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Sustainable Water Development and Suitability of Ground Water for Irrigation Purposes in a Small Coral Island of Minicoy, Union Territory of Lakshadweep, India

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Sustainable water development and suitability of ground water for Irrigation purposes in a small coral Island of Minicoy, Union Territory of Lakshadweep, India have been studied in detail. In the Island of Minicoy ground water occurs under phreatic condition and is seen as a thin lens floating over the saline water and coral sands and coral limestone form the principal aquifers. The depth to the water level in the Island varies from 0.62 to 1.75 mbgl and the depth of the wells varies from less than a meter to about 6 mgbl. The depth to the water table is highly influenced by the tides. The ground water in the Island is generally alkaline and EC varies from 592 to 2130 micromhos cm^{-1} at 25° C. The ground water is generally alkaline and under Na^{+}-SO_4^{2-} type and shallow meteoric percolation type. The factors affecting the quality are rainfall, tides, ground water recharge and draft, human and animal wastes, oil spills and fertilizers. The premonsoon 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 in groundwater. The groundwater of the area comes under Na^{+}-SO_4^{2-} type and shallow meteoric percolation type. The hydrochemistry is mainly controlled by evaporation, partly influenced by water–rock interaction and aquifer material.

(***Key words:*** *Coral Island, Minicoy, Sustainability, Union Territory of Lakshadweep*)

The Lakshadweep Islands (LD Islands) are a group of tiny coral Islands, located in the Arabian Sea, about 400 km from the main land (southern tip of the Indian peninsula). They spread over a distance of 300 km, consists of 36 coral Islands and a number of sunken banks, open reef and sand banks and are typically a chain of low Islands surrounding a shallow lagoon, consisting of large recent sediments on top of older coral limestones. The Minicoy Island has a delicate ecosystem with very limited fresh water resources. Though the Island receive 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 freshwater 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 highlight sustainable water development and to know the suitability of ground water for irrigation purposes in the small coral Island of Minicoy. The sustainability has dual imperatives- developers must recognize the legitimacy of and give full attention to environmental concerns in their plants and projects and environmentalists must recognize the legitimacy of and full attention to economic development concerns in their efforts to protect environment. The sustainable development indicates environmentally sound development with minimum damage to the environment. The UN Conference on Environment and Development/Agenda 21 defines the sustainable development (sustainability) as the development that needs the present without compromising the ability of future generation. The works on sustainability of water resources were carried out by Joji and Nair (2002) and many others but the small Island hydrogeological studies were carried out many authors. These include Barker (1984) on freshwater–saltwater relation, Peterson (1984) on groundwater recharge, storage and development on Atoll Islands, Chapman (1985) on the use of water balances for water resource estimation with special reference to small islands, Dale *et al.* (1986) on coral island hydrology, UNESCO (1991) on hydrology and water resources of small island, Falkland (1992) on review of ground water resources of home and west island, cocos (Keeling)

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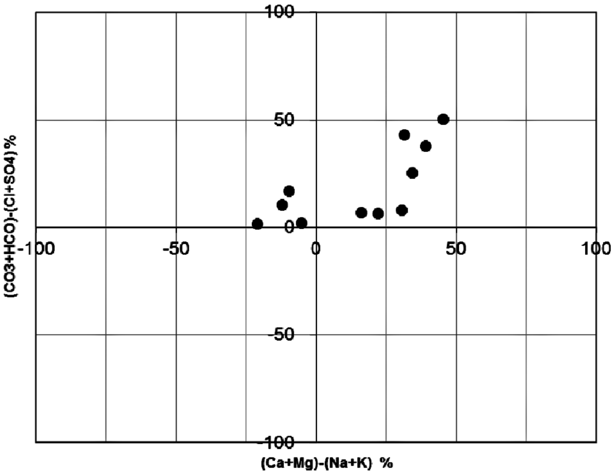

