Research Article

Major ion chemistry and identification of hydrogeochemical processes of evolution of ground water in a small tropical coral Island of Minicoy, Union Territory of Lakshadweep, India

Abstract

Major ion chemistry and identification of hydro geochemical processes of groundwater in the small island of Minicoy indicate that ground water occurs under phreatic condition and is seen as a thin lens floating over the saline water. The coral sands and coral lime-stones act as principal aquifers. The depth of the wells varies from 1.9 to 3.5mbgl and depth to the water table 0.62 to 1.75mbgl. The ground water is generally alkaline and EC varies from 592 to 2130 micromhos/cm at 25°C. The ground water is under Na+-SO42- type and shallow meteoric percolation type and generally alkaline in nature. The factors affecting the quality of ground water are rainfall, tides, ground water recharge and draft, human and animal wastes, oil spills and fertilizers. Water samples collected from different parts of the island during pre-monsoon period and post monsoon samples had not been collected due to inaccessibility caused by rough weather. The water sample chemical analysis indicates that water type ranges from Ca-HCO3 (recharge type) to Na- HCO3 (Base Exchange water type). Among the cations Ca+ and Na+ and anions HCO3- and Cl- dominate the ionic concentration in groundwater which made the water both recharge and base exchange water types. The hydrochemistry is mainly controlled by evaporation, partly influenced by water-rock interaction and aquifer materials. The chloro alkali indices of water samples of Minicoy atoll are negative indicating the ion exchange predominance in the study area. The rock water interaction played major role in the evolution of water chemistry, which was partly by evaporation process also. The ground water in the study area is generally suitable irrigation for all types of soil.

Keywords: atoll, fresh water lens, chloro alkali indices, rock-water interaction, irrigation

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Abbreviations: pH, potential of hydrogen; F, florine; Cl, chlorine; NO_3, nitrate; HCO_3, bicarbonate; SO_4^{2-}, sulphate Ion; Ca^{2+}, calcium ion; Mg^{2+}, magnesium ion; Na^+, nitrate ion; K^+, potassium ion; EC, electrical conductivity; SAR, sodium adsorption ratio; Na, sodium; PI, permeability index; KI, kelley's index; SSP, soluble sodium percentage; MR, magnesium ratio

Introduction

The Lakshadweep islands (LD islands) are a group of tiny coral islands, located in the Arabian Sea, about 400km from the main land (southern tip of the Indian peninsula). They spread over a distance of 300km, consists of 36 coral islands and a number of sunken banks, open coral reef and sand banks. These islands are typically a chain of low islands surrounding a shallow lagoon, consisting of large recent sediments on top of older coral lime-stones. Minicoy Island has a delicate ecosystem with very limited fresh water resources. Though the island receives high rainfall, lack of surface storage and the limited ground water storage capacity, where fresh water is occurring as a small lens floating over saline water, makes fresh water a precious commodity. High porosity of the aquifers allow mixing of fresh water with sea water and due to high population density, waste water gets mixed with the fresh water in the aquifer, make the management of the limited fresh water resources multifaceted. The purpose of the study is to assess the evolution of ground water resources of the island and to know the hydro geological characteristics. The small island hydro geological and hydro chemical studies were carried out by many authors at international and regional levels. These include Nura UK, et al.[1] on evaluation of factors Influencing the Groundwater Chemistry in a Small Tropical Island of Malaysia, Aris AZ, et al.[2] applied factor analysis tool to the hydro chemical data set of Manukan Island in order to extract the principal factors corresponding to the different sources of variation in the hydrochemistry, Belkhiria L, et al.[3] studied geochemical evolution of groundwater in an alluvial aquifer in the case of El Eulma aquifer, East Algeria, Arslan H[4] used application of multivariate statistical techniques in the assessment of groundwater quality in seawater intrusion area in Bafra Plain, Turkey. Kumar G[5] carried out assessment of groundwater quality for Veppanthattai taluk, Perambalur district, Tamil Nadu using Remote Sensing and GIS, Barker JA[6] on fresh water-salt water relation, Mondal NCVS, et al.[7] Appraisal of groundwater resources in an island condition and many others. The present study is an attempt to highlight the major ion chemistry and identification of hydro geochemical processes of evolution groundwater in a small tropical coral island of Minicoy small coral island of Minicoy, Union Territory of Lakshadweep, India.

