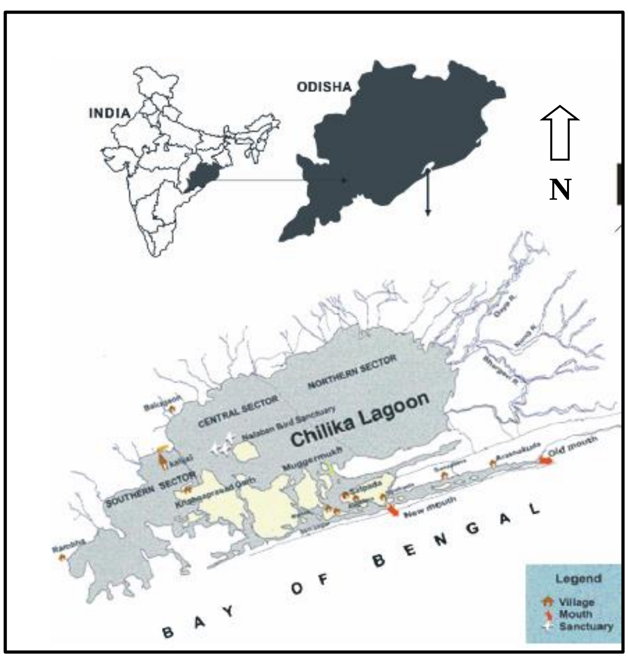

Figure 2.1 Schematic Map of Chilika Lagoon and its location in India (Sahu et al., 2014)

A larger portion of the lagoon is in the Puri district of Odisha, a small north-eastern part is in Khurda district and small south western part is in Ganjam district. The study area encompasses two blocks of Puri district, Bramhagiri, and Krushnaprasad.

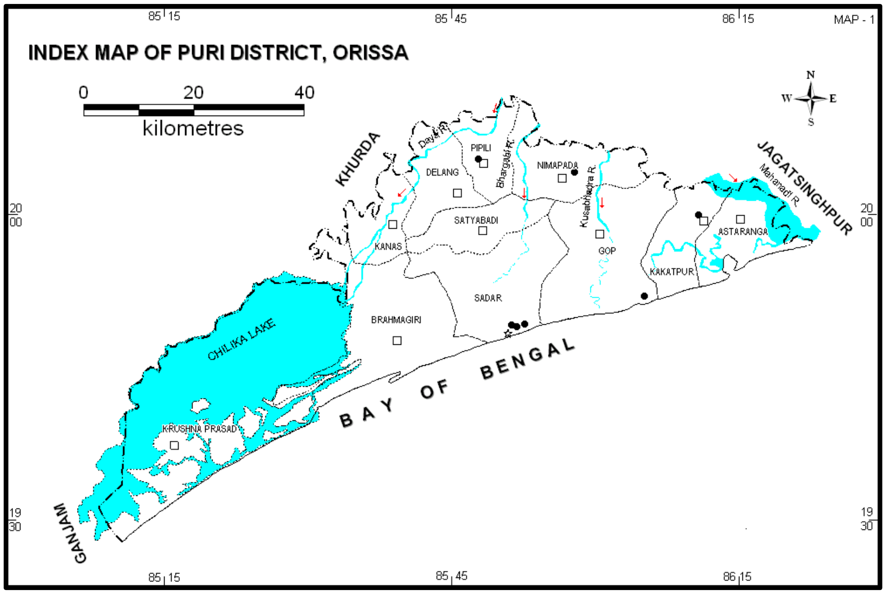

Figure 2.2 Location of Chilika Lagoon in the District of Puri, Odisha, India (Sahu et al., 2014)

Samples were taken from 7 locations of these two blocks and these locations are extended from Bramhagiri in north to Malud in south.

Figure 2.3 Location Map of Studied Area(Google Earth Image)

2.3 Accessibility

There are mostly village areas along the fringe of Chilika lagoon and the islands of this lagoon are mainly villages. Along the eastern fringe within our study area, Bramhagiri is the nearest small town, which is well connected to district town Puri by road. The islands are dependent on boats and vessels generally. Satapada is the place from were boats are available for travel and daily work purposes. Vessels carry bus and autos from Satapada to the next island, that help the rural people to keep a regular connection with the town. This area is connected to Bhubaneswar (approxemately160km) by road.

2.4 Demographics

The overall density of population is not that high in this region. Between the study area Bramhagiri to Satapada the density of population is more or less same as the whole district population density. According to the 2001 census data, the density of population in this district is 138 per km^2. But it differs in case of the islands. From Kurupal to Malud population density decreases than that of the main land. Most of the people live here are rural people. Fisheries and travel guiding are their main earing. Irrigation is also a way of living here. But not all the lands here are irrigable.

Figure 2.4 Fishing – one of the major livelihood of the area

2.5 Rainfall and Climate

The south-west monsoon is the principal source of rainfall in the district. Average annual rainfall of the district is 1449.1 mm. About 75% of the total rainfall is received during the period from June-September. Floods are quite common in the district. As the district mainly receives rainfall from south-west monsoon which is very erratic. Analysis of 24 years of rainfall data from 1982 to 2006 reveals that the rainfall is uneven with maximum rainfall (2146mm) in 1991 and minimum (522mm) in 1974. The climate of the district is subtropical with hot and dry summer and pleasant winter. The summer season extends from March to middle of June followed by the rainy season from June to September. The winter season extends from November till the end of February.

2.6 Geological Set-up

According to Phleger (1969), coastal lagoons were formed worldwide during the Holocene sea level rise. The Chilika lagoon is believed to have originated about 5000 years ago corresponding to the same period. Different views are available about the origin of this lake. Hunter has opined that it was formed as a result of subsidence of land and subsequent ingress of sea water from the Bay of Bengal as a result of the sea level rise. The second view suggests that the lake was a part of the Bay of Bengal and in due course of time the bay became shallower due to siltation forming mud flats in the southern and northern parts of the bay. The present shape of the lagoon could have occurred after it got separated from the sea by a barrier spit developed under the influence of littoral drift. Annandale and Kemp (1915) had also opined that the lake was a Bay and its present configuration had emerged due to the formation of the barrier spit on its north eastern margin. There is also a theory that Chilika lake was part of a river or river delta with freshwater vegetation, which in due course of time, acquired characteristics of an estuary with mangrove vegetation, that has later developed into a lagoon of the present shape after the separation from the sea.

Our study area falls in South Mahanadi Delta region. The geological formations in the Puri district spans in age from Archean to Recent (Quaternary). In our study are the Tertiary and Quaternary formations occurring over major parts. The Quaternary deposits consist of laterites and alluvium. While the laterite occurs only in the western and northwestern parts, major parts of the district are covered by alluvium of varying thickness. There are mainly three types of soils in the area, which are Alfisols, Ardisols and Entisols. The deltaic alluvial soils belong to Alfisols group occupy major parts of the area. Ardisols are saline and saline alkali soils found near the coast and are restricted to Krushnaprasad. Entisols are theyoungest alluvial soils occurring as the coastal sandy soils around ChilikaLake and in the coastal tract.

2.7 Hydrological and Geo-hydrological Set-up

The younger alluvium, which covers nearly 90% of the area, occurs as flood plain deposits along the course of major rivers and streams. These sediments consist of an admixture of silt, sand, gravel and pebble. The thickness of shallow aquifers (near surface aquifer) varies widely due to salinity problem. The geological setup as discussed earlier controls the occurrence and movement of groundwater. The sand and gravel layers form the main repository of ground water in this area. The occurrence of fresh water bearing deeper aquifers are identified here. The deeper aquifers occur under semi confined and confined conditions. The common groundwater abstraction structures are dug-wells, shallow tube-wells, deep tube-wells and filter points. In the southern sector of the area, adjoining Chilika lake a numbers of auto flow wells are found. Autoflow wells are located in Krushnaprasad, Brahmagiri blocks.

2.8 Flora and Fauna

The ecological richness of the lake is of great value in preserving the genetic diversity because of the multiplicity of its habitat, flora and fauna. The Zoological Survey of India (ZSI) surveyed the lake between 1985 and 1988 and identified 800 species of fauna, including many rare, endangered, threatened and vulnerable species, but excluding terrestrial insects. 24 mammalian species were reported. 37 species of reptiles and amphibians are also reported. Recent surveys revealed an overall 726 species of flowering plants belonging to 496 genera and 120 families. Chilika Lake is the largest wintering ground for migratory birds, on the Indian sub-continent. It is one of the hotspots of biodiversity in the country.

Figure 2.5 Flora and Fauna

2.9 Major issues related to Ground water

- Frequent sea water ingress because of heavy pumping of groundwater is the major threat for the studied area.
- Rapid proliferations of tourism causing a sharp increase to the demand of fresh water, which radically imply a huge stress on fresh water bearing aquifers.
- High rate of sedimentation at the eastern fringe causing frequent development of new islands where both inhabitation and agriculture are imposing a steady growth on fresh water demand.
- As all the newly developed villages (Kurupal, Morada, Malud) are located in those areas which are virtually separated by lagoon water, the installation of pipelines for supplying treated saline water is not possible. In all the cases the only source of fresh water is the nearby subsurface water.
- As water is being pumped continuously from numbers of nearby dug and tube wells, superimposition of multiple small cone of depression ultimately resulted in a formation of a single large cone of depression which causing frequent sudden dewatering of some dug and tube wells. Figure 2.6 reveal a general view of the irrigation field with the aid of pumped water by tube well.

Figure 2.6 Irrigation

- Throughout the entire studied area the width of the land mass is almost like a narrow stripe. Therefore the surface runoff fraction of the precipitation received is (both spatially and temporally) considerably low.

