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EVALUATION OF GROUNDWATER QUALITY AND ITS SUITABILITY FOR DRINKING AND AGRICULTURAL USE IN KAVARATTI ISLAND IN THE LAKSHADWEEP ARCHIPELAGOS, INDIA

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ABSTRACT

This study attempts to address the processes controlling the chemical composition of the Kavaratti aquifer system of Lakshadweep Island in India. Major ions and other physico-chemical parameters were determined in the Kavaratti of the Lakshadweep Island system and analyzed to assess the major ion chemistry and suitability of water for domestic and drinking purposes. Chemical parameters of groundwater such as pH, electrical conductivity (EC), total dissolved solids (TDS), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined. The geochemical study showed that the groundwater is alkaline in nature. Higher concentration of sodium and chloride indicates leaching of secondary salts and anthropogenic impact by industry and salt water intrusion. The concentration levels of trace metals such as Iron (Fe), Lead (Pb), Nickel (Ni), Bromide (Br), Iodide (I) and Aluminum (Al) have been compared with the world standard. Majority of the groundwater samples in the study area were found to be unsuitable for domestic and drinking purposes.

KEYWORDS – Kavaratti, Lakshadweep Island, Hydrochemical, Groundwater, Geochemistry

INTRODUCTION

Hydrogeological and geochemical studies are the basis for scientific groundwater resource management (Senthilkumar et al. 2014). Due to the ever increasing demand for potable and irrigation water and inadequacy of available surface water, the importance of groundwater is increasing exponentially every day (World Bank Report 2010; Selvam and Sivasubramanian 2012).

Seawater intrusion is one of the most common problems in almost all coastal aquifers around the globe (Melloul and Goldenberg 1997, 1998; Sivakumar and Elango 2008; Chidambaram et al. 2009; Mondal et al. 2010, 2011; Srinivasamoorthy et al. 2011). This phenomenon can be elucidated by a variety of conditions such as gentle coastal hydraulic gradients, tidal and estuarine activity, sea level rises, low infiltration, excessive withdrawal and local hydrogeological conditions (Sarma et al. 1982; Longe et al. 1987; Rajmohan et al. 2000; Barret et al. 2002; Saxena et al. 2004; Kacimov et al. 2009). The common method for assessing seawater intrusion through an aquifer in coastal belts is the periodic analysis of groundwater (Todd 1980; Kim et al. 2009; Mondal et al. 2010, 2011; Krishnakumar et al. 2012). The chemistry of groundwater is an important factor that determines its use for domestic, irrigation and industrial purposes. Interaction of groundwater with aquifer minerals through which it flows greatly controls the groundwater chemistry. The geochemical properties of the groundwater depend on the chemistry of water in the recharge area as well as on the different geological processes that take place in the subsurface (Senthilkumar et al. 2014). The groundwater chemically evolves due to the interaction with aquifer minerals or by the intermixing among the different groundwater reservoirs along the flow path in the subsurface (Domenico 1972; Wallick and Toth 1976). Degradation of groundwater quality in the coastal region generally occurs due to natural processes such as saline water intrusion, wind-driven sea spray and marine aerosols deposited on the top soil, evaporation and interaction of groundwater with brines and sedimentary formation (Sanford et al. 2007).

Groundwater is the most important source for water supply in Lakshadweep. Groundwater chemistry of a region is generally not homogeneous and is controlled by geochemical processes, flow and recharge processes, evaporation, evapotranspiration and possible presence of contamination sources (Senthilkumar et al. 2014). Identification of various geochemical processes will help to understand the causes for changes in water quality due to the interaction with aquifer material. An attempt has been made in this study to evaluate the results of hydrogeochemical characteristics of groundwater and its suitability for drinking and agricultural purposes of Kavaratti Island. The trace metal contamination in the groundwater samples was also analyzed.

STUDY AREA

Lakshadweep, a group of coral islands located in the Arabian Sea off the west coast of India, forms an integral part of Chagos-Maldive-Laccadive Ridge in the Indian Ocean (Fig 2.1). The Lakshadweep group of islands is the smallest Union Territory of India. It has 36 islands and islets consisting of 12 coral atolls, 3 reefs and 5 submerged banks lying between Latitudes of 8 to 12^{o} 30’ N and Longitudes of 71 and 74^{o} East (Mannadiar 1977) and is considered as a geographical extension of the Maldives Island chain further south. The geographical area of the entire group of islands put together is 32 km^2 with a coastline of length 123 km and lagoon area of 4,200 km^2. The islands are grouped into 3 clusters named as Laccadive, Amindivi and Minicoy and the islands comprising each group which include both inhabited and uninhabited islands.