Study area

The Minicoy Island is the southern-most island of Lakshadweep, situated at a distance of 398 km south-west of Kochi between 8°15’ and 8°20’ N latitude and 73°01’ and 73°OS’ E longitude, having an area of 4.80sq.km. This island lies near the 9.0 Channel, which is one of the busiest shipping routes and is about 130km from the northern-most island of Maldives. The climate of Minicoy is similar to the climatic conditions of Kerala. March to May is the hottest period of the year. The temperature ranges from 25°C to 35°C and humidity ranging from 70-76 per cent for most of the year. The average rainfall received is 1600mm a year. Monsoon prevails here from 15th May to 15th September. During the monsoon time, boats are not allowed outside the lagoon because of the violent sea. The presence of the reef maintains calm at the lagoon.

The location map of LD islands including Minicoy Island is compiled (Figure 1) and various salient features of Minicoy are compiled (Table 1). The coral island is the work of minute sea organisms called coral polyps and they congregate in large colonies. When the organisms die, their skeletons, which are made of lime-stones, form big clusters, some of which rise above the water. Charles Darwin first described the different types of coral reef after his voyage by HMS Beagle among the Galapagos Isles in Pacific Ocean (Subsidence theory for the origin of coral reefs). In oceanic island fresh ground water occurs as a lens floating over saline water. The hydro dynamic balance of fresh and saline water determines the shape and movement of interface and may be controlled by some of the following factors viz. water table fluctuation due to diurnal tides, seasonal fluctuation of water table due to recharge or draft, dispersion and molecular diffusion. Due to these factors there is an alternate up and down movement of the interface.

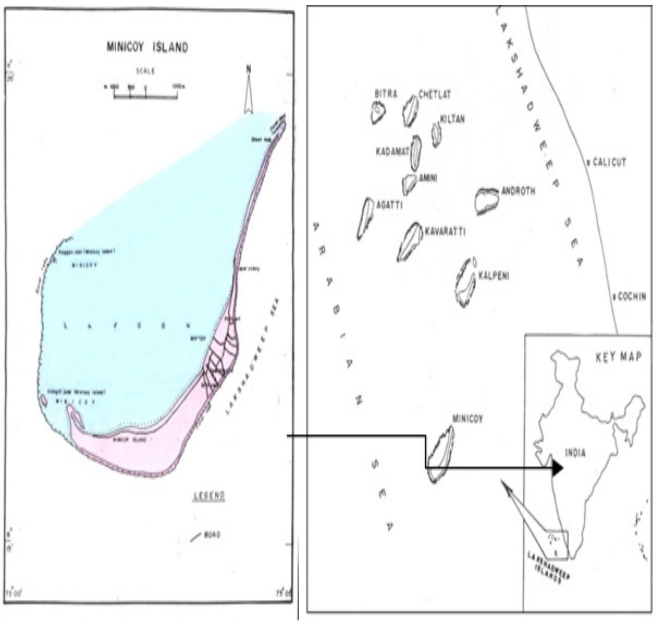

Figure 1 Location Map of Lakshadweep Islands.

Table 1 Salient features of Minicoy islands

#	Item	Detail
1	Latitudes	8° 15' and 8° 20'N
2	Longitudes	73° 01' and 73° 05'E
3	Total geographical area	4.80sq.km
4	Population (as per 2011 census)	10444
5	Average annual rainfall	1660mm
6	Annual range of temperature	25-30°C
7	Major geological formation	Coral
8	Net ground water availability	0.55MCM/Yr.
9	Stage of ground water development	63%
10	Lithology	Coralline sand and coral lime stones
11	Drainage	Surface water bodies and rivers generally absent or ephemeral
12	Aquifer geometry	Not well defined by coral colonies & eustatic changes
13	Effect of over draft of ground water	Upcoming of saline water from bottom
14	Effect of recharge	Fresh water lens expands & fractional rise in levels
15	Ground water estimation	By water balance or chloride budgeting
16	Ground water potential	Lower the per permeability, higher the potential
17	Drainage	Surface water bodies and rivers generally absent or are ephemeral.
18	Aquifer geometry	Not well defined by coral colonies & eustatic changes
19	Ground water	As lens, in hydraulic continuity with sea water
20	Effect of over draft of ground water	Upcoming of saline water from bottom
21	Effect of recharge	Fresh water lens expands &fractional rise in levels
22	Ground water estimation	By water balance or chloride budgeting

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Materials and methods

The base map of Minicoy and various layers were prepared by using Map Info 6.5 techniques and in the ground water resource of Minicoy has been computed based on the methodology recommended by the GEC 1997. The recharge to ground water lens=rain fall-interception- evapo-transpiration and *Ground water utilisation= Evapotranspiration + mixing + pumping + outflow, f*or water balance study monthly water budgeting or weekly water budgeting gives appropriate value of recharge. The main consumer of ground water is coconut palms because one coconut tree consumes 40lpd and density of coconut trees is 25 000-35000sq. km but draft through plant is slow, steady and spread uniformly.