Chapter 3

Materials and Methods

Chapter 3: Materials and Methods

3.1 General

The present study comprises of field investigation during Pre-monsoon session, in the month of March 2018 and analysis of samples thereafter. The entire scheme of methodology as deployed may be categorized as Collection of samples, Instantaneous filed estimation of some physicochemical parameters. Chemical analysis and preparation of graphical plots to get an idea on spatial variation of water quality both for dug and tube-wells to get a comparative qualitative status of the subsurface water. Finally the updated suitability status of groundwater of the studied area for irrigation and drinking purpose were also anticipated by some standard hydrochemistry plots.

3.2 Collection of Water Samples

Groundwater samples were collected from different tube-wells and dug-wells of the study area during pre-monsoon period, to document the spatial distribution of different elements and change on parameters. The sampling stations were selected in such a way that uniformly and equi-spatially cover the entire eastern fringe of the Chilika Lagoon (study area). Certain parts of the study area were inaccessible due to lack of proper road communication. In such cases wells were selected approximately closest possible to a planned location in order to have more or less homogenous spatial coverage. At the outset spatial geographical coordinates i.e. latitude and longitude (above MSL) of the location were taken by using ‘Garmin eTrex-20x’ GPS, with a minimum catch of six satellites having a peripheral radius of maximum 3.0m.

Water samples were taken in clean and thoroughly washed double capped polyethylene bottles. Tube-wells were pumped for a few blows to dispose off the top level water first to avoid stagnant water in the tube attached to well and the water sample was collected in a properly cleaned double capped 500ml plastic bottles. Location number of the sample was mentioned properly on the bottle. Samples from the dug well were obtained by immersing a clean steel bucket from the top to at least 1 meter deep from the water surface of the well, to get a comparatively less contaminated sample. For convenience of further logistics samples from the tube and dug wells were collected in two differently colored capped bottles and packed properly for further chemical analysis.

Figures 3.1(a-c) Instruments and sample bottles used during acquisition of filed data and water samples, (a) Usage of GPS to detect the accurate geo-spatial coordinate of locations; (b) Ropes and tapes; (c) sample bottles for tube and dug wells

3.3 Estimation of Physicochemical Parameters of Groundwater

Out of the major controlling physicochemical parameters of groundwater of the study area, few were measured directly in the field in all the seven locations and concentration of ions were detected and estimated in the chemical laboratory following standard procedures.

3.3.1 Field measurements

In each location depth of ground water table from the land surface were measures only in dug wells by dropping a meter tape mounted by a 0.25 m steel rod of weight 500gm at its head. Proper water depths were finally estimated by deducting the 'head' and 'cut'. Altitude of the locations was also noted, which almost in all locations were less than 0.5m, so neglected to calculate the subsurface water head. Instantaneous measurements of major physical parameters of the collected samples were recorded by using Hanna portable multi-parameter water testing instrument (model HI98194). The probes were immersed to the thoroughly washed sampler tube until the equilibrium of the display units was reached. The major parameters measured in situ were pH; Electrical Conductivity (EC), and Total Dissolved Solids (TDS). Figures 3.2 (a-c) reveal the different steps as followed for sample collection, in-situ filed measurements of water depth and estimation of some major physicochemical properties by water meter

Figures 3.2 (a-c) Steps followed during sample collection, (a) Collection of water in sample bottle; (b) Estimation of some major physicochemical properties by Hanna portable multi-parameter water testing meter ; (c) In-situ filed measurements of water depth

3.3.2 Laboratory analysis

This stage involves chemical analysis of water samples to find out the concentration of different ions in the water and elucidate the water quality. Based on water quality, with the help of different techniques the suitability of water for domestic use and irrigation purposes can be found.

Chemical analysis of water samples were carried out in the Chemical laboratory of SWID, Kolkata, using the standard chemical procedure (APHA, 1995). The concentration of major anions include chloride (Cl^-) and sulfate (SO_4^{2}) $^-$were determined by ion chromatography and the major cations consisting of Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Potassium (K^+) and Sodium (Na^+) were determined by flame atomic absorption spectrophotometer. Acid titration with HCl was used to determine the Bicarbonate (HCO_3^-).

Obtained data from the chemical analysis were used to evaluate the overall suitability of the ground water for health, domestic and irrigation purposes. Parameters like, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Kelly's ratio (KR) were derived. Further, these parameters were used to estimate the suitability of ground water for agricultural and drinking purposes by plotting these values on standard reference diagrams like Wilcox, U.S. Salinity [US Salinity Lab (1954)], Doneen's plot (Doneen, 1964) and Piper's tri-linear diagrams (Piper 1944).

3.4 Suitability of Groundwater

Once the quantitative determination of physical and chemical water quality parameters has been carried out, the obtained data may be used for determining the groundwater quality and sources of the parameters present. For this purpose, graphical representation like U.S Salinity diagram, Piper's diagrams are prepared. Groundwater quality can also be ascertained by calculating SAR(Sodium Absorption Ratio), SSP(Soluble Sodium Percentage), KR(Kelly's Ratio), MAR(Magnesium Adsorption Ratio). The categories assigned to these parameters help to define the suitability of water samples.

3.4.1 Sodium adsorption ratio (SAR)

Sodium adsorption ratio is a measure of the sodicity of the soil determined through quantitative chemical analysis of water in contact with it. An excess of HCO_3^- and CO_3^{2-} ions in water react with Na^+ in soil, resulting in a Sodium hazard. The Sodium adsorption ratio (SAR) was calculated using the following equation (Richards 1954)

$$SAR = \left[Na^+\right] / \left\{\left(\left[Ca^{2+}\right] + \left[Mg^{2+}\right]\right)/2\right\}^{1/2} \quad (3.1)$$

Where, concentrations of all ions have been expressed in meq/l.

SAR values are plotted against EC values (in µmhos/cm) over the U.S. Salinity diagram (Richards 1954) to categorize analyzed water samples according to their irrigational suitability quotient.

3.4.2 Magnesium adsorption ratio (MAR)

Generally, in most groundwater Ca^{2+} and Mg^{2+}maintain a state of equilibrium. During equilibrium more Mg^{2+} in groundwater adversely affects the soil quality rendering it alkaline which result in decrease of crop yield. Paliwal developed an index for calculating the magnesium hazard called Magnesium adsorption ratio(MAR). MAR is calculated using the formula after Raghunath 1987.

$$MAR = \left(Mg^{2+} \times 100\right) / \left(Ca^{2+} + Mg^{2+}\right)$$

Where, concentrations of all ions have been expressed in meq/L.

MAR categorizes water into two broad classes – water having MAR < 50 is considered suitable for irrigation whereas water with MAR > 50 is considered unsuitable.

3.4.3 Soluble sodium percentage (SSP)

The adsorption of Sodium by clay particles is facilitated due to release of Calcium and Magnesium ions resulting into internal drainage patterns in soil causing high sodium ion concentration in soil. The following equation was used to calculate SSP (Todd 1980)

$$SSP = \left[\left(Na^{+} + K^{+}\right) \times 100\right] / \left[Ca^{2+} + Mg^{2+} + K^{+}\right] \quad (3.2)$$

Where, concentrations of all ions have been expressed in meq/l.

3.4.4 Permeability Index (PI)

In past few decades, researchers have evolved a solution for estimating the quality of agricultural waters by modified criterion based on the reaction occurring in the soil solution from cation exchange and on the solubility of salts (Gupta and Gupta, 1987). The parameters such as sodium content, total hardness and bi-carbonate content influences the soil permeability and affecting it by long-term use of irrigation water. Doneen (1964), introduced the term 'Permeability Index' by incorporating the first three items after conducting a series of experiments for which he had used a large number of irrigation waters varying in ionic relationships and concentration. The permeability index is given by the following formula:

$$PI = Na^{+} + \left[\left\{\left(HCO_3^{-}\right)^{\frac{1}{2}} / \left(Ca^{2+} + Mg^{2+} + Na^{+}\right)\right\} \times 100\right]$$

Where, the ions are expressed in meq/L.

3.4.5 Kelly's Ratio (KR)

To measure sodium ion concentration against Calcium and Magnesium ion concentrations Kelly's Ratio (Kelly, 1940) is used:

$$KR = Na^{+} / \left(Ca^{2+} + Mg^{2+}\right)$$

Where, concentrations of all ions have been expressed in meq/L. Waters with a KI value <1 are considered suitable for irrigation, while those with greater ratios are rendered unsuitable.

Chapter 4

Result and Discussions

Chapter 4: Result and Discussions

4.1 General

In the present study is intended to study the overall variations of major physicochemical parameters measured along the eastern fringe of Chilika lagoon, the strip of land in between the sea at eastern side and saltwater lagoon in its western side, during pre-monsoon session 2018. Estimation of concentration of major ions, pH, TDS were done and suitability of ground water quality for domestic and irrigation purpose were evaluated both for the samples collected separately from dug well and tube well form all the seven locations. The concentration of major ion chemistry of the aquatic system is the most crucial issue and predominantly controlled by the weathering processes of rock forming minerals with a negligible contribution from atmospheric and anthropogenic sources (Berner and Berner 1987; Sarin et al. 1989; Singh and Hasnain 2002). The relative proportions of the various ions in solution depend on their relative abundance in the host rock as well as on their solubility (Sarin et al. 1989).