Lakshadweep islands have a delicate ecosystem with very limited fresh water resources. Though the islands receive high rainfall, the lack of surface storage and the limited groundwater storage capacity, where fresh water is occurring as a small lens floating over salt water, makes fresh water a precious commodity. High porosity of the aquifers allows mixing of freshwater with sea water. Due to the dense population, waste water gets mixed with the fresh water in the aquifer. These constraints complicate the management of the limited fresh water resources in the islands. Growing population and the constantly improving standards of living also impart considerable stress on the available fresh water resources (http://www.cgwb.gov.in/District_Profile/Lakshadweep/Lakshadweep.pdf).

Kavaratti is the capital of Union Territory of Lakshadweep and is located in the central part of Lakshadweep (Fig. 1). This is the most developed island among the Lakshadweep islands. This island is a distance of 404 km from Kochi (Kerala) and is located between Agatti Island on the west and Androth Island on the east. The maximum length of the island is about 5.5 km and maximum of 1.4 km width and it is oriented in a NE-SW direction. The total area of the island is 4.22 km^2 and has 3^{rd} rank in size among the inhabitated islands in Lakshadweep. The islands lies between 10^0 32'N and 10^0 35'N latitude and 72^0 35' and 72^0 40'E longitude. The island has a vast lagoon in its west side and in the eastern part the fringing reef is seen without a lagoon in between.

Kavaratti islands have a tropical humid, warm and generally pleasant climate, becoming more equatorial in the southern islands of the territory. Southwest monsoon period is the chief rainy season which lasts from late May to October. April and May months are the hottest with the mean minimum and maximum temperatures of 26.8^oC and 33.1^oC respectively. December and January are the coldest months with the mean minimum and maximum temperatures of 24^oC and 31.1^oC respectively. Vegetation intercepts part of rainfall and causes transpiration to occur. Interception and transpiration tend to decrease recharge and hence, decrease the available groundwater resource. Depending on the depth to water table and type of vegetation, direct transpiration losses from groundwater aquifers can increase. In Lakshadweep islands, the variability of evapotranspiration is much lower than that of rainfall. Typical annual values of potential evapotranspiration in the islands are between 1600 mm and 1800 mm.

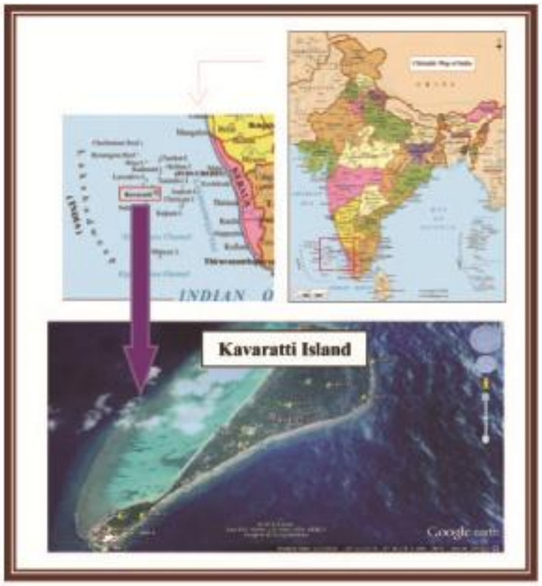

Fig. 1: Study area

MATERIALS AND METHODS

In the present study, water samples were randomly collected from 14 dug wells in the study area (Table 1). The fieldwork included water level measurements, well inventory and collection of water samples from dug wells and the study of geological and geomorphological features of the area in general. The samples were collected during November 2016. High-density polyethylene (HDPE) bottles were used for sample collection. The samples were filled up to the brim and were immediately sealed to avoid exposure to air and were labeled systematically. The water samples collected in the field were analyzed for electrical conductivity (EC), pH, total dissolved solids (TDS), total alkalinity, total hardness, and major cations like calcium, magnesium, sodium, potassium, and anions like bicarbonate, carbonate, chloride and nitrate, in the laboratory using the standard methods given by the American Public Health Association (APHA 1995). Heavy metals and trace elements analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Søndergaard et al. 2015). The ICP-MS analysis was carried out in the centralized instrumentation centre, Department of Geology, University of Kerala, Kariavattom campus, Thiruvananthapuram. Sampling and analytical techniques followed the suggestions by APHA (1998).

The suitability of groundwater for agricultural and domestic purposes was evaluated by comparing the values of different water quality parameters with those of the WHO (2004) and

ISI (1993) guidelines values for drinking water. The degree of association or the strength of a linear relationship among the chemical variables was evaluated by calculating the Pearson’s coefficient of correlation (r) using SPSS version 11.5.