The various hydro geological parameters collected during the field study and water level data observed during low and high tide. The pre monsoon groundwater samples collected from shallow aquifers (dug wells) in polyethylene bottles and analysed for pH, EC, F^-, Cl^-, NO^{3-}, HCO^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+ as per standard procedures[8] and the in situ measurements of EC and pH were carried out by using EC and pH meters. The total dissolved solids were estimated by ionic calculation methods. The F^-, Cl^- and NO^{3-} ions were determined by ion selective electrode; HCO^{3-} by potentiometric titration; SO_4^{2-} by modified titration method after Fritz JS, et al.[9] and Haartz JC, et al.;[10] Ca^{2+} and Mg^{2+} in absorption mode while Na^+ and K^+ in emission mode of the atomic absorption spectrophotometer. The analytical results were tested for accuracy by calculating the Normalized Inorganic Charge Balance.[11] The analytical precision was such that the ion charge balance was little above ±5% for the samples. The quality of the analysis was ensured by standardization using blank, spike, and duplicate samples.

Results and discussion

The major factors influence the hydrological characteristics of the island are climate, humidity, temperature, evapo-transpiration, physiography, hydro geological aspects, soil, vegetation, population geomorphology, aquifer nature and human interference. The major hydrochemistry is discussed below.

Climate, humidity, temperature, evapo-transpiration, physiography, hydro geological aspects, soil, vegetation, population, geomorphology, aquifer nature and human interference

The climate of a small island is one of the major influences on the availability of naturally occurring freshwater resources.[12] The rainfall distribution, quantity and its spatial and temporal variations and the evapo-transpiration play an important role on the availability of the freshwater resources. The maximum, mean and minimum annual rainfall on Minicoy for the period 1961-1991 is 2634(1961), 1555 and 945mm (1980) respectively. The humidity is lower during January to April when it is between 75 and 78% in the morning hours and 66 to 69% evening hours. It is higher during June to August when it ranges from 85 to 87% in the morning hours and 83 to 86% in the evening hours. April and May months are the hottest with the mean minimum and maximum temperatures of 26.8 and 33.1°C respectively. The evapo-transpiration is very high and most of the months except in high rainfall season it exceed the rainfall making the water surplus on the negative side. The entire LD islands lay on the northern edge of the 2500km long North-South aligned submarine Lakshadweep-Chagos ridge. The island has coarse sandy soil of high porosity and permeability resulting in little or no surface runoff. The vegetation of LD islands consists of coconut trees, bushes and grasses. The Minicoy Island is a typical atoll and height of the land above msl is about 1-2m and the coral sands and the coral lime-stones act as principal aquifers. The Ghyben-Herzberg relation determines the depth of the interface between fresh water and sea water. The water level data of monitoring wells in Minicoy Island is compiled (Table 2) and depth of the wells ranges from 1.9 to 3.5mbgl and the DTW ranges between 0.62 to 1.75mbgl whereas diurnal fluctuation in water level due to tides is in the range of 0 to 80cms. The climate water balance method of recharge estimation widely used for estimating the recharge on small islands (Falkland, 1992). Human activities influence both the availability of freshwater and water quality.

Major ion chemistry and hydro geochemical processes

The major ion chemistry and hydro geochemical processes of ground water and its evolution have been examined. The groundwater of different geological horizons can be classified depending upon their ionic strength of select anions and Soltan ME[13] categorized groundwater based on the meq/l content of Cl^-, SO_4^{2-} and HCO_3^-. The water is Normal chloride type if Cl^- is <15meq/l, Normal sulphate type if SO_4^{2-} is<6meq/l and Normal bicarbonate type if HCO_3^- varies between 2 and 7meq/l. Distribution of groundwater samples based on the Soltan ME[14] classification has indicated that majority of the samples are of Normal chloride type, followed by Normal sulphate type and concentration of salts in natural waters depend on the geology, environment, and movement of water.[15,16] The Base Exchange indices, r1 ($r1=Na^+-Cl^-/SO_4^{2-}$ meq/l) and r2 ($r2=K^++Na^+-Cl^-\ SO_4^{2-}$ meq/l) after Soltan ME[13] could be applied for the further classification of groundwater. The groundwater can be grouped as Na^+-HCO_3^- type if r1>1 and Na^+-SO^{4-} type with r1<1; r2<-1 groundwater is of deep meteoric percolation type and >1, shallow meteoric percolation type. The groundwater of the area comes under Na^+-HCO_3^- type and shallow meteoric percolation type except a few one which is deep meteoric percolation type, chemical analysis data of ground water and other details are compiled (Table 3 & Table 4).