Table 4.1 Physicochemical parameters measured in the field

Location No.	Location Name	Physical Parameters						
		DW				TW		
		Water Table Depth (m - bgl)	pH	TDS (ppm)	E.C (µmhos/cm)	pH	TDS (ppm)	EC (µmhos/cm)
1	Bramhagiri	2.90	7.25	156.0	312.0	6.43	555.0	1108
2	Panaspada	3.10	6.51	636.0	1272	7.55	1064	2133
3	Baghamunda	4.70	6.52	162.0	324.0	7.49	301.0	602.0
4	Alupatana	5.30	6.95	220.0	440.0	6.73	435.0	870.0
5	Kurupal	2.40	6.80	2413	4828	7.29	2584	4986
6	Morada	2.00	7.37	349.0	697.0	6.82	1289	2581
7	Malud	2.20	6.60	303.0	606.0	6.74	1331	1661

Table 4.1, reveals the physicochemical parameters those were measured instantaneously in the field during the collection of the samples, separately for DW and TW.

Tables 4.2 (a-b), represent the location wise concentration of major cations and anions of the water, separately for the TW and DW water respectively, as estimated through standard laboratory tests mentioned in the Chapter 3.

Table 4.2a Concentration of major cations and anions of the water, for TW

Location No.	Location Name	Tube well (TW)					
		Ionic Concentration (mg/l)					
		Na^+	Ca^+	K^+	Mg^+	Cl^-	HCO_3^-
1	Bramhagiri	95.88	18.59	73.36	31.59	156.00	240.0
2	Panaspada	94.00	18.48	7.00	35.58	615.68	329.4
3	Baghamunda	63.00	18.48	10.00	22.89	135.15	244.0
4	Alupatana	94.68	19.46	4.80	21.87	156.00	190.0
5	Kurupal	973.5	23.89	29.19	53.46	1070	370.0
6	Morada	19.00	25.20	23.00	43.19	575.63	512.4
7	Malud	175.59	24.68	285.52	53.46	440.00	420.0

Obtained data from the chemical analysis were used to evaluate the overall suitability of the ground water for health, domestic and irrigation purposes. Parameters like, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR), Kelly's ratio (KR).

Table 4.2b Concentration of major cations and anions of the water, for DW

Location No.	Location Name	Dug well (DW)					
		Ionic Concentration (mg/l)					
		Na^+	Ca^+	K^+	Mg^+	Cl^-	HCO_3^-
1	Bramhagiri	15.19	30.00	16.42	21.87	35.45	120.0
2	Panaspada	49.00	28.56	32.00	31.37	175.19	146.4
3	Baghamunda	14.00	8.40	11.00	8.54	110.12	97.6
4	Alupatana	32.39	12.80	4.25	12.15	85.00	100.0
5	Kurupal	594.50	38.90	301.24	97.20	1042	220.0
6	Morada	22.00	42.00	6.00	18.30	140.15	280.6
7	Malud	33.59	41.50	36.60	26.73	78.00	160.0

Further, these parameters were used to estimate the suitability of ground water for agricultural and drinking purposes by plotting these values on standard reference diagrams like Wilcox, U.S. Salinity [US Salinity (1954)], Doneen's chart and Piper's diagram. Table 4.3 show the values of derived indexing chemical parameters as estimated for TW and DW location wise.

Table 4.3 Indexing chemical parameters to evaluate water quality

Loc. No	Location Name	Indexing Water Quality Parameters							
		(DW)				(TW)			
		SAR	SSP	MAR	KR	SAR	SSP	MAR	KR
1	Bramhagiri	0.51	24.55	54.85	0.19	3.12	63.60	73.90	1.17
2	Panaspada	1.49	42.19	64.67	0.52	2.93	43.00	76.24	1.05
3	Baghamunda	0.80	44.04	62.88	0.53	1.44	42.87	67.36	0.96
4	Alupatana	1.54	47.87	61.27	0.85	3.48	51.02	65.19	1.47
5	Kurupal	11.53	76.97	80.63	2.57	25.18	84.791	78.85	7.49
6	Morada	0.71	23.44	42.06	0.26	0.529	17.447	74.06	0.17
7	Malud	0.99	35.79	51.77	0.33	4.52	92.50	78.30	1.34

4.2 Fluctuation of Water Table Depth

Pre-monsoon water table depth as recorded along the eastern fringe of Chilika Lagoon starting from Bramhagiri(L_1) at north to Malud(L_7) at south varies from 2 meter to 5.3 meter below ground level. Figure 4.1 reveals the graphical plot of fluctuation of ground water table depth during PRM session 2018. Location wise plot (Figure4.1) of water table depth reveals that from Bramhagiri(L_1) to Alupatana(L_4) there is a steady increase of water table depth proceeding southwards. Here, it is interesting to note that from Alupatana(L_4) to Morada(L_6) the trend of the curve is dramatically opposite. That is depth of ground water table decreases steadily and thereafter a slight hike in depth was noted from Morada(L_6) to Malud(L_7).

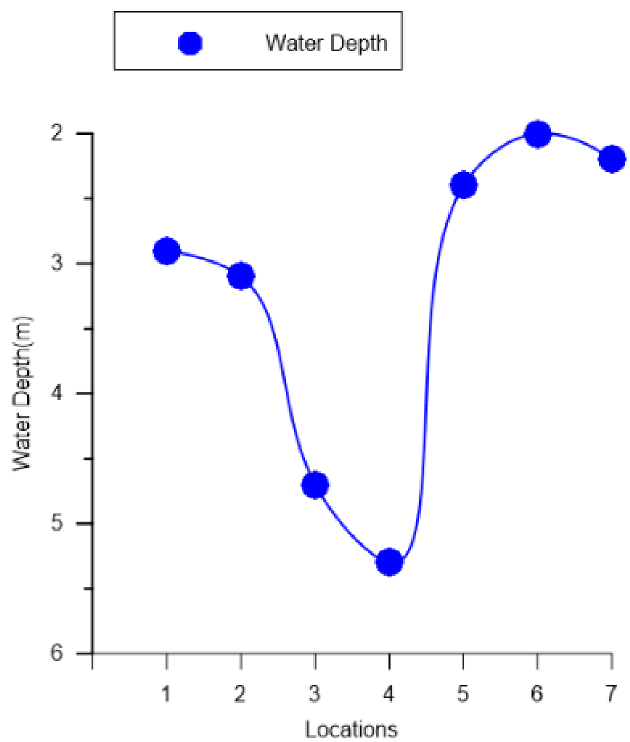

Figure 4.1 Fluctuations of water level depth in DW(m, bgl)

As par the spatial position of the locations as studied, it reveals clearly, that the transverse distance of the location studied from the lagoon were maximum for Baghamunda(L_3) and Alupatana(L_4). Not only that, these locations located near to the sea mouth (Figure 2.3). As these locations are at central part of the studied area and are absolutely within the network of interconnected saline streams, probably the rate of sediment deposition was maximum. This contributes comparatively loosely compacted recent sediment with high porosity and permeability, which may be the key reason for the depth of water table that lies far below than that of the other locations, that are comparatively instable soil area with thick vegetation cover. It can be seen from the map that the central part of the studied area is comparatively less wide than that of the northern and southern parts. It is also noted that the northern and southern parts have good amount of cultivation and vegetation cover. The central part has no cultivation at all with little amount of vegetation cover. So may be due to presence of crops and vegetation roots, the upper part of the soil is saturated with a substantial amount of water.

From the demographics it is clearly noted that anthropological interventions in the form of tourism is mostly concentric around the Satapada area (near to L_4 and L_5), which leads to comparatively dense construction and inhabitation in the area. In accordance with that exploitation of groundwater thorough pumping is comparatively more intense in these locations. This overexploitation may be a key factor for comparatively high water table depth in this area.

As the depth of water table is gradually increasing towards the central part from northern and southern ends, this zone is major recharged zone of the studied area. Whether, northern and southern ends act as discharge zone. From the plot it is also clear that the groundwater moves just in opposite direction from the northern with that of the southern end. Therefore, these directionally opposite movement of subsurface water obviously affect the rate of sea water ingress within the groundwater, which is a frequent and chronic issue as par the water quality of the studied area is concerned. Differential concentrations of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-,HCO_3^-,CO_3^{2-}) at different locations as noted through the chemical analysis is probably the resultant of this almost steady subsurface movement of groundwater in the studied area.

4.3 Variation of Physicochemical Parameters

Locations wise Substantial variations were noted in the measured major **physicochemical parameters** in the water of the studied area. The observed and estimated fluctuations in the major parameters are discussed in this subheading with possible geo-hydrological and geological explanations.

4.3.1 pH

The hydrogen ion concentration or pH is very important characteristics of groundwater as a whole towards its suitability for both drinking and irrigation purposes. Overall activities of biosphere and ecological dynamicity depend a large on it. The recorded pH value of the water (in-situ) show a moderate fluctuation through the entire study area and no such specific trend was noticed in its fluctuations. Figure 4.2 shows the plots of pH of the water sample location wise from north to south for DW and TW. X-axis of the plot represents the location number from north to south almost having longitudinal equidistance broadly, where the Y-axis represents the pH values. The maximum pH value is noted around 7.6(L_2) and minimum pH is 6.4(L_1) both in tube-wells.