Table 1: Description of sampling locations

Sample No.	**Location**	**Distance of well from sea**	**Depth of well (m) (from ground level)**	**Thickness of water table (cm)**
S1	N 10^0 32’ 543’’ E 72^0 37’ 059’’	120 m from east coast 212 m from west coast	2.1 m	70 cm
S2	N 10^0 32’ 646’’ E 72^0 37’ 110’’	85 m from west coast	1.4 m	40 cm
S3	N 10^0 32’ 658’’ E 72^0 37’ 257’’	30 m east coast	1.9 m	90 cm
S4	N 10^0 33’270’’ E 72^0 37’903 ’’	100 m from east coast 408 m from west coast	3.4 m	40 cm
S5	N 10^0 33’ 408’’ E 72^0 37’ 798’’	65 m from west coast	3.9 m	50 cm
S6	N 10^0 33’ 411’’ E 72^0 37’ 923’’	290 m from east coast 260 m from west coast	3.25 m	125 cm
S7	N 10^0 33’ 660’’ E 72^0 38’ 280’’	390 m from east coast 585 m from west coast	2.65 m	100 cm
S8	N 10^0 33’ 744’’ E 72^0 38’ 861’’	40 m from east coast 1.45 km from west	3 m	50 cm
S9	N 10^0 33’869’’ E 72^0 38’ 585’’	590 m from east coast 890 m from west coast	1.65 m	60 cm
S10	N 10^0 34’ 268’’ E 72^0 38’ 301’’	120 m from west coast 1.30 km from east coast	3.6 m	85 cm
S11	N 10^0 34’ 165’’ E 72^0 38’ 617’’	660 m from east coast 750 m from west coast	2.35 m	55 cm
S12	N 10^0 34’ 460’’ E 72^0 38’ 497’’	330 m from west coast 735 m from west coast	2.25 m	65 cm
S13	N 10^0 34’ 138’’ E 72^0 38’ 960’’	20 m from east coast	3.20 m	60 cm
S14	N 10^0 34’ 511’’ E 72^0 38’ 350’’	16 m from west coast	3.35 m	65 cm

RESULT AND DISCUSSION

The drinking water standard derived from standards of World Health Organization (WHO 2004) was used as the standard to determine groundwater quality for drinking purposes (Table 2).

pH

The pH indicates the strength of the water to react with the acidic or alkaline material present in the water. It controls by carbon dioxide, carbonate and bicarbonate equilibrium. The combination of CO_2 with water forms carbonic acid, which affects the pH of the water (Rao et al. 2012). The pH in the study area ranges from 7.48 to 7.88 (Table 2), which clearly shows that the groundwater in the study area is slightly alkaline in nature and found within the permissible limits of WHO standards. For drinking water, a pH range of 6.0–8.5 is recommended (De 2002). Though pH has no direct effect on human health, but it shows close relations with some other chemical constituents of water.

Electrical conductivity (EC)

Electrical conductivity is a parameter related to TDS. The importance of TDS and EC lies in their effect on the corrosivity of a water sample and their effect on the solubility of slightly soluble compounds such as $CaCO_3$ (Nas and Berktay 2010). The most desirable limit of EC in drinking water is prescribed as 1,500 μS/cm (WHO 2004). The EC of the groundwater vary from 680 to 42800 μS/cm (Table 2). Lower EC in the study area indicates the low enrichment of salts in the groundwater. The value of electrical conductivity may be an approximate index of the total content of dissolved substance in water. It depends upon temperature, concentration, and types of ions present (Hem 1985). Srinivas et al. (2000) opined that the higher value of EC in groundwater is due to the high dissolved solids which may subscribe to the conductivity and has a direct bearing on the percentage of total solids.

In the present study, 42.86% the total groundwater samples show conductivity within the permissible limit of WHO standard value and the remaining 57.14% sample shows higher conductivity above the WHO standard value. The highest conductivity of 42800 µs/cm was reported from S3; the sampling location near the incinerator site, which is very close to sea coast nearly about 30 m from sea and the well used for pumping water to the incinerator. Seawater intrusion occurred originally due to excess pumping in that part close to the sea (Dökmen 2012).

Rao et al. (2012) classified EC as type I, if the enrichments of salts are low (EC<1,500 μS/cm); type II, if the enrichment of salts are medium (EC: 1,500 and 3,000 μS/cm); and type III, if the enrichments of salts are high (EC>3,000 μS/cm, Prasanth et al. 2012). According to the above classification 42.86% of the total groundwater samples come under type I (low enrichment of salt) and 21.43% comes under type II (medium enrichment of salt) and 35.7%

sample comes under type III (high enrichment of salt). EC value increased along the proximity of sea due to salt water intrusion. The mode, quantity and duration of continuous withdrawal of water from well are also directly linked with increase in EC and TDS through salt water intrusion.