Hydro chemical evolution study based on Na^+/Cl^- molar ratio Na^+/Cl^- molar ratio will be 1 if halite dissolution is responsible for sodium dominance in groundwater and >1 if Na^+ is released from silicate weathering process.[17] The Na^+/Cl^- molar ratio is <1 in many samples of the season, indicating that halite dissolution was the primary process responsible for the release of Na^+ into the groundwater.

Hydro-chemical facies

The groundwater is further evaluated to determine its facies by plotting the percentages of select chemical constituents in Modified Piper diagram.[18] The plots for the season indicated distribution within the fields 2, 5 and 8 of the Chadha's diagram (Figure 2) and are characterized by alkali metals exceed alkaline earths Na^+ K> Ca+ Mg, alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively $(Ca+Mg)+(CO_3+HCO_3)>(Na+K)+(Cl+SO_4)$ and alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. $(Na+K)>(Ca+Mg)>(CO_3+HCO_3)>(Cl+SO_4)$ respectively. As the water samples falls under the hydro chemical facies Field I and IV, they are of Ca-HCO_3 Type (recharge type) and Na-HCO_3 type (base exchange water type) respectively. The Chadha´s diagram further strengthens that the mineralogy of the aquifer material played an important role in determining the water chemistry. The plots also suggest that among cations Ca^{+} and Na^{+} and anions HCO_3^- and Cl^- dominate the ionic concentration in groundwater.

Hydro-geochemical evaluation

The high sodium content among cations in the groundwater for the period could be due to halite dissolution which was further enhanced by evaporation and/or evapo-transpiration processes. The Na^+/Cl^- molar ratio will be 1 if halite dissolution is responsible for sodium dominance in groundwater and >1 if Na^+ is released from silicate weathering process.[17] The Na^+/Cl^- molar ratio is >1 in the samples of water can only evolve to brine rich in NaCl if it encounters highly soluble chloride minerals; typically associated with evaporative deposits/evaporates.[19] As all the groundwater samples of the season with Na^+/Cl^- molar ratio less than one or nearer to one, halite dissolution is responsible for sodium dominance in groundwater of the small coral island of Minicoy, Union Territory of Lakshadweep.

The study of Ca^{2+}/Mg^{2+} ratio reveals dolomite dissolution responsible for Ca^{2+}-Mg^{2+} contribution in attaining the present chemical make-up of the groundwater. The Ca^{2+}/Mg^{2+} ratio of 1 indicated dissolution of dolomite and of >2 reflected an effect of silicate minerals on the groundwater chemistry; suggested calcite dissolution for Ca^{2+}-Mg^{2+} concentration in groundwater.[20] Majority of the samples in the region have Ca^{2+}/Mg^{2+} ratio between 1 and <2, indicating dolomite dissolution responsible for Ca^{2+}-Mg^{2+} contribution. The scatter diagram of $Ca^{2+}+Mg^{2+}$ vs $HCO_3^-+SO_4^{2-}$ (Figure 3) shows that majority of samples in the season fall below the equiline, indicating that silicate weathering was the primary process involved in the evolution of groundwater (Datta and Tyagi 1996). If bicarbonate and sulphate are dominating than calcium and magnesium, it reflects that silicate weathering was dominating and, therefore, was responsible for the increase in the concentration of HCO_3^- in groundwater.[21] The plot of $Ca^{2+}+Mg^{2+}$ against $HCO_3^-+SO_4^{2-}$ further proves the influence of dolomite dissolution on Ca^{2+}-Mg^{2+} contribution in the groundwater.

Evolution of groundwater

Gibbs RJ[22] plots, in which TDS vs $Na^+/(Na^++Ca^{2+})$ for cations and TDS vs $Cl^-/(Cl^-+HCO_3^-)$ for anion were plotted to know evolution process of the groundwater and the influence of host rock on ground water chemistry. It is revealed that the samples, occupied the rock dominance to evaporation dominance fields. The rock water interaction played major role in the evolution of water chemistry, which was partly by evaporation process (Figure 4A & Figure 4B). The geological location is one of the most important factors affecting the groundwater quality.[23]

Chloro alkali indices

The role of aquifer material in the evolution of groundwater chemical composition has been examined by determining the chloro alkali indices for cations (CAI-1) and anions (CAI-2). The CAI-1 $[Cl^--(Na^++K^+)]Cl^-$ and CAI-2 $[Cl^- -(Na^++K^+)/(SO_4^{2-}+HCO_3^-+CO_3^-+NO^-)]$, developed by Schoeller H,[24] relate the ion exchange process between ground water and aquifer material. The CAI-1 and CAI-2 are negative in the samples indicating the ion exchange between Na^+-K^+ in water and Ca^{2+}-Mg^{2+} in rocks.[25] It is imperative to understand the modifications in water chemistry during its movement and residency time for better evaluation of the hydrochemistry of any area more so when different geological formation are involved in a watershed or river basin.[26] As CAI-1 and CAI-2 are negative in the samples indicating the ion exchange predominance in the study area.