Fig. 2. Modified Piper Diagram

MATERIALS AND METHODS

The U.T. of Lakshadweep consists of 10 inhabited Islands, 17 uninhabited Islands, attached islets, 4 newly formed islets and 5 submerged reefs. The Islands are scattered in the Lakshadweep sea between North latitude 8° 00′ and 12° 13′N and East longitude 71° 00′ and 74° 00′E. Chetlat, Kiltan and Kadamat are closely spaced and are on the northern part of the archipelago. The location map of LD Islands including Minicoy Island is compiled (Fig.1 and 2). Apart from the above there are 17 uninhabited Islands located in the close vicinity of the inhabited Islands. They are namely Pitti (Birds Island), Viringili, Cheriyam, Kodithala, Tilakkam (i), Thilakkam (ii), Thilakkam (iii), Pitti (i), Pitti (ii), Bangaram, Thinnakara, Parali(i), Parali (ii), Parali (iii), Kalpitti, Suheli Valiya Kara, Suheli Cheriya Kara.

The base map of Minicoy and various layers were prepared by using Map Info 6.5 techniques and the ground water resource of Minicoy has been computed based on the methodology recommended by the GEC 1997. The recharge to ground water lens = rainfall – interception – evapotranspiration and Ground water utilisation = Evapotranspiration + mixing + pumping + outflow, for water balance study monthly water budgeting or weekly water budgeting gives appropriate value of recharge. The main consumer of ground water is coconut plant because one coconut tree consumes 40 lpd and density of coconut trees is 25000 – 35000 km^2 but draft through plant is slow, steady and spread uniformly. The various hydrogeological parameters collected during the field study and water level data observed during low and high tide. The pre and post monsoon groundwater samples collected from shallow aquifers (dug wells) from in polyethylene bottles and analysed as per standard procedures and the in situ measurement of EC and pH carried out by using EC and pH meters.

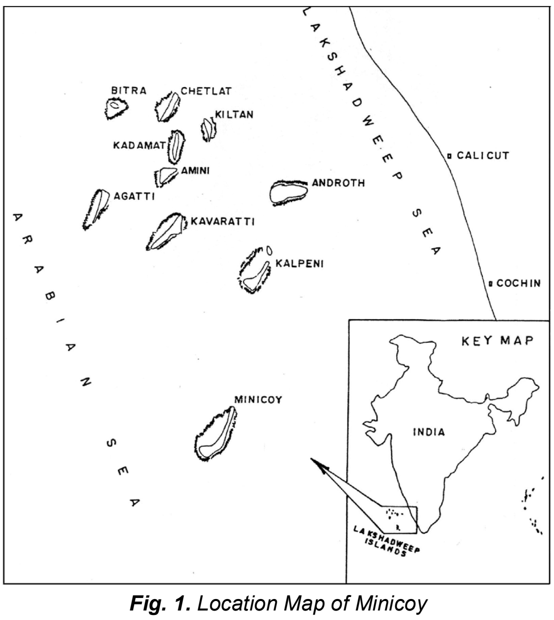

Fig. 1. Location Map of Minicoy

RESULTS AND DISCUSSIONS

The various hydrogeological and quality aspects and the major ion chemistry and their sustainable utilization and conservation aspects are also discussed.

Climate, humidity, temperature, evapotranspiration

The climate of a small Island is one of the major influences on the availability of naturally occurring freshwater resources (UNESCO, 1991). The rainfall distribution, quantity and its spatial and temporal variations and the evapotranspiration play an important role on the availability of the freshwater resources. The maximum, mean and minimum annual rainfall on Minicoy for the period 1961-91 are 2634 mm (1961), 1555 mm, and 945 mm (1980) ,respectively. It is lower during January to April when it is between 75 and 78% in the morning hours and 66 to 69% in the 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°C. And 33.1°C respectively. December and January are the coldest months with the mean minimum and maximum temperatures of 24°C and 31.1°C respectively. This is very high and most of the months except in high rainfall season it exceeds the rainfall making the water surplus on the negative side and the rainfall infiltrates into the ground and a small portion goes to recharge the ground water and the major portion is lost as subsurface run off and as potential evaporation losses. The PET is high due to shallow water table conditions.