Total dissolved solids (TDS)

The permissible limit of TDS of drinking water is 500 mg/l (WHO 2004). TDS values range from 329 to 23112 mg/l (Table 2). 35.71% of total groundwater samples come under the desirable limit for drinking (TDS<500 mg/l) and 28.57% sample fall in between desirable and maximum permissible limit (500-2000 mg/l) and the remaining 35.71% above the maximum permissible limit (TDS>2000 mg/l). According to Davis and De Wiest (1996) classification of groundwater based on TDS is specified in table 3. The S_3 sample with the highest TDS value was taken from the well near the incinerator which is very close to sea water (30 m from sea) and it is clear that the well was highly influenced with sea water intrusion. The distance of well from sea and mode and quantity of withdrawal from the well also play a major reason for salt water intrusion.

Total alkalinity (TA)

Alkalinity of water is its capacity to neutralize a strong acid and it is normally due to the presence of bicarbonate, carbonate, and hydroxide compound of calcium, sodium, and potassium (Patil and Patil 2010), which are characteristic of the source of water and natural processes taking place at any given time (Sharma 2004). The standard desirable limit of alkalinity in potable water is 120 mg/l (WHO 1984) and the values of this parameter in well waters varied from 120 to 455.84 mg/l (Table 2). Only 21.43% of total groundwater samples come within the permissible limit and the remaining 78.57% of the have crossed the maximum permissible limit of 200 mg/l. The mild alkaline nature suggests that approximately 95% of CO_2 in water is present as bicarbonate (Azeez et al. 2000). Studies by Zafar (1966) and Suryanarayana (1995) pointed out that the water tends to be more alkaline when it possesses carbonates. In some cases, ammonia or hydroxides are also accountable to the alkalinity (Sawyer et al. 2000). The higher concentration of alkalinity in samples may be due to the dissolution of calcium carbonate from coral reefs and influence of salt water intrusion.

Salinity

In the present study, the salinity of the study area ranges from 300 to 27200 mg/l (Table 2). The sample S_3 shows the highest salinity; the sample taken near the incinerator. Higher salinity is due to the effect of sea water intrusion. According to the salinity classification by Rabinove *et al* (1958) groundwater were classified into non-saline/ fresh water (TDS <1000 mg/l), slightly saline (TDS= 1000-3000 mg/l), moderately saline (TDS = 3000- 10,000 mg/l) and very saline (TDS >10,000 mg/l). According to this classification, 64.28% of total groundwater samples were non saline/ fresh water; 14.29% belongs to slightly saline; 14.29% fit into moderately saline condition and the remaining 7.14% comes under very saline condition. When the dissolved solid increases the salinity also increases. Chemical analysis indicate that some groundwater occurring in dug wells as well as bore wells is influenced by salinity due to tidal recharge near the coast (Keerthiseelan et al. 2001).

Table 2: Physico-chemical characteristics of groundwater in the study area

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	WHO (2004)	ISI (1983)	BIS (1991)
pH	7.66	7.53	7.69	7.48	7.49	7.88	7.85	7.66	7.8	7.79	7.73	7.48	7.66	7.74	6.5-8.5	6.5-9.2	6.5-8.5
EC	680	10340	42800	5680	3940	1210	820	7260	980	750	1020	1660	1620	1880			
TDS	329	5670	23112	3000	2020	584	398	3900	473	361	491	818	794	926	1500		
SAL	300	5080	27200	3100	2100	600	400	4000	500	400	500	800	800	900	1000		2000
TA	165.76	310.8	120.17	414.4	290.08	290.08	215.49	455.84	252.78	281.79	194.77	236.2	294.22	281.79			
Cl	109.59	4688.09	46968	1663.49	1272.05	330.73	109.59	2739.8	70.45	43.05	101.76	313.36	313.36	356.26	600	1000	1000
TH	229.18	2083.5	11250.9	1376.11	1125.09	441.7	291.69	1625.13	458.37	412.53	391.69	562.54	550.04	666.72	500	600	600
CH	129.17	625.05	1083.42	300.02	308.36	120.84	108.34	308.36	141.67	129.17	112.5	166.6	133.34	112.5			
Ca	51.67	250.02	433.37	120	123.34	48.33	43.34	123.34	56.67	51.67	45	66.64	53.34	45	200	200	200
Mg	24.3	354.4	2470.7	261.48	198.46	77.96	44.55	319.9	76.96	68.86	67.84	95.21	101.26	134.67	150	100	100
Na	51.25	2517	11956	954	576	134.5	72.2	1212.5	36.35	28.34	63.05	152.8	164	189.1	200		150
K	3.75	119	400	26	7	2	6.6	36	1.75	1.38	4.8	1.05	3.05	32.2	12		

All the values are in milligram per liter, except EC. Units of EC are µS/cm. EC - electrical conductivity, TDS - total dissolved solids, SAL – Salinity, TA – Total alkalinity, TH - total hardness, CH – Calcium hardness