Irrigation suitability

The irrigation suitability of ground water has been attempted based on the study of electrical conductivity (EC), Sodium Adsorption Ratio (SAR), Percent Sodium (% Na), Permeability index (PI), Kelley's Index (KI), Soluble Sodium Percentage (SSP) and Magnesium Ratio (MR) methodologies (Table 5) and Wilcox classification of irrigation water and U S Salinity diagram for irrigation Water, methodology and analytical results are compiled (Table 6).

Electrical conductivity

The EC is a measure of salinity hazard to crops and classified into five major types, as per Raghunath HM[15] and that the samples in the study area are under excellent, good, permissible and doubtful categories.

Sodium absorption ratio, SAR

The sodium alkali hazard or Sodium Absorption Ratio (SAR) of water is an indicator of sodium hazard in irrigation water (Gholami and Srikantaswamy, 2009). As per Richard, 1954, the computed SAR values show that all the samples are excellent. Wilcox's (1955) diagrams relating to Percent Sodium and electrical conductivity of the samples (Figure 5) and U S Salinity diagrams for irrigation water (Figure 6) show that majority of samples fall under the excellent to good categories of Percent Sodium and in the case of EC good to permissible for irrigation.

Percent sodium (% Na)

The % Na is used to assess the ground water quality, because a higher level of sodium in irrigation water may increase the exchange of sodium content of irrigated soil and affect soil permeability, structure and create toxic condition for plants.[27,28] Based on the relative proportions of cation concentration, samples come under good to permissible categories and can be used for irrigation on almost all types of soil.

Permeability index, PI

Doneen (1964) has classified the irrigation water quality into three classes based on permeability-class I, II and III and all the samples come under Class II and suitable for irrigation in all types of soil.

Kelley's index, KI

Kelley (1940) and Paliwal (1967) proposed the suitability of irrigation water quality based on the sodium concentration against calcium and magnesium. The water is suitable for irrigation if KI value is<1; water with KI value of>1 is considered as of poor quality for irrigation and>2 KI makes the water unsuitable for irrigation. Both cation exchange and reverse ion exchange are encouraged by aquifer materials and land use practices, in waterlogged area, marshy/swampy land, creek, mud/tidal flat represented by Montmorillonite clays, which lead to the release of Na or Ca into groundwater and adsorption of Ca or Na, respectively (Alison, et al. 1992). About 82% KI values are below 1 indicating the water in the study area is suitable for irrigation.

Table 2 Depth to the water table (mbgl) data of monitoring wells in Minicoy island

Period of monitoring	T1- zainaba manzil South bandaram		T3- korimauge South bandaram		T4- govt quarter no.93/B, 50 Acre		T5- quarter no.29/c, 50 Acre		T7- holida complex bada village		T8- valum augothi amina bada village		T10- RO plant well near PWD office	
	FN	AN	FN	AN	FN	AN	FN	AN	FN	AN	FN	AN	FN	AN
01.02.2010	0.73	0.69	0.95	0.89	1.03	0.96	0.86	0.82	0.99	0.93	1.72	1.6	1.45	1.34
08.02.2010	0.76	0.62	0.96	0.97	1.11	1.05	0.93	0.81	0.85	0.76	1.73	1.52	1.53	1.75
15.02.2010	0.78	0.71	0.94	0.81	0.93	0.88	0.78	0.63	0.88	0.83	1.52	1.42	1.44	1.35
22.02.2010	0.71	0.67	1.72	1	1.08	1.03	0.94	0.91	1.04	0.97	1.71	1.52	1.52	1.41