Physiography, soil, vegetation, human impact, geomorphology and geology

The entire LD Islands lies on the northern edge of the 2500 km long North-South aligned submarine Lakshadweep-Chagos ridge. The Lakshadweep Sea separates this ridge from the west coast of India. The ridge rises from a depth of 2000-2700 mbmsl along the eastern side and 400 mbmsl along the Western side. The LD Islands typically have coarse sandy soil of high porosity and permeability resulting in little or no surface runoff. The retention capacity is a function of the texture of the soil and its thickness. The vegetation of LD Islands consists of coconut trees, bushes and grasses. Coconut trees of the LD Islands act as phreatophytes, which draw water directly from DWT and can contribute a reduction in ground water resources during dry periods. Human activities influence the availability of freshwater and its quality. In LD Islands consumption of water for domestic purposes is a major component in the water balance. The Minicoy Island is flat, rarely rising more than two meters, and consist of fine coral sand and boulders compacted into limestones. A gradual accretion of sediments by this process has led to the growth of the Islands. The Lakshadweep ridge is supposed to be the continuation of Aravalli mountain chain of Rajasthan prior to the faulting of Deccan traps along the west coast of India.

Hydrogeology of minicoy

The Minicoy Island is made up of coral reefs and materials derived from them and generally enclosing a lagoon. The hard coral limestone was exposed all along the beach during low tides and in the well sections. Ground water occurs under phreatic condition and is seen as a thin lens floating over the sea water. The coral sands and the coralline stone form the principal aquifer. Ground water is developed by open dug wells and to a limited extent through shallow filter point wells. The water level data of monitoring wells in Minicoy Island is compiled (Table 1) and depth of the wells ranges from 1.9 to 3.5 mbgl and the DTW ranges between 1.31 to 2.9 mbgl whereas diurnal fluctuation in water level due to tides is in the range of 0 to 80 cms.

Ground water resources

Ground water draft is mainly used for domestic purposes. Irrigation draft is minimum and there is no industrial draft. The climate water balance method of recharge estimation widely used for estimating the recharge on small Islands (Falkland, 1992).The water balance equation used for estimating ground water recharge can be expressed as $P = ETa + R + dV$; where P is Precipitation (rainfall), ETa Actual Evapotranspiration, R Recharge to ground water and dV change in soil misture. Where there are no coconut trees, the recharge to ground water is about 50% of the rainfall and as the coconut tree increases to a full cover, the recharge can reduce to about 30% of the rainfall. The PET estimates were derived from mean monthly temperature data for the period from 1961. The PET values range from 134.5 mm for February to 174.2 mm for May in Lakshadweep Islands. On coral atoll Islands surface runoff can be considered negligible. The ground water resource of Minicoy has been computed based on the methodology recommended by the GEC 1997 and is compiled (Table 2).

Table 1. *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- Valumaugothi 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	1.60	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	1.00	1.08	1.03	0.94	0.91	1.04	0.97	1.71	1.52	1.52	1.41

Table 2. Ground water resources of Minicoy

#	Annual components of water balance	Minicoy
1.	Population	9495
2.	Area (sq.km)	4.37
3.	Total Resource (water surplus MCM)	1.97
4.	ET loss from trees for 8 months (MCM)	0.63
5.	Water loss due to outflow to sea {10% of (3) (MCM)	0.39
6.	Buffer zone for reserve during delayed or lesser monsoon period {10% of (3) (MCM)	0.39
7.	Balance available resource(MCM)	0.55
8.	Domestic draft (100 lpcd) (MCM)	0.35
9.	Gross annual draft(MCM)	0.35
10.	Ground water balance(MCM)	0.20
11.	Stage of development	63%
12.	Category	Safe

Major ion chemistry and hydrogeochemical processes of ground water

The Major ion chemistry and hydrogeochemical processes of ground water and evolution have been examined.