Table 3: Classification of groundwater based on TDS (Davis and De Wiest, 1996)

TDS(mg/l)	Water type	% of samples
<500	Desirable for drinking	35.71
500-1000	Permissible for drinking	28.57
1000-3000	Useful for irrigation	14.28
>3000	Unfit for drinking and irrigation	21.43

Chloride (Cl^-)

In the study area, the concentration of chloride ranges between 43.05 to 46968 mg/l (Table 2). The desirable limit of chloride for drinking water is specified as 250 mg/l and the maximum permissible limit is 1000 mg/l (ISI 1993) whereas WHO international standard specified 200 mg/l as the most desirable limit and 600 mg/l as the maximum allowable limit (WHO 2004). According to the ISI (1993) standards, 35.71% of total groundwater samples fall within the desirable limit, 28.57% get into line of maximum permissible limit (250-1000 mg/l) and the remaining 35.71% have crossed the maximum permissible limit of 1000 mg/l for drinking water. High chloride concentration of groundwater may be attributed to the influence of salt water intrusion and tidal recharge. Over withdrawal with high horsepower motor enhance the mixing of salt water.

Total hardness (TH)

Ca^{2+} and Mg^{2+} are the principle ions responsible for total hardness (Rao et al. 2012). The degree of hardness of water determines the suitability of water for domestic, industrial and drinking purposes. Sawyer and McCarty (1967) classified groundwater on the basis of total hardness, soft (0 to 70 mg/l), moderately hard (75 to 150 mg/l), hard (150 to 300 mg/l) and very hard (above 300 mg/l). According to above classification no soft water and moderately hard water found from the entire study area. 14.28% of total groundwater samples come under hard water (150-300 mg/l) category and the remaining 85.71% under very hard category (>300 mg/l). According to WHO (2004) the maximum permissible limit of total hardness as $CaCo_3$ for drinking purpose is 500 mg/land hence only 42.86% of total groundwater samples come within the maximum permissible limit. Hardness of the water may be due to the presence of higher level of calcium and magnesium. The high values in total hardness may be attributed to the leaching out of calcium and bicarbonates from the corals. Another major source is the presence of marine organisms with calcium shell. The leachating process of calcium from these shells enables mixing with groundwater, thereby increasing the calcium levels. Salt water intrusion also contributes to the high groundwater hardness.

Sodium (Na^+) and potassium (K^+)

Sodium ranks sixth among the elements in order of abundance and is present in most of natural waters (Prasanth et al. 2012). Sodium concentrations were reported as 28.34 to 11956 mg/l. According to WHO (2004) international standard, the maximum permissible limit of Na in drinking water is 200 mg/l. The study reveals that 35.71% of the samples exceed the permissible limit of WHO and ISI (Tables 2). The potassium concentration in the study area varied from 2 to 400 mg/l. As per WHO (2004) standard the maximum permissible limit of drinking is 12 mg/l. 78.57% of total groundwater samples were found within the maximum permissible limit for drinking water and the remaining 21.43% were found above the maximum permissible limit.

Calcium (Ca^{2+}) and magnesium (Mg^{2+})

Calcium and magnesium are directly related to hardness. Calcium and magnesium are the most abundant elements in the natural surface and groundwater, and exist mainly as bicarbonates and to a lesser degree in the form of sulfate and chloride. Calcium is directly related to hardness (Devi & Premkumar, 2012). Calcium concentration ranged between 43.34 to 433.37 mg/l (Tables 2). A limit of 75 mg/l as desirable limit and 200 mg/l as maximum permissible limit has been recommended for drinking water (WHO 2004; BIS 2012). 64.29% of total groundwater samples were reported to be within the desirable limit of 75 mg/l and 21.43% above the desirable limit and falls within the maximum permissible limit of 200 mg/l. The remaining 14.29% have crossed the maximum permissible limit of 200 mg/l. In the present study, the highest calcium level was observed in the sample S_3 433.37 mg/l, procured from a well near incinerator site.