Table 3 Chemical analysis data of ground water in Minicoy

Pre Monsoon 2010

#	pH	EC	TH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F	SAR	RSC	TDS	%Na
1	8.53	1720	410	92	44	202	48	60	500	185	97	81	0.56	4.33	1.98	1030	54.91
2	8.22	950	215	56	18	95	25	0	256	107	49	77	0.53	2.82	-0.08	556	52.7
3	7.97	2130	440	92	51	275	58	0	683	298	117	79	0.39	5.7	2.4	1312	60.44
4	8.06	592	215	64	13	34	5	0	299	39	25	8.5	0.28	1.01	0.63	338	27.37
5	8.38	798	280	84	17	50	11	6	293	60	27	73	0.16	1.3	-0.6	472	30.48
6	8.23	1770	390	112	27	214	26	0	537	185	91	150	0.37	4.7	0.98	1074	56.04
7	7.92	1270	340	96	24	106	11	0	342	128	62	136	0.52	2.5	-1.17	735	41.92
8	7.37	1095	265	68	23	55	14	0	415	67	40	21	0.6	1.47	1.51	496	34.19
9	7.67	920	305	86	22	63	10	0	378	99	43	47	0.86	1.57	0.09	560	32.89
10	7.19	1369	400	108	32	108	17	0	488	185	87	7.3	0.85	2.34	-0.03	789	38.97
11	7.48	1785	630	106	89	152	4	0	726	288	95	3.9	0	2.63	-0.72	1101	34.7
Min	7.19	592	280	64	13	34	4	0	293	39	25	3.9	0	1.01	-1.17	338	27.37
Max	8.53	2130	630	112	89	214	48	60	726	288	97	150	0.86	4.33	1.98	1312	60.44
Mean	8	1309	354	88	33	123	21	6	447	149	67	62	1	3	0.5	769	42
SD	0.4	488.7	120	19	21.9	78	18	18	156.5	87.7	32	50.4	0.2	1.5	1.2	317.1	11.7
BIS	8.5	750	300	75	30	NR	NR	NR	500	250	200	45	1				

Table 4 Different parameters of pre monsoon water samples

Well Nos	Cl^-	SO_4^{2-}	HCO^{3-}	Base Exchange Index, (r1)	Base Exchange Index, (r2)	Na/Cl	Ca/Mg	Chloroalkali Indices for Cations, CAI-1	Chloroalkali Indices for Anions, CAI^{-2}
1	5.22	2.02	8.2	6.2	2.37	1.09	1.27	-0.92	-0.35
2	3.02	1.02	4.2	1.17	1.72	0.89	1.89	-0.58	-0.27
3	8.41	2.44	11.2	8.51	2.07	0.92	1.1	-0.6	-0.34
4	1.1	0.52	4.9	-0.63	0.98	0.87	2.99	-0.46	-0.09
5	1.69	0.56	4.8	-0.84	1.36	0.83	3	-0.45	-0.11
6	5.22	1.9	8.8	6.55	2.51	1.16	2.52	-0.91	-0.36
7	3.61	1.29	5.61	1.81	0.99	0.83	2.43	-0.35	-0.14
8	1.89	0.83	6.8	0.12	1.03	0.82	1.8	-0.45	-0.11
9	2.79	0.9	6.2	-0.38	0.23	0.64	2.38	-0.07	-0.03
10	5.22	1.81	8	1.82	-0.05	0.58	2.05	0.02	0.01
11	8.12	1.98	11.9	2.5	-0.72	0.53	0.72	0.17	0.1
Mean	4.21	1.39	7.33	2.44	1.13	0.83	2.01	-0.42	-0.15
Min	1.1	0.52	4.2	-0.84	-0.72	0.53	0.72	-0.92	-0.36
Max	8.41	2.44	11.9	8.51	2.51	1.16	3	0.17	0.1
SD	2.47	0.66	2.57	3.22	1.02	0.19	0.75	0.35	0.16

(# Concentration, meq/l)

Table 5 Methodology adopted for computations of irrigation suitability

spects	Formula	Range	Classification	Reference
EC, µS/cm at 25oC		<250	Excellent	Raghunath[15]
		250-750	Good	
		750-2000	Permissible	
		2000-3000	Doubtful	
		>3000	Unsuitable	
SAR	SAR=Na/√(Ca+Mg)/2	<10	Excellent	Richards
		10–18	Good	
		18–26	Doubtful	
		>26	Unsuitable	
%Na	%Na=((Na+K)/(Ca+Mg+Na+K))*100	<20	Excellent	Raghunath[15]
		20–40	Good	
		40–60	Permissible	
		60-80	Doubtful	
		> 80	Unsuitable	
PI	PI=((Na+ (√HCO_3)/(Ca+Mg+Na))*100	>75	Class I	Durfer[28]
		25- 75	Class II	
		<25	Class III	
KI	KI=Na/Ca+Mg	>	Unsuitable	Kelley
		2-Jan	Poor	
		< 1	Suitable	
SSP	SSP=Na*100/Ca+Mg+Na	>50	Unsuitable	Khodapanah
		< 50	suitable	
Mg Ratio	MR=(Mg*100)/(Ca+Mg)	>50	Unsuitable	Lloyd and Heathcote
		< 50	suitable	