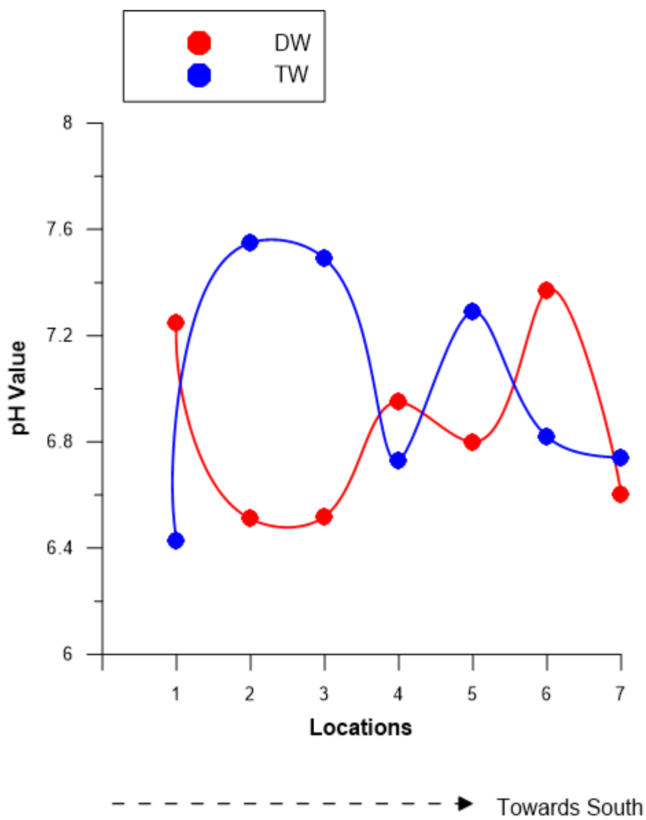

Figure 4.2 Location wise variation of pH of the DW and TW water

It was noted the overall pH values are frequently fluctuating throughout the studied area and particularly no such trend was observed. Though the extreme observed pH value ranges in between the acceptable limits for domestic, drinking and irrigational purpose. Gross difference is noted between the pH values of dug-well and tube-well water for almost all the locations (except L_7). In some cases water of the dug-well shows high value of pH compared to tube-well water(L_1,L_4,L_6) and in some locations it is just vice-versa(L_2,L_3,L_5). Only in the location L_1 the pH value was slightly acidic (6.4). The average pH value of DW and TW are 6.85 and 7.00 respectively. Both are absolute in the ideal range for use.

Differential fluctuation of pH values in between dug-well and tube-well water is probably due to interaction tube-well water(which has greater depth than dug-well water) with the present rock-type. As the dug-well water is in the shallow depth, probability of the interaction with the rock-type is less.

4.3.2 Electrical conductivity (EC)

Electrical conductivity is the measure of ability to pass electrical current flow. The ability is directly related to the concentrations of ions in water. These conductive ions come from dissolved salts and inorganic materials. The more the ions are present, the higher the conductivity water is. EC of water can also be proportionally related to the dissolved solids in water, as the flow of current is dependent on the quantity and conducting capability of these dissolved particles. According to Wilcox (1948) the range of values for EC with reference to the classification of water for its drinking suitability is shown in the Table 4.4.

Table 4.4 Classification of groundwater based on EC (after, Wilcox - 1948)

EC range (microSimens / cm)	Class
<250	Excellent
250 - 750	Good
750 - 2000	Permissible
2000 - 3000	Doubtful
>3000	Unsuitable

From the classification of groundwater based on EC (Wilcox-1948) location wise irrigation suitability is shown in the table 4.5.

Table 4.5 Location wise irrigation suitability of water according to EC

Location no.	Location Name	Suitability for Irrigation	
		DW	**TW**
1	Bramhagiri	Good	Permissible
2	Panaspada	Permissible	Doubtful
3	Baghamunda	Good	Good
4	Alupatana	Good	Permissible
5	Kurupal	Unsuitable	Unsuitable
6	Morada	Good	Doubtful
7	Malud	Good	Permissible

Location wise plot of the EC separately for dug-well and tube-well are represented by Figure 4.3. The value of EC ranges from 312 μ.Simens/cm to maximum of 5171 μ.Simens/cm. From the values of EC it is noted that water from the tube-well is in 'Permissible' to 'Doubtful' class in almost all the cases, whereas dug-well water is in 'Good' class for almost all locations. An abnormal high value of EC is noted at Kurupal(L_5).

The plot indicates an overall high value of EC in case of tube-well water than dug-well water. Over exploitation of water mainly through tube-well for expansion of irrigation may be a key reason for which there is continuous ingress of sea water. As the usage of dug-well water is comparatively less than that of tube-well water, the water quality is fresh in nature.

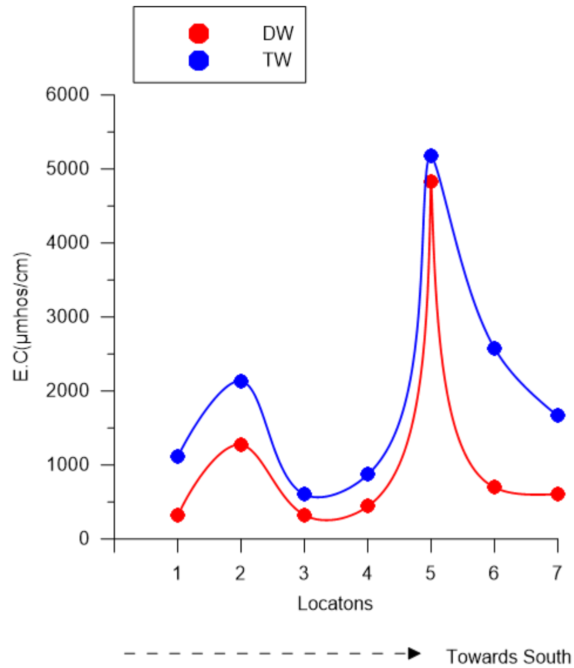

Figure 4.3 Location wise variation of EC of the DW and TW water

4.3.3 Total dissolves solids (TDS)

The sum of concentrations of all of the dissolved constituents in a water sample is known as the Total Dissolved Solids or TDS and is expressed in mg/l. Million(ppm). Generally, calculated from EC by multiplying it with 0.64. Often TDS is expressed in parts per thousand(ppt) or parts per million (ppm). According to Ela (2007) the range of values for total dissolve solids are presented in the Table 4.6.

Table 4.6 Classification of water on TDS (Ela 2007)

TDS Range (ppm)	Classification
<1000	Fresh
1000 – 10,000	Brackish
10,000 – 30,000	Saline
>30,000	Brine

Location wise plot of TDS both for tube-well and dug-well water is represented by Figure 4.4.The value of TDS for dug-well ranges from 156 ppm to maximum of 2413 ppm.

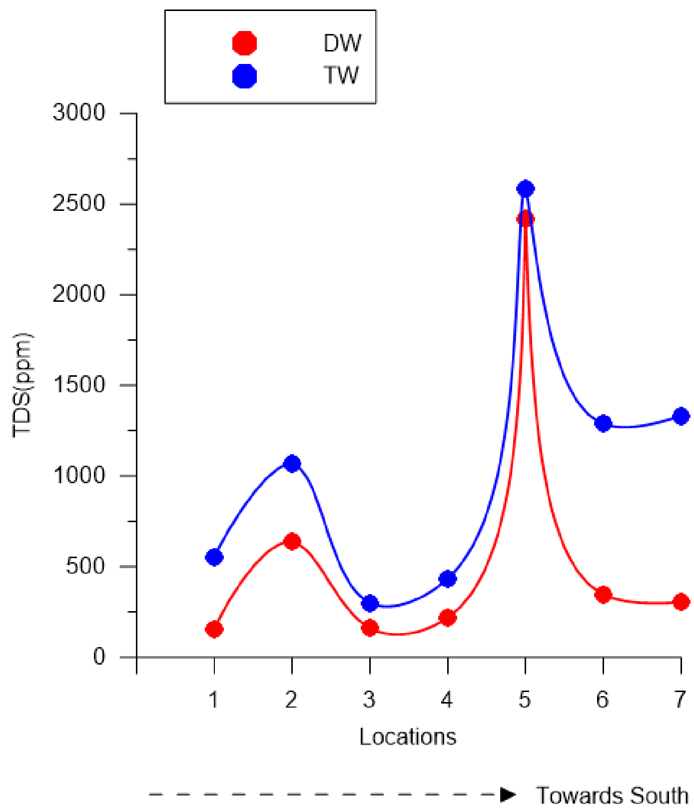

Figure 4.4 Location wise fluctuation of TDS

From the plot it is also estimated that water from tube-well are almost brackish in nature but dug-well water from the same location are fresh and safe. Kurupal(L_5) is showing an abnormal high value of TDS both for tube-well and dug-well water.

The plots clearly indicate that for the tube-well water there is continuous ingress of sea water in the groundwater table and obviously this is because of the over rated pumping of the subsurface fresh water needed drastically for the irrigation in the newly born islands. Dug-well water usage is comparatively much lower than tube-well water that is why those are fresh in nature. The following terms are used to qualitatively express TDS to estimate the suitability of water for irrigation purposes as shown location wise for the studied area in the Table 4.7, both for DW and TW water.

Table 4.7 Location wise irrigation suitability of water according to TDS concentration

Location no.	Location Name	Suitability for Irrigation	
		DW	TW
1	Bramhagiri	Fresh	Fresh
2	Panaspada	Fresh	Brackish
3	Baghamunda	Fresh	Fresh
4	Alupatana	Fresh	Fresh
5	Kurupal	Brackish	Brackish
6	Morada	Fresh	Brackish
7	Malud	Fresh	Brackish

4.3.4 Sodium (Na^+)

Sodium (Na^+) is the one of the most abundant element on earth and is widely distributed in soil cover, plants and water. Most of the world has significant deposit of Sodium containing mineral, most notably Sodium Chloride(salt). Sodium is often found in groundwater, because most of the crustal rocks and soils contain substantial volume of Sodium compounds from which Sodium is easily dissolved.