Mg^{2+} is an essential ion for functioning of cells in enzyme activation, but at higher concentration, it is considered as laxative agent (Garg et al. 2009). In the present study, the concentration of magnesium in samples ranges from 24.3 to 2470.7 mg/l, which indicates that Mg concentration, is high in most of the samples analyzed from the study area. The magnesium concentration in 14 samples is found to be higher than that of calcium. A lower concentration of magnesium compared to calcium is normally observed in groundwater environment. Magnesium-dominant groundwater is found in dolomitic terrain. In coral islands and limestone terrain, magnesium occurs in significant amounts, but it is seldom found to have dominance over calcium. Dissolution of limestone and the consequent release of the adsorbed magnesium from it is the source of magnesium in groundwater. This being the only source of magnesium in the island, a reasonable correlation can be expected between calcium and magnesium ions in the groundwater. However, the dominance of Mg over Ca in the water may be due to the involvement of other factors influencing the concentration of these ions, than the dissolution process. Once magnesium is released to groundwater as a result of dissolution, the process is not easily reversible. Hence, the magnesium concentrations may increase even under a situation where calcium precipitates as a result of oversaturation. This, in conjunction with the mixing of seawater, results in a high Mg:Ca ratio in some of the areas. Mg:Ca ratio is high in seawater. This is because of the higher consumption of Ca by marine organisms. The mixing zones in the island have a distinct, high Mg:Ca ratio (Najeeb and Vinayachandran, 2013).

Table 4: Correlation matrix of Physicochemical parameters of ground water in the study area.

	pH	**EC**	**TDC**	**SAL**	**TA**	**Cl**	**TH**	**CH**	**Ca**	**Mg**	**Na**	**K**
pH	1											
EC	-0.11	1										
TDS	-0.12	0.99	1									
SAL	-0.09	0.99	0.99	1								
TA	-0.28	-0.32	-0.32	-0.35	1							
Cl	-0.02	0.98	0.98	0.99	-0.43	1						
TH	-0.08	0.99	0.99	0.99	-0.36	0.99	1					
CH	-0.29	0.99	0.96	0.94	-0.2	0.9	0.93	1				
Ca	-0.29	0.96	0.96	0.94	-0.2	0.9	0.93	0.99	1			
Mg	-0.06	0.99	0.99	0.99	-0.37	0.99	0.9	0.92	0.92	1		
Na	-0.08	0.99	0.99	0.99	-0.37	0.99	0.99	0.95	0.95	0.99	1	
K	-0.07	0.99	0.99	0.99	-0.38	0.98	0.99	0.95	0.95	0.98	0.99	1

Water quality for irrigation purposes

Sodium adsorption ratio (SAR) or sodicity index

SAR and EC reciprocally can be used to evaluate irrigation water quality. The SAR is defined as the square root of the ratio of the sodium (Na) to calcium + magnesium (Ca + Mg). The SAR recommended by the salinity laboratory of the US Department of Agriculture (Wilcox 1955) is calculated using the formula (Lesch and Suarez 2009):

$$\mathbf{SAR = Na / \sqrt{(Ca+Mg) / 2}}$$

where all cation measurements are expressed in milliequivalents per liter (meq/l). Irrigation water is classified on the basis of SAR (WHO 1989). Sodium concentration can reduce the soil permeability soil structure (Todd 1980). The calculated values of sodium adsorption ratio (SAR) in the study area vary between 8.27 and 144.82 (Table 5). Classifications of ground water based on SAR are shown in table. 50% sample falls within the range of excellent to good category. 14.29% samples from the study area found doubtful and 35.7% found unsuitable for irrigation purpose.

Table 5: Quality parameters determined for irrigation suitability

Sample No	SAR	KI	SSP	Mg Ratio
1	8.32	0.67	41.99	31.99
2	144.82	4.16	81.35	58.63
3	313.72	4.12	80.97	85.08
4	69.08	2.5	71.98	68.54
5	45.43	1.79	64.43	61.67
6	16.92	1.07	51.94	61.73
7	10.89	0.82	47.27	50.69
8	81.43	2.74	73.8	72.17
9	4.45	0.27	22.19	57.59
10	3.65	0.24	19.78	57.13
11	11.87	0.56	37.55	60.12
12	16.98	1.01	48.73	58.83
13	18.66	1.06	51.94	65.5
14	19.95	1.05	55.19	74.95

A more detailed analysis for the suitability of water for irrigation can be made by plotting the sodium absorption ratio and electrical conductivity (Fig. 2) data on the US Salinity Laboratory (USSL) diagram (Richards 1954). Accordingly, 28 samples fall in the category of C3S1 (59.57%), indicating a high salinity/low sodium type. Of the remaining 19 samples, six samples belong to C4 and C5S1, indicating very a high salinity/low sodium type (12.77%), while ten and three samples belong to the C2S1 (21.28%) and C1S1 (6.38 %) groups, illustrating medium salinity/low sodium and low salinity/low sodium types, respectively.

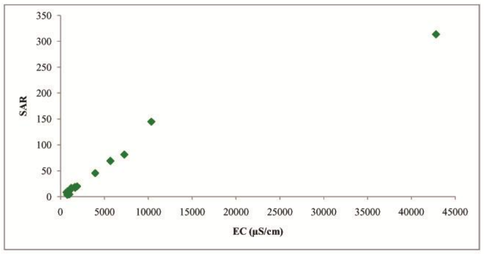

Fig 2: USSL classification of groundwater in the study area

Magnesium Hazard

A ratio namely index of magnesium hazard was developed by Paliwal (1972). According to this, high magnesium hazard value (>50 %) has an adverse affect on the crop yield as the soil becomes more alkaline.