Table 6 Quality parameters of Pre monsoon water samples determined for Irrigation Suitability

#	Location	SAR	%Na	KI	P I	SSP	EC , µS/cm	Mg Ratio
1	Lom Bomauge	4.33	54.91	1.07	68.49	51.65	1720	0.79
2	Dondale Kagothi	2.82	52.7	0.96	73.46	49.1	950	0.53
3	Fallissery Mosque	5.7	60.44	1.36	73.74	57.61	2130	0.91
4	Juma Masjid	1.01	27.37	0.35	64.23	25.72	592	0.33
5	Aoukohorathm Manikage	1.3	30.48	0.39	56.16	27.97	798	0.33
6	Kibula Mosque	4.7	56.04	1.19	71.65	54.33	1770	0.4
7	Odivalu Mosque	2.5	41.92	0.68	61.29	40.49	1270	0.41
8	Badu Village	1.47	34.19	0.45	65.07	31.12	1095	0.56
9	New Govt. Quarter	1.57	32.89	0.45	59.08	30.95	920	0.42
10	Dak Bungalow	2.34	38.97	0.58	59.11	36.89	1369	0.49
11	LPWD PWSW	2.63	34.7	0.52	52.3	34.36	1785	1.38
Mean		2.76	42.24	0.73	64.05	40.02	1309	0.6
Min		1.01	27.37	0.35	52.3	25.72	592	0.33
Max		5.7	60.44	1.36	73.74	57.61	2130	1.38
SD		1.53	11.71	0.36	7.2	11.34	488.71	0.32

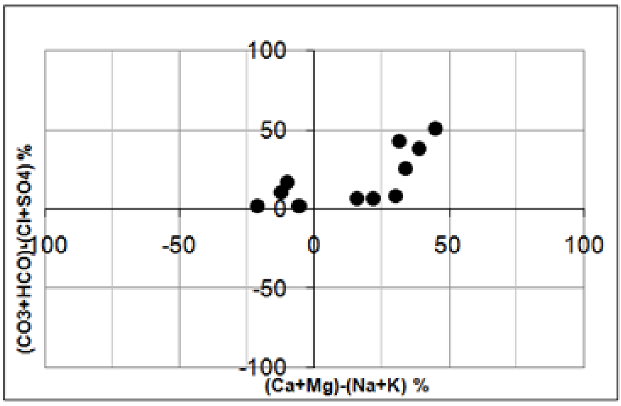

Figure 2 Modified piper diagram.

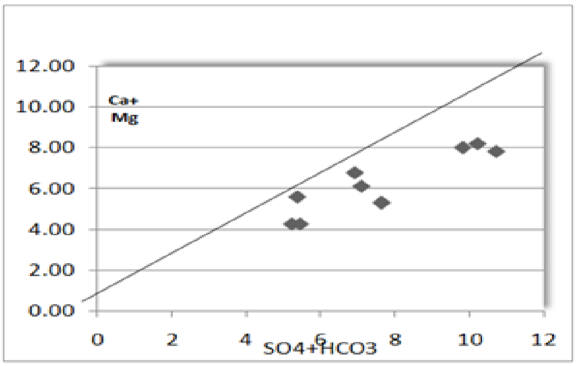

Figure 3 Plot of Ca+Mg and SO4+HCO3 pre-monsoon.

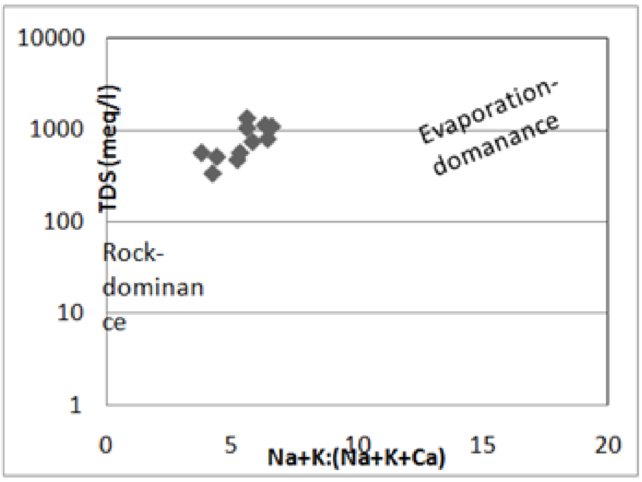

Figure 4A Gibb's plotsfor cation, 2010.