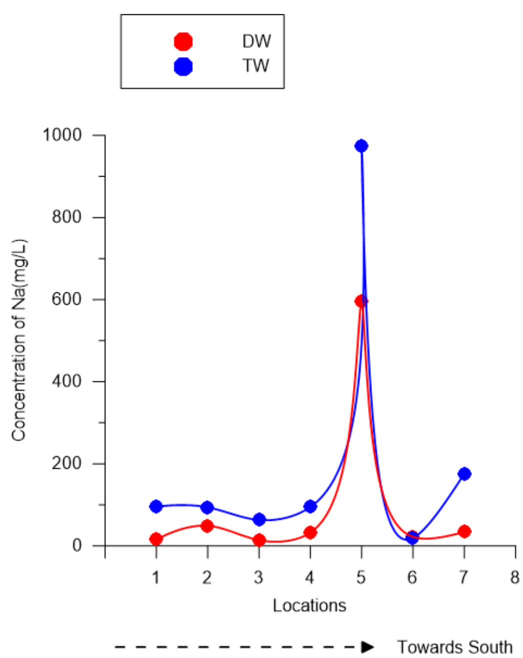

Figure 4.5 Location wise variation of Na^+ ion concentration of the DW and TW water

Figure 4.5 represents the variation of Na^+ ion concentration of both tube-well and dug-well water. Ranges of Na^+ ion concentration varies widely from 15.19 mg/l up to 973.5 mg/l. From the plot it may be noted that from Bramhagiri(L_1) to Baghamunda(L_3) and from Malud(L_7) to Morada(L_6) concentration of Na^+ ion is decreasing for both dug-well and tube-well water. At location Morada(L_6) both tube-well and dug-well water shows almost same value of Na^+ ion concentration. Both Tube-well and dug-well water show abruptly a high value at Kurupal(L_5). Overall Na^+ ion concentration of tube-well water is greater than that of DW water, except at Morada. High rate of water exploitation through tube-wells for both irrigation and domestic purpose may be the main reason behind the higher concentration of Na^+ ion in tube-wells rather than dug-wells. That is why sea water ingress is continuous and sea water has high concentration of dissolved Na^+ in it, which leads to increase the Na^+ ion concentration of groundwater.

4.3.4 Calcium (Ca^{2+})

Calcium is the fifth most abundant natural element. It enters the fresh water system through the weathering of rocks, especially limestone and from the soil through seepage and leaching.

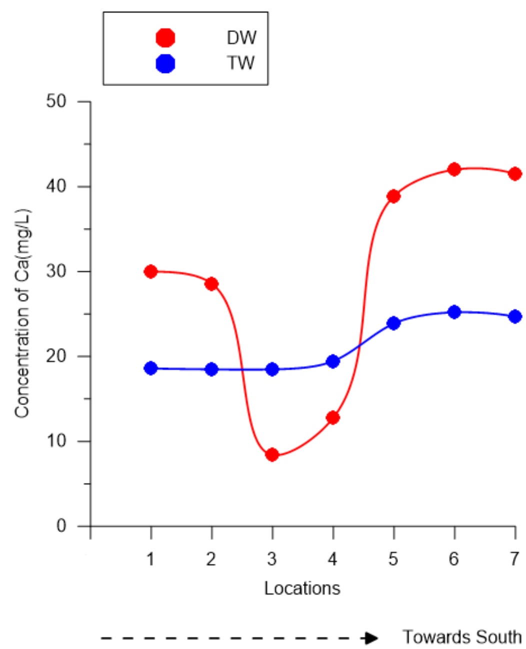

Figure 4.6 Location wise variation of Ca^{2+} ion concentration of the DW and TW water

Figure 4.6 represents the variation of Ca^{2+} ion throughout the study area for dug and tube-well water. It varies from 8.4 mg/L to 38.9 mg/l. It is evident from the variation plots that overall Ca^{2+} ion concentration of DW water is higher than that of TW except at Baghamunda(L_3) and Alupatana(L_4). From Bramhagiri to Panaspada Ca^{2+} ion concentration of dug-well water is decreasing steadily and then there is a sharp decrease. After that it is increasing again sharply to Kurupal (L_5) and then the increment is steady to the last location Malud, of our study area. Whereas in case of tube-well water from Bramhagiri(L_1) to Malud(L_7) concentration is increasing steadily overall. But the scale of fluctuation is very low and in all the location concentration is below the lower limit of ideal concentration of Ca^{2+} in water and that is no good for drinking.

4.3.5 Potassium (K^+)

Potassium is an element commonly found in soils and rocks. Sources of Potassium include weathering and erosion of Potassium bearing minerals, such as Feldspar, leaching of fertilizer and sea water intrusion. Figure 4.7 represents the variation of K^+ ion concentration of the studied area for both tube-well and dug-well water. It varies from 6 mg/l to 301.24 mg/l.

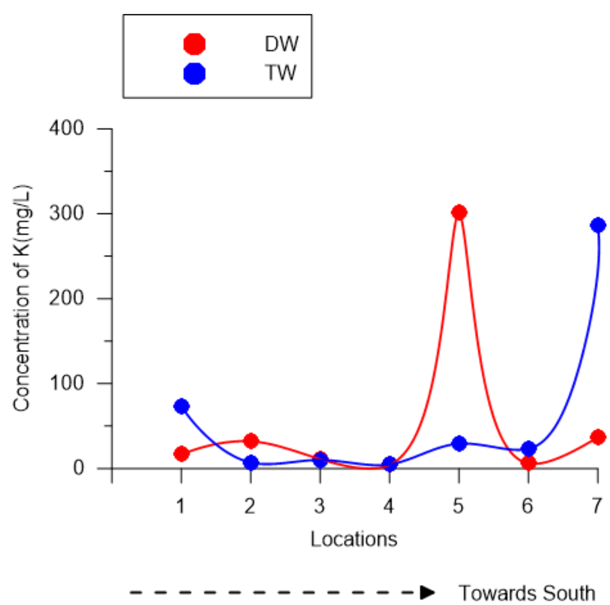

Figure 4.7 Location wise variation of K^+ ion concentration of the DW and TW water

It can be seen from the plot that variations of concentration of K^+ ion for tube-well and dug-well water are not similar. It varies from 6 mg/L up to maximum of 301.24 mg/l. From

Bramhagiri(L_1) to Alupatana(L_4) K^+ ion concentration decreases for tube-well water, and then from Alupatana to Malud(L_7) concentration increases. Whereas K^+ ion concentration at first increases and then decreases from Bramhagiri(L_1) to Alupatana(L_4). Again there is a hike in the concentration at Kurupal(L_5) and then it decreases rapidly. Finally from Morada(L_6) to to Malud(L_7) concentration of K^+ ion again increases. Baghamunda(L_3) and Alupatana(L_4) have almost similar concentration of K^+ ion. Maximum deviation between dug-well and tube-well water is there in Kurupal(L_5) and Malud(L_7). There is an anomaly of the K^+ ion content in the dug-well water at Kurupal, probably because of some radical change of surface soil materials restricted in that area or may be due to use of fertilizers like Phosphates for irrigation.

4.3.6 Magnesium (Mg^{2+})

Magnesium is the eighth abundant natural element. It generally get into the subsurface water from the weathering of subsurface rock or soil. Mg^{2+} present in the water would adversely affect soil quality, rendering it alkaline and affect its usage for irrigation and drinking purpose. Figure 4.8 shows the overall variation of Mg^{2+} ion throughout the study area for both DW and TW water. The concentration varies widely from 8.54 mg/l to 97.2 mg/l.

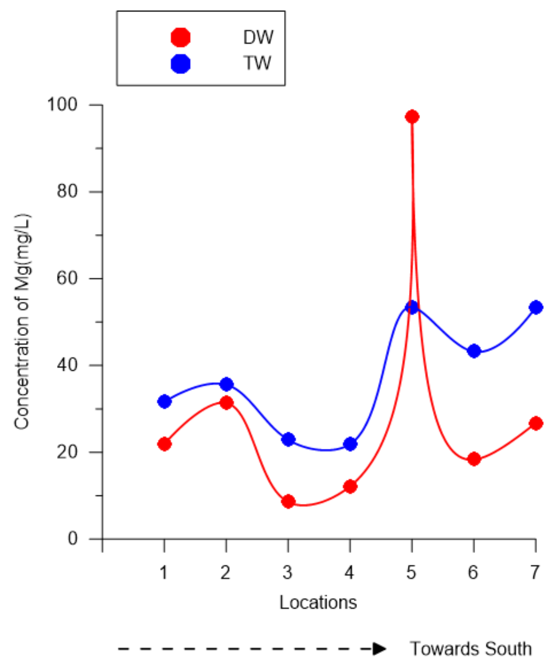

Figure 4.8 Location wise variation of Mg^{2+}ion concentration of the DW and TW water

Here, location wise Mg^{2+}ion concentration plots reveal that overall concentration of Mg^{2+} ion in TW water is considerably higher than of DW water except at Kurupal(L_5). From Bramhagiri(L_1) to Panaspada(L_3) the trend of tube-well water is increasing steadily, after that decreasing up to Alupatana and then increasing at Kurupal. From Kurupal to Morada this trend is decreasing again and then increasing at Malud. Overall, Dug-well water is showing same trend as that of tube-well water, except a sharp anomaly at Kurupal.