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

In the study area the magnesium hazard values falls in the range of 31.99 to 85.08% (Table 5). In the study area, 7.14% of the samples collected showed MH ratio <50% (suitable for irrigation) while 92.86% falls in the unsuitable category with magnesium hazard >50%. The evaluation illustrates that 92.86% samples can cause adverse effect on the agricultural yield.

Kelly’s Index

Sodium measured against Ca^{2+} and Mg^{2+} is used to calculate Kelley’s ratio (Kelly 1940, 1951; Paliwal 1967). A Kelly’s index of more than 1 indicates an excess level of sodium in waters. Hence, waters with a Kelly’s index less than 1 are suitable for irrigation, while those with a ratio more than 1 are unsuitable. Kelly’s index in the present study varied from 0.24 to 4.16, and 64.29% of the samples are unsuitable for irrigation according to Kelly’s index.

$$\text{KI} = \text{Na}^{+} / \text{Ca}^{2+} + \text{Mg}^{2+}$$

Soluble Sodium Percentage (SSP)

Sodium is an important ion used for the classification of irrigation water due to its reaction with soil, which reduces its permeability (Nag and Das 2017). Sodium is usually expressed in terms of percent sodium or soluble-sodium percentage (%Na). Percentage of Na^+ is widely used for assessing the suitability of water for irrigation purposes (Wilcox 1955). The soluble sodium percentage (SSP), an important parameter of the groundwater has been calculated by using the formula (Todd 1980; Raghunath 1987):

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

The calculated soluble sodium percentage is shown in table 4. From table 4 it is observed that 42.86% of the samples are suitable for irrigation. In Fig. 3 (Wilcox 1955) the plot of SSP vs. EC of the groundwater samples in the area has been shown (Fig 3). This shows that all the samples lie within very good to permissible fields. So the groundwater is suitable for irrigation in the area throughout the year.

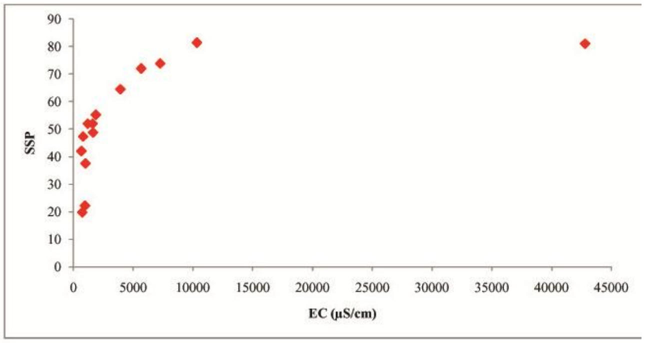

Fig 3: SSP vs EC plot

Trace metal concentration in ground water

In the present study, the concentrations of all the analyzed trace metals (Table 6) in the fourteen samples were found to be within the permissible limits of BIS and WHO, except magnesium. The magnesium concentration was found to be higher than calcium except in one sample. In sea water Ca:Mg ratio is high. Therefore, it is observed that the magnesium dominant nature over calcium is due to the sea water mixing. Other trace metals analyzed include lead (Pb), Iron (Fe). Manganese (Mn), Zinc (Zn), Arsenic (As), Copper(Cu), Nickel (Ni), Aluminum (Al), Chromium (Cr), Cobalt (Co), Selenium (Se), Silver (Ag), Barium (Ba), Vanadium (V), Strontium (Sr), Lithium (Li), Rubidium (Rb), which were observed to be within the limit and Cadmium (Cd), and Cesium (Cs) remained undetectable.

Table 6: Concentration of trace metals in ground water samples (mg/l)