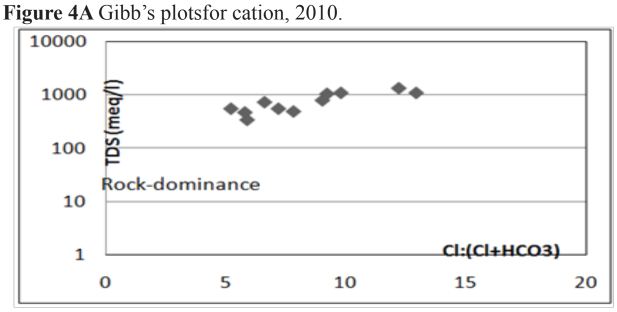

Figure 4B Gibbs plots for anion 2010.

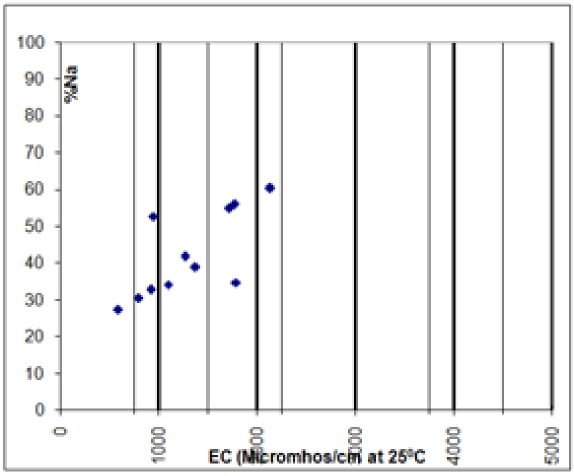

Figure 5 Wilcox classification of irrigation water (pre-monsoon).

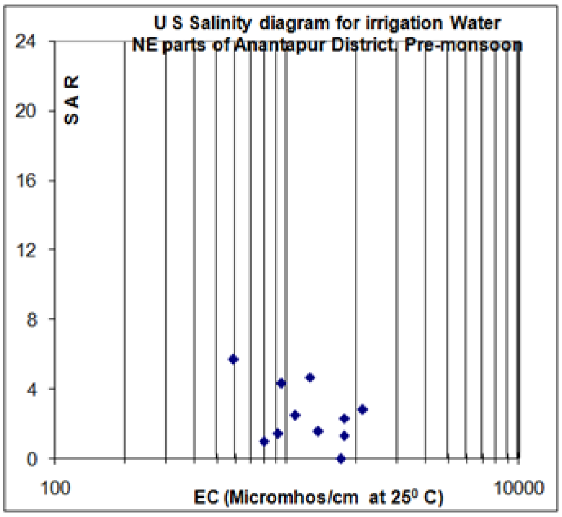

Figure 6 U S Salinity diagram for irrigation Water (pre-monsoon).

Soluble sodium percentage, SSP

Water with less than or equal to 50 SSP value is of good quality and more than 50 is not suitable for irrigation as permeability will be very low. In the study area almost all the water samples with SSP values less than 50.

Magnesium Ratio, MR

Water with less than or equal to 50 MR value is of good quality and >50 is considered unsuitable for irrigation.[29] In the study area all the water samples except one water sample with MR value less than 50.

Conclusion

Major ion chemistry and identification of Hydro geochemical processes of groundwater in the small coral island of Minicoy, Union Territory of Lakshadweep, India has been examined. The Minicoy Island is of coral origin (a typical atoll) and ground water occurs under phreatic condition floats as thin lens over saline water and is abstracted mainly by open dug wells. The DWT in the island varies from 0.62 to 1.75mbgl and depth of the wells varies from less than a meter to about 6mbgl and is controlled by tides when compared to the groundwater recharge and draft. The ground water in the island is generally alkaline with few exceptions. The electrical conductivity ranges from 592 to 2130 micromhos/cm at 25°C. The factors affecting the quality are rainfall, tides, ground water recharge and draft, human and animal wastes, oil spills and fertilizers. The EC varies from 592 to 2130 micromhos/cm at 25°C and the ground water is generally alkaline and under Na^{+}-SO_4^{2-} type and shallow meteoric percolation type. The groundwater samples of different areas are of Ca- HCO_3 Type (Recharge type) and Na- HCO_3 Type (Base Exchange water type) and among cations Ca^{+} and Na^{+} and anions HCO_3^{-} and Cl^{-} dominate the ionic concentration. The hydrochemistry is mainly controlled by water-rock interaction, evaporation and aquifer material.

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Conflict of interest

The author declares no conflict of interest.

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