4.4 Suitability for Irrigation and Drinking Purposes

Ingress of saline water both from the sea and lagoon is a chronic and common issue that play a crucial role to degrade the overall groundwater quality both regarding its suitability for irrigation and domestic usage. On irrigated lands, salinization is the major cause of loss of production and is one of the most prolific adverse environmental impacts associated with irrigation. Saline conditions severely limit the choice of crops, adversely affect crop germination and yields, and can cause soils to be difficult to work. Standard driven out parameter on the basis major ion concentrations were estimated location wise for both DW and TW water to depict an overall PRM water quality status for this strip of studied area. Major water suitability parameters estimated were SAR (Sodium Absorption Ratio), MAR (Magnesium Adsorption Ratio), SSP (Soluble Sodium Percentage), KR (Kelly's Ratio),), U.S Salinity and Piper's Diagrams.

4.4.1 Sodium adsorption ratio (SAR)

Irrigation water containing large amount of sodium is of special concern due to Sodium's effect on the soil and poses a sodium hazard. Sodium hazard is usually expressed in terms of SAR or Sodium Adsorption Ratio. SAR values are calculated using the Eqn.3.1. Table 4.8 show the standard classification of groundwater based on its SAR value (Richards 1954)

Table 4.8 Classification of water based on its SAR value

SAR values	Class
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsafe

Location wise plot showing the variation of estimated SAR values is revealed by Figure 4.9. The plots show an abnormal high value at Kurupal(L_5). The trend is almost similar for both the TW and DW water. Overall value is slightly higher for TW water than DW, which is due to relatively high Na^+ concentration in case of TW water.

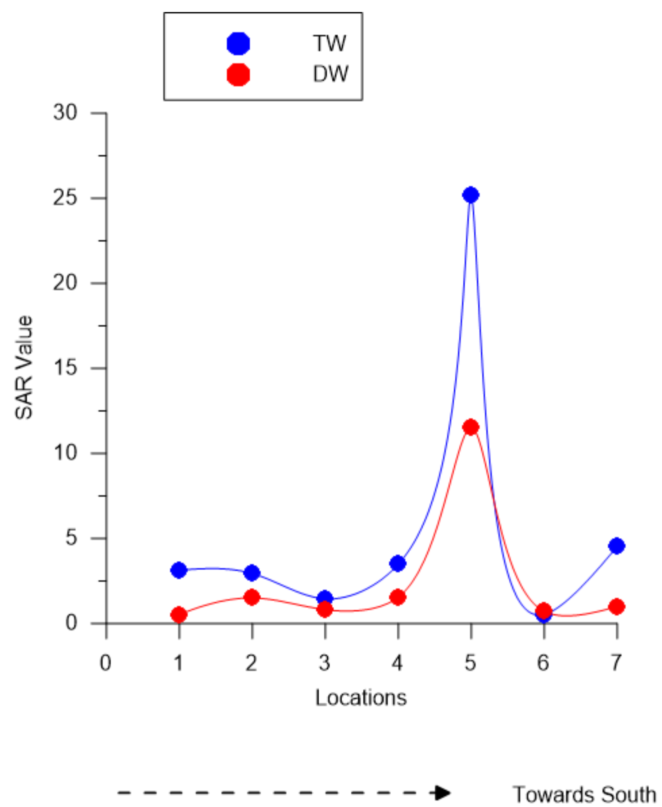

Figure 4.9: Location wise variations of SAR values of DW and TW water

Table 4.9 represents the location wise irrigation suitability of both DW and TW water as classified according to the estimated SAR value. It is revealed from the classification DW water are of excellent class. Whereas for TW water most of the locations have excellent water except Kurupal(L_5). Random and prolonged usage of motor pump to withdraw the subsurface water is the basic reason for this degradation of TW water, especially for villages with regular cropping practices.

Table 4.9 Irrigation Suitability based on its SAR value

Location no.	Location Name	Irrigation Suitability	
		DW	TW
1	Bramhagiri	Excellent	Excellent
2	Panaspada	Excellent	Excellent
3	Baghamunda	Excellent	Excellent
4	Alupatana	Excellent	Excellent
5	Kurupal	Excellent	Good
6	Morada	Excellent	Excellent
7	Malud	Excellent	Excellent

4.4.2 Magnesium adsorption ratio (MAR)

Magnesium ratio is the excess amount of Magnesium over Calcium and Magnesium amount. Mg^{2+} present in the water would adversely affect soil quality, rendering it alkaline. Figure 4.10 shows the variability of MAR values of different locations throughout the study area for both dug-well and tube-well water.

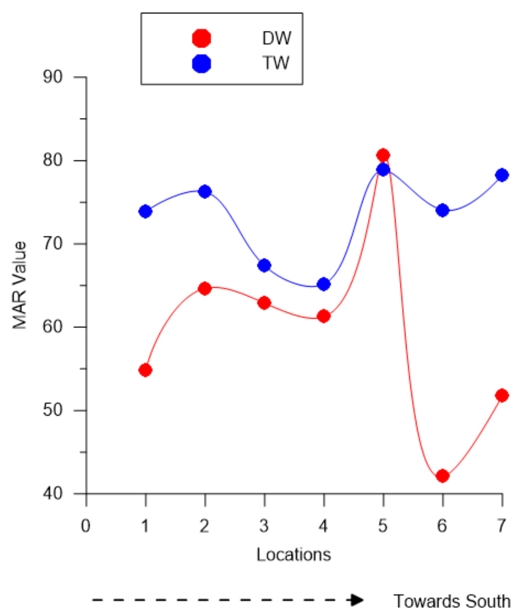

Figure 4.10 Location wise variations of MAR values of DW and TW water

4.4.3 Soluble sodium percentage (SSP)

Soluble Sodium Percentage or SSP is also used to evaluate sodium hazard. SSP is defined as the ratio of sodium in epm(equivalent per million) to the total cation ppm multiplied by 100. Table 4.10 shows the standard classification of groundwater based on its SSP value.

Table 4.10 Classification of water based on its SSP value

SSP values	Class
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

Figure 4.11 represents the variation of SSP values of different location both for dug-well and tube-well water.

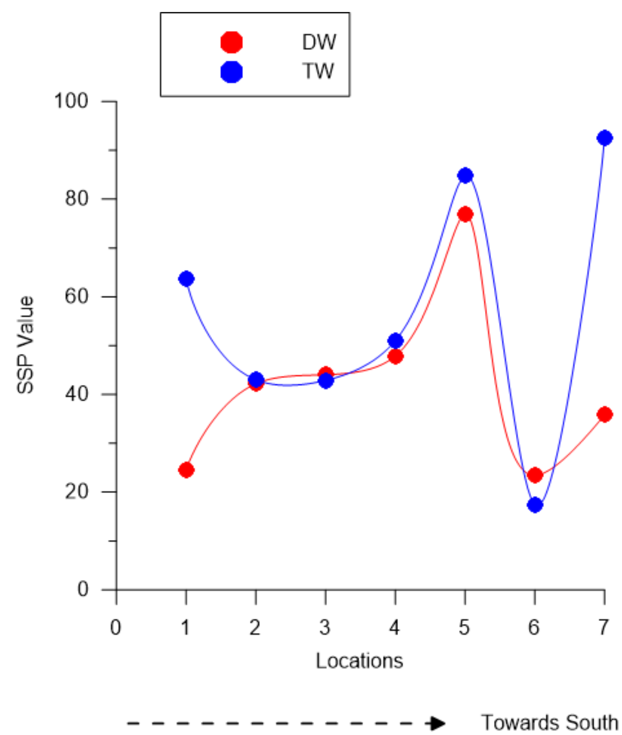

Figure 4.11 Variation of SSP values of Dug-well and Tube-well Water

Both the dug-well and tube-well water follow same trend. Kurupal(L_5) has anonymously high value of SSP. Tube-well water has overall high SSP value than dug-well water except at Kurupal(L_5).

Table 4.11 represents the location wise irrigation suitability for both dug-well and tube-well water. It is revealed from the table that almost all the location have permissible irrigation suitability for dug-well water except at Kurupal(L_5) and Morada(L_6). Also for tube-well water almost all the locations have permissible irrigation suitability except at Kurupal(L_5) and Malud(L_7), these have unsuitable water for irrigation.

Table 4.11 Irrigation suitability of Dug-well and Tube-well water on the basis of SSP

Location no.	Location Name	Irrigation Suitability	
		DW	TW
1	Bramhagiri	Good	Good
2	Panaspada	Permissible	Permissible
3	Baghamunda	Permissible	Permissible
4	Alupatana	Permissible	Permissible
5	Kurupal	Doubtful	Unsuitable
6	Morada	Good	Excellent
7	Malud	Permissible	Unsuitable

4.4.4 Kelly's ratio (KR)

Kelly's ratio is measured considering Sodium ion concentration against Calcium and Magnesium ion concentration. This is another and last parameter which is taken into consideration to determine the quality of ground water within this study area. It is clear from the graph that the trend is almost similar for dug-well and tube-well water. Overall tube-well water has high value of KR than dug-well water except at Morada(L_6). Maximum value of KR is at Kurupal(L_5).