The groundwater of different geological horizons can be classified depending upon their ionic strength of select anions and Soltan (1998) categorized groundwater based on the meq l^{-1} content of Cl^-, SO_4^{2-}, and HCO_3^-. The water is Normal Chloride type if Cl^- is <15 meq l^{-1}, Normal Sulphate type if SO_4^{2-} is <6 meq l^{-1} and Normal Bicarbonate type if HCO_3^- varies between 2 and 7 meq l^{-1}. Distribution of groundwater samples based on the Soltan's 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 depends on the geology, environment, and movement of water (Raghunath, 1982; Gopinath and Seralathan 2006). The base exchange indices, r1 ($r1 = Na^+ - Cl^-/SO_4^{2-}$ meq l^{-1}) and r2 ($r2 = K^+ + Na^+ - Cl^-\ SO_4^{2-}$ meq l^{-1}) after (Soltan,1999) 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&4).

Hydrochemical 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 (Meybeck, 1987). 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.

Hydrochemical Facies

The groundwater is further evaluated to determine its facies by plotting the percentages of select chemical constituents in Modified Piper diagram (Chadha, 1999). The plots for the season indicated distribution within the fields 2, 5 and 8 of the Chadha's diagram (Fig. 3) 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 hydrochemical 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^{2+} and Na^+ and anions HCO_3^- and Cl^- dominate the ionic concentration in groundwater.

Hydrogeochemical evaluation of ground water

The high sodium content among cations in the groundwater for the period could be due to halite dissolution which was further enhanced by evaporation

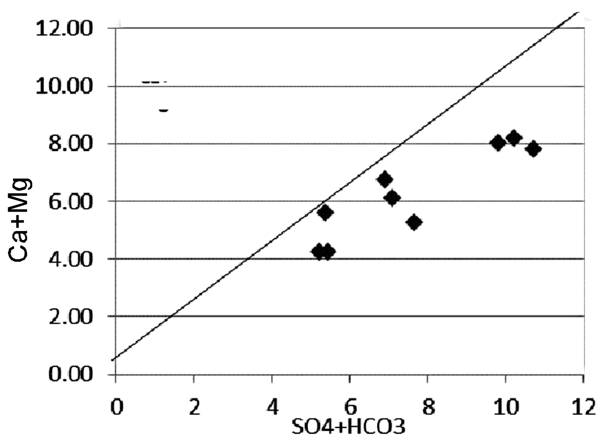

Fig. 3. Plot of Ca+Mg and So_4+ HCO_3 Premonsoon

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	52.70
3	7.97	2130	440	92	51	275	58	0	683	298	117	79	0.39	5.70	2.40	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	1.30	-0.60	472	30.48
6	8.23	1770	390	112	27	214	26	0	537	185	91	150	0.37	4.70	0.98	1074	56.04
7	7.92	1270	340	96	24	106	11	0	342	128	62	136	0.52	2.50	-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	34.70
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	120.3	18.5	21.9	78.3	17.5	18.0	156.5	87.7	31.9	50.4	0.2	1.5	1.2	317.1	11.7
BIS	8.50	750	300	75	30	NR	NR	NR	500	250	200	45	1.00				

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	8.20	6.20	2.37	1.09	1.27	-0.92	-0.35
2	3.02	1.02	4.20	1.17	1.72	0.89	1.89	-0.58	-0.27
3	8.41	2.44	11.20	8.51	2.07	0.92	1.10	-0.60	-0.34
4	1.10	0.52	4.90	-0.63	0.98	0.87	2.99	-0.46	-0.09
5	1.69	0.56	4.80	-0.84	1.36	0.83	3.00	-0.45	-0.11
6	5.22	1.90	8.80	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	6.80	0.12	1.03	0.82	1.80	-0.45	-0.11
9	2.79	0.90	6.20	-0.38	0.23	0.64	2.38	-0.07	-0.03
10	5.22	1.81	8.00	1.82	-0.05	0.58	2.05	0.02	0.01
11	8.12	1.98	11.90	2.50	-0.72	0.53	0.72	0.17	0.10
Mean	4.21	1.39	7.33	2.44	1.13	0.83	2.01	-0.42	-0.15
Min.	1.10	0.52	4.20	-0.84	-0.72	0.53	0.72	-0.92	-0.36
Max.	8.41	2.44	11.90	8.51	2.51	1.16	3.00	0.17	0.10
SD	2.47	0.66	2.57	3.22	1.02	0.19	0.75	0.35	0.16