Sample	Ca	Mg	Pb	Fe	Mn	Zn	As	Cd	Cu	Ni	Al	Cr	Co	Se	Ba	Rb	Sr	Li	V
S1	40.2	24.2	ND	0.002	0.0006	0.001	0	ND	0.003	0.001	0.012	0.0003	1.1×10^{-4}	0.006	0.009	0.009	1.9	0.003	0.007
S2	102	71.18	ND	0.002	0.0003	0.001	0.001	ND	0.001	0.001	0.006	0.0001	7×10^{-5}	0.004	0.007	0.002	2.8	0.008	0.003
S3	171.7	868.27	ND	0	0.0004	0.001	0	ND	0	0	0.011	0.0001	2×10^{-5}	0	0.001	0.013	0.7	0.046	0.005
S4	120.4	185.2	ND	0.001	0.0007	0.002	0.004	ND	0.005	0.003	0.003	0.0002	8×10^{-5}	0.005	0.004	0.009	2.4	0.016	0.011
S5	113.2	89.78	ND	0.001	0.0003	0.002	0.001	ND	0.001	0.001	0.004	0.0001	8×10^{-5}	0.005	0.004	0.004	2.5	0.018	0.005
S6	103.9	65.49	ND	0.001	0.0003	0.002	0.001	ND	0.001	0.001	0.002	0.0001	5×10^{-5}	0.004	0.006	0.005	2.7	0.007	0.002
S7	104	31.62	ND	0.001	0.0002	0.002	0.001	ND	0.001	0.001	0.004	0.0001	5×10^{-5}	0.005	0.007	0.014	1.6	0.007	0.006
S8	130.2	172.77	ND	0.001	0.0004	0.001	0.006	ND	0.002	0.001	0.002	0.0002	7×10^{-5}	0.004	0.008	0.007	2.4	0.018	0.006
S9	62.5	36.56	ND	0.001	0.0002	0.002	0	ND	0.001	0	0.001	0.0001	6×10^{-5}	0.004	0.006	0.001	2.6	0.007	0.001
S10	105.1	46.21	ND	0.001	0.0002	0.001	0.002	ND	0.004	0	0.003	0.0001	3×10^{-5}	0.004	0.005	0.002	2.6	0.007	0.001
S11	110.5	31	ND	0.001	0.0003	0.001	0.003	ND	0.003	0.001	0.005	0.0001	1×10^{-4}	0.006	0.005	0.008	2.2	0.006	0.014
S12	45.6	18.85	ND	0.001	0.0002	0.001	0.001	ND	0.001	0	0.005	0.0001	4×10^{-5}	0.005	0.011	0	1.4	0.002	0.001
S13	106	79.15	ND	0.001	0.0002	0.001	0.002	ND	0.001	0	0.004	0.0001	4×10^{-5}	0.005	0.004	0.001	2.4	0.009	0.003
S14	125.3	69.06	0.0001	0.006	0.0006	0.002	0.003	ND	0.004	0.002	0.011	0.0004	1.4×10^{-4}	0.005	0.009	0.029	1.7	0.011	0.013
Avg.	**102.9**	**127.81**	**0.0001**	**0.001**	**0**	**0.001**	**0.002**	**ND**	**0.002**	**0.001**	**0.005**	**0**	**0**	**0.004**	**0.006**	**0.007**	**2.14**	**0.012**	**0.006**
BIS*	**75**	**30**	**0.01**	**0.3**	**0.1**	**5**	**0.01**	**0.003**	**0.05**	**0.02**	**0.03**	**-**	**-**	**0.01**	**0.7**	**-**	**-**	**-**	**-**

*Acceptable limit as per BIS 10500 (2012)

CONCLUSION

The chemical evolution of groundwater in the coral islands of Lakshadweep is due to the combined effect of various processes such as mixing of waters, contributions by marine aerosols, cation exchange, and dissolution of $CaCO_3$ etc. in varying proportions. These processes discussed above govern the relative concentrations of major ions in these aquifers.

To find out the groundwater suitability for domestic and agricultural purposes in the Kavaratti Islands, 14 samples of groundwater have been studied in detail. Hydrochemical studies have been carried out in details for the collected samples. The groundwater quality of the study area reveals that pH was slightly alkaline in nature and found within the permissible limits of WHO standards. TDS values range from 329 to 23112 mg/l and 35.71% exceeded the maximum permissible limit (TDS>2000 mg/l). 57.14% samples showed higher conductivity above the WHO standard value. The values of total alkalinity in well waters varied from 120 to 455.84 mg/l. The salinity of the study area ranges from 300 to 27200 mg/l indicating that some groundwater occurring in dug wells as well as bore wells is influenced by salinity due to tidal recharge near the coast. The concentration of the trace metals were found to be within the permissible limits of BIS and WHO, except magnesium.

The results from the water analysis have been used as a tool to identify the process and mechanisms affecting the chemistry of groundwater from the study area. SAR values for 50% sample falls within the range of excellent to good category, 14.29% samples found doubtful and 35.7% unsuitable for irrigation purpose. SSP values for 42.86% of the samples proved suitable for irrigation. The magnesium hazard values falls in the range of 31.99 to 85.08% indicating 7.14% of the samples suitable for irrigation, while 92.86% fall in the unsuitable category. 64.29% of the samples were unsuitable for irrigation according to Kelly's index.

Hence, the study has helped to improve understanding of water quality of the area for effective management and proper utilization of groundwater resources for better living conditions of the people. A continuous monitoring program of water quality is required to avoid further deterioration of the water quality of the study area.

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