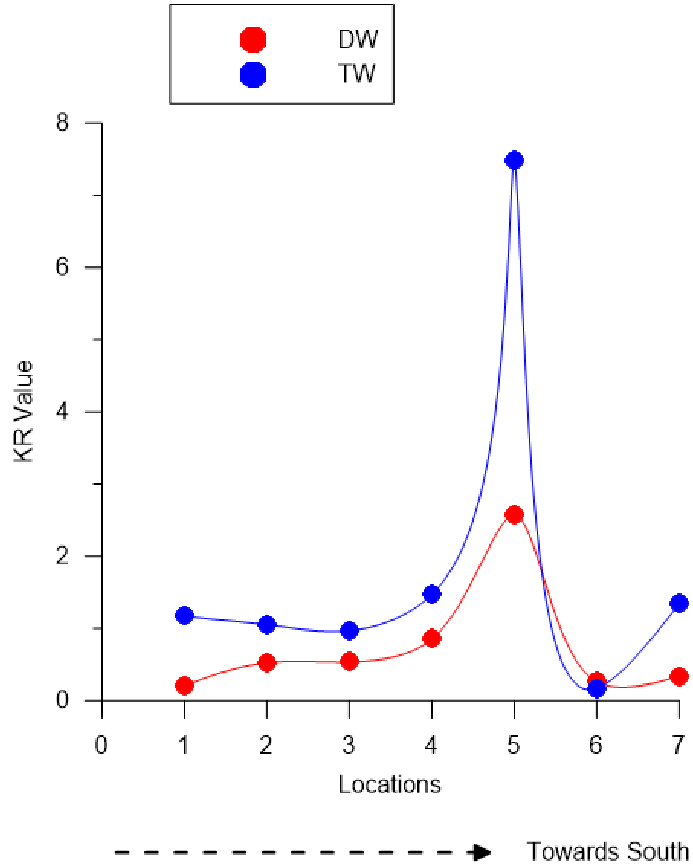

Figure 4.12 Variation of KR values of Dug-well and Tube-well Water

4.5 Irrigation Suitability

Degradation of water quality in respect to its irrigation suitability imposes a long-term adverse impact on overall socio-economic and public health issues. Frequently, salinization of water is the major cause of loss of production (Stumm, 1981). Abnormal abundance or absence of major controlling ionic concentration severely affect public health, its domestic uses and limit the choice of crops, unfavorably affect the cultivation processes from germination to crop yields. It is important that all evaluation regarding irrigation water quality is linked to the evaluation of the soils to be irrigated and to be done in a recurring interval (Ayers and Wescot, 1985). The present study reports the updated status of all the hydro-chemical properties and parameters of groundwater following the standard international analogy and methods to evaluate its overall suitability for irrigation purpose.

4.5.1 U.S. salinity diagram

The irrigational suitability of water samples is categorized using the U.S. Salinity diagram of the water samples on US Salinity Diagram (Richards 1954), based on the SAR values. Plots on the U.S. Salinity diagram for dug-well (Figure 4.13a) reveal that overall water of the area fall in low Sodium hazard zone except at Kurupal(L_5), here it is in high Sodium hazard zone, whereas plots on U.S Salinity diagram for tube-well water (Fig. 4.13b) reveal that overall water of the area fall in low Sodium hazard zone, but Kurupal(L_5) falls in Very high Sodium hazard zone. Therefore, dug and tube-well water of the area is suitable for irrigation except at Kurupal.

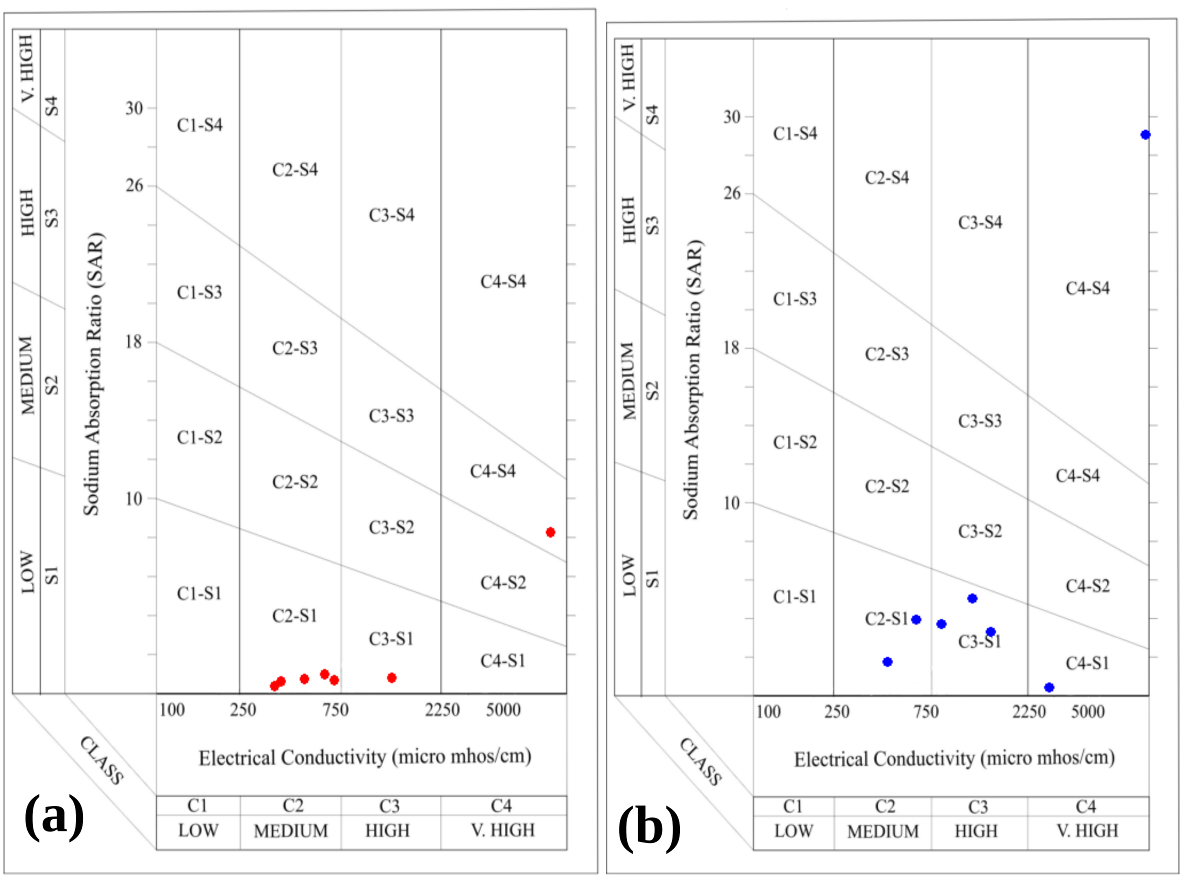

Figure 4.13 Irrigation Suitability based on U.S Salinity Diagram (a) Dug-well; (b) Tube-well

4.5.2 Wilcox diagram

Figures 4.14 and 4.15, represent the Wilcox Diagram as represented by the plots of SSP versus the respective EC values (Wilcox, 1955).

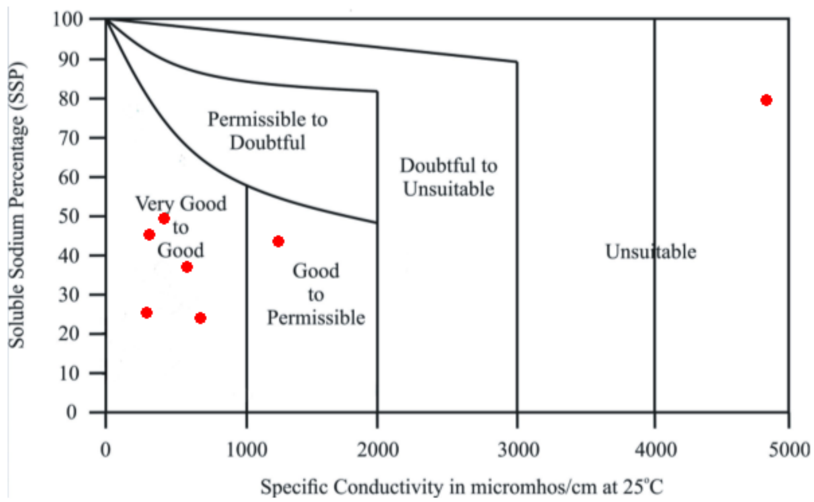

Figure 4.14 Irrigation Suitability based on Wilcox Diagram for Dug-well

It is evident from the plots that the dug-well water of the area mostly fall in the Very Good to Good region.

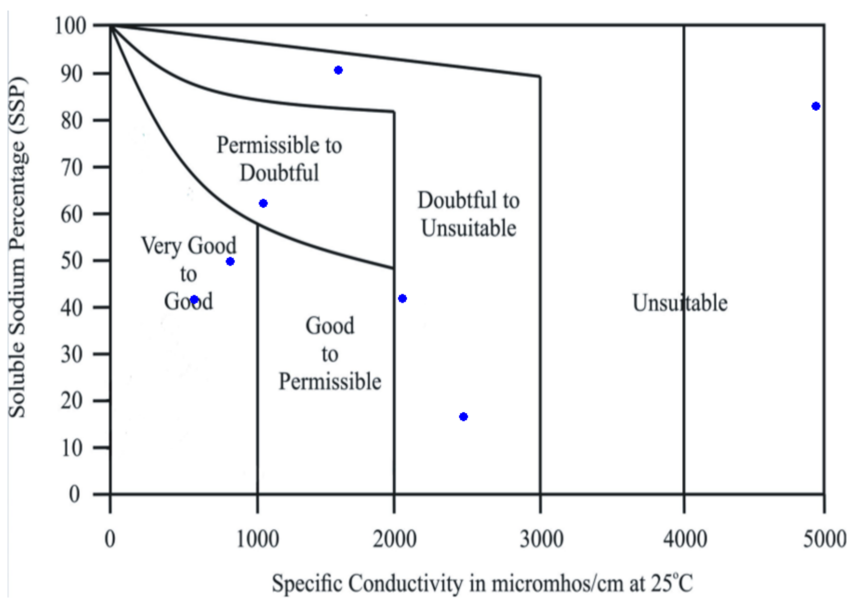

Figure 4.15 Irrigation Suitability based on Wilcox Diagram for Tube-well

From this diagram (Figure 4.15) it is clear that tube-well water of the area falls in Doubtful to Unsuitable region mostly and in some places from Very Good to Good region.