(# Concentration, meq l^{-1})

and/or evapotranspiration 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 (Meybeck 1987). 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 (Gosselin *et al.*, 2003). 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 (May and Loucks 1995). 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 $HCO_3^- + SO_4^{2-}$ (Fig. 4) shows that majority of samples in the seasons and different geological terrainfall below the equiline, indicating that silicate weathering was the primary process involved in the evolution of groundwater (Datta and Tyagi, 1996). If bicarbonate and sulfate 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 (Elango *et al.*, 2003; Elango and Kannan, 2007). 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 ground water

Gibbs (1970) 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.

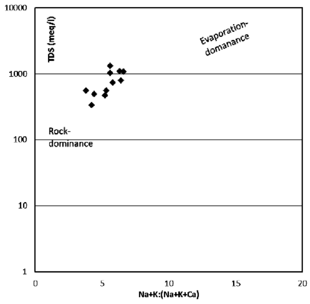

Fig. 4 a. *Gibb's plots for cation, 2010*

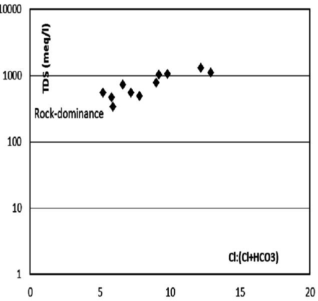

Fig. 4b. *Gibbs plots for anion 2010*

The rock water interaction played major role in the evolution of water chemistry, which was partly by evaporation process (Fig. 5a and b). Geological location is one of the most important factors affecting the groundwater quality (Beck *et al.*, 1985).

Chloroalkali indices

The evolution of groundwater chemical composition has been further examined by determining the Chloroalkali 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 (1967), 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 (McIntosh and Walter, 2006). 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. As CAI-1 and CAI-2 are negative in the samples indicating the ion exchange predominance in the study area.