4.5.3 Doneen's chart

From the Figure 4.16(a-b) it is evident that dug-well water of the area has Permeability Index mostly Class I and Class III, whereas in case of tube-well water it is mostly Class II. Overall tube-well water is categorized as 'Good' for irrigation and dug-well water is categorized 'Moderate' for irrigation suitability.

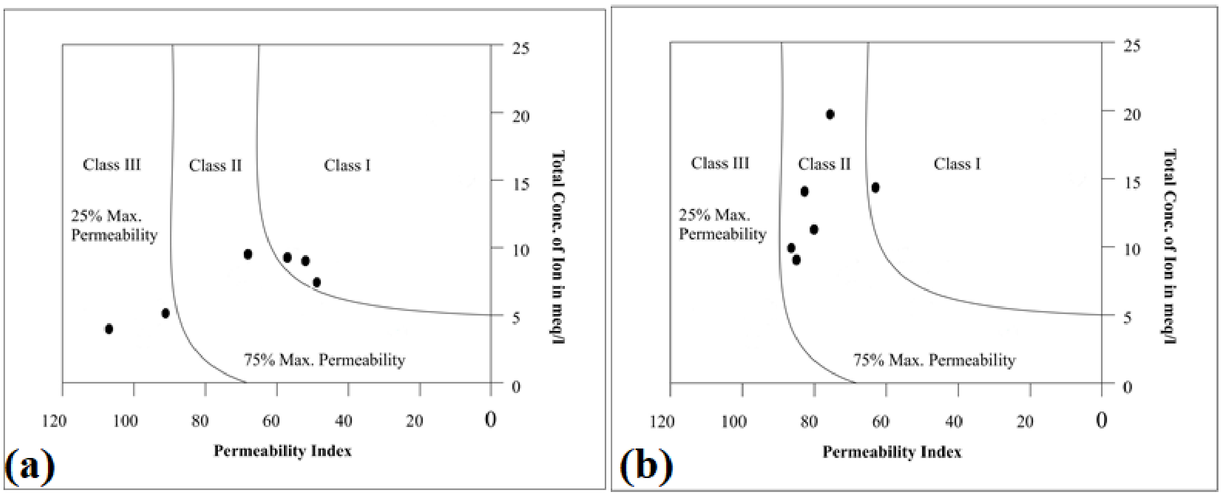

Figure 4.16 Irrigation Suitability based on Doneen's Chart; (a) Dug-well; (b)Tube-well

4.6 Drinking Suitability

The Piper Tri-linear diagram is represented by plotting the major cations and anions to determine the geochemical evolution of groundwater (Piper 1944). The cations and anions are shown by separate ternary plots. The apexes of the cation plot are Calcium, Magnesium and Sodium plus Potassium cations. The apexes of the anion plot are Sulphate, Chloride and Carbonate plus Hydrogen Carbonate anions. The two ternary plots are then projected onto a diamond. The diamond is a matrix transformation of a graph of the anions [(Sulphate + Chloride)/ total anions] and cations[(Sodium + Potassium)/total cations]. Piper diagram can predict the water type in three ways – Fresh type, Sulphate type and Saline type.

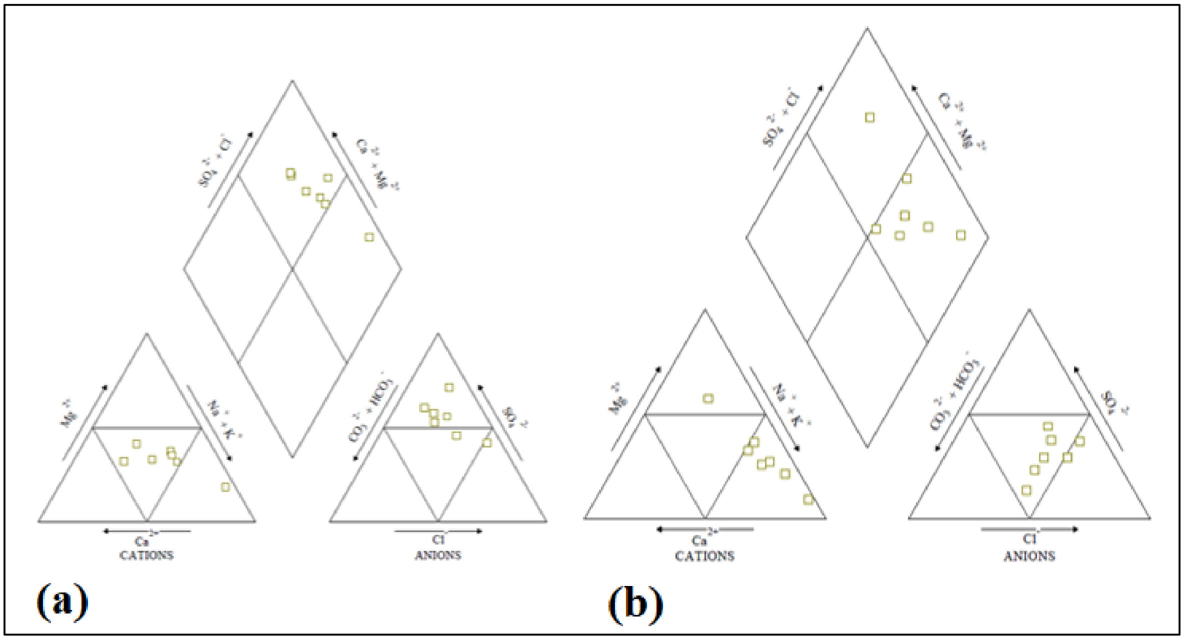

Figure 4.17 Drinking Suitability based on Piper Diagram; (a) Dug-well; (b) Tube-well

The plots of Figure 4.16(a-b) reveal that most of the dug-well water falls in Sulphate rich domain, whereas tube-well water is saline in nature. Both of these are not good for drinking purpose. Therefore it may be concluded that over exploitation of groundwater for the irrigation in the inhabited islands completely encircled by the lagoon, is responsible for the quite steady ingress of saline water within subsurface aquifer and causing a continuous deterioration of its suitability for the same.

Chapter 5

Conclusions

Chapter 5: Conclusions

5.1 Conclusions

Groundwater is the major source of the water for drinking, other domestic purposes, irrigation and in some cases for industrial purposes also. The present study reports a set of physical and hydro-geochemical parameters from the eastern fringe of Chilika lagoon. This area is important for its biodiversity and ecological uniqueness. Sporadic upcoming of new islands because of migration of sea mouth and peripheral outline of the lagoon is a continuous geophysical process of this particular area. Expansion of inhabitation and tourism causing a substantial stress towards the subsurface fresh water, which is being depleted in quality on the aspect of its suitability. Therefore to maintain the sustainable quality of groundwater reserve, it is required to assess its quality in a regular intervals.

Groundwater quality and its level in the dug-wells along the fringe of Chilika Lagoon from Bramhagiri in north to Malud in south, have been discussed here. All together 7 locations were taken, each having one dug-well and tube-well samples. From the overall field study and chemical evaluation of groundwater it may be concluded that the pH and TDS values of collected water samples are safe for drinking and irrigation purpose, as because these two are not causing any health hazards according to the WHO standard for drinking water(2004). Other elements such as Iron (Fe^{2+}), Calcium(Ca^{2+}), Magnesium(Mg^{2+}), Sodium(Na^{+}), Chloride(Cl^{-}),Bi-carbonate(HCO_3^{-}) and Sulphate (SO_4^{2-}) are within the allowable limits, but some places are having higher concentration which is beyond allowable limits. From the Piper's diagram it can be noted that the dug-well water of the studied area is Sulphate rich and the tube-well water is saline, which are not good for drinking purposes.

Overall it can be concluded that:

- The water table depth below ground level increases southwards up to Alupatana (L_4) and then decreases. This may be due to high porosity, high permeability loosely compacted sediment in the central part of the studied area near to sseamouth and overexploitation of groundwater in the densely populated Alupatana, Satapada area.

- Entire study area has pH value, which is allowable for drinking purposes.

- EC of the overall studied area is good for dug-well water and permissible to doubtful for tube-well water. Whereas in case of TDS dug-well water is almost fresh in all the places and tube-well water is fresh to brackish.

- Kurupal(L_5) has anonymously high value of all chemical and physical parameters. Kurupal is situated in a location where interplay between sediment and saline water is quite dynamic. Probably this interaction and a steady temporal and spatial fluctuation of sea mouth is the responsible factor for this abnormal scenario of this location.

- Overall the groundwater near the fringe of Chilika Lagoon is not good for drinking purpose, also intense irrigation has been seen away from the fringe. That is away from the effect of saline water intrusion from the lagoon (which is connected to the Bay of Bengal) into the groundwater.

5.2 Future Scope of Study

The present study was constricted within a temporal span of pre-monsoon session of 2018 only. Whatever data that has been represented the physical and chemical evaluation the studied area, were taken in the pre-monsoon session. Therefore, to obtain an overall scenario of ground water status, there is a need to study the same physicochemical parameters for post-monsoon session. The researchers are hereby agreed that there is a remaining task of post-monsoon field work to be done to draw a final and more specific conclusions on the temporal and spatial change of the physicochemical parameters of the subsurface water of the study area.

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