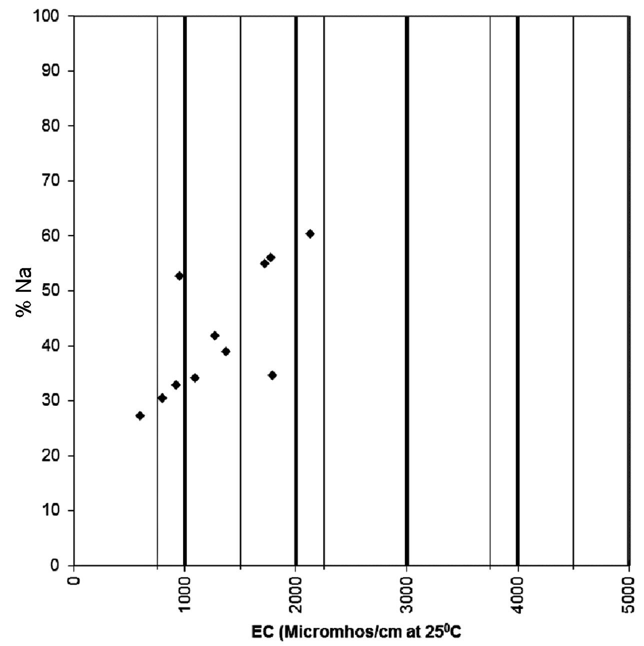

Fig. 5. *Wilcox classification of irrigation Water (Pre monsoon)*

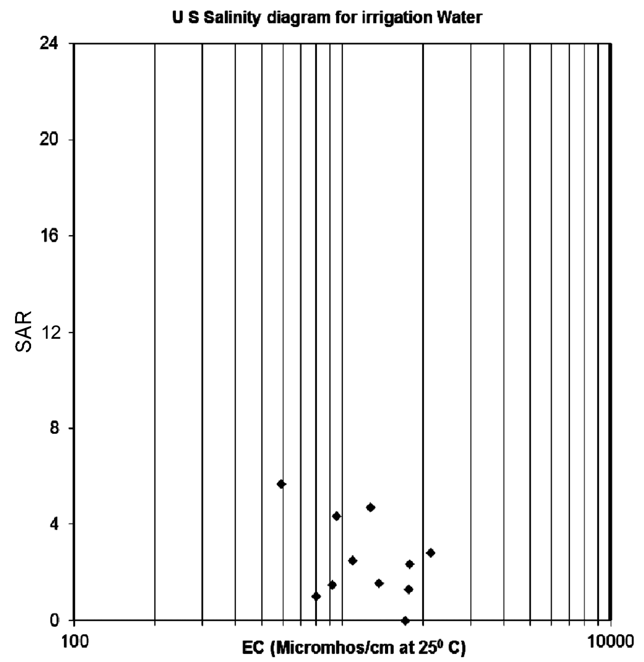

Fig. 6. *U S Salinity diagram for irrigation Water (Pre monsoon)*

Suitability of ground water for Irrigation purposes

The irrigation suitability of ground water has been attempted based on the 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 (1982) and that the samples in the study area are in 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. As per Richard (1954) the computed SAR value shows that all the samples are excellent. Wilcox's diagrams relating to Percent Sodium and electrical conductivity of the samples (Fig. 6) and U S Salinity diagrams for irrigation water (Fig. 7) show that majority of samples fall under the excellent to good category of Percent Sodium and in the case of EC good to permissible for irrigation.

Percent sodium (% Na)

The % Na 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 (Bangar *et al.*, 2008; Durfer and

***Table 5**. Methodology adopted for computations of Irrigation Suitability*

Aspects	Formula	Range	Classification	Reference
EC, μS cm^{-1} at 25°C		<250 250-750 750-2000 2000-3000 >3000	Excellent Good Permissible Doubtful Unsuitable	Raghunath (1982)
SAR	SAR = Na / H (Ca+Mg) / 2	<10 10–18 18–26 >26	Excellent Good Doubtful Unsuitable	Richards (1954)
%Na	%Na = ((Na+K) / (Ca+Mg+Na+K))*100	<20 20–40 40–60 60-80 > 80	Excellent Good Permissible Doubtful Unsuitable	Raghunath (1982)
PI	PI = ((Na+ (HHCO_3) / (Ca+Mg+Na))*100	>75 25- 75 <25	Class I Class II Class III	Doneen (1964)
KI	KI= Na/Ca+Mg	> 1-2 < 1	Unsuitable Poor Suitable	Kelley (1940)
SSP	SSP= Na*100/ Ca+Mg+Na	>50 < 50	Unsuitable Suitable	Khodapanah *et al.* (2009)
Mg ratio	MR = (Mg*100) / (Ca+Mg)	>50 < 50	Unsuitable suitable	Lloyd and Heathcote (1985)

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

S.No	Location	SAR	%Na	KI	P I	SSP	EC, μS cm^{-1}	Mg ratio
1	Lom Bomauge	4.33	54.91	1.07	68.49	51.65	1720	0.79
2	Dondale Kagothi	2.82	52.70	0.96	73.46	49.10	950	0.53
3	Fallissery Mosque	5.70	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	1.30	30.48	0.39	56.16	27.97	798	0.33
6	Kibula Mosque	4.70	56.04	1.19	71.65	54.33	1770	0.40
7	Odivalu Mosque	2.50	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	34.70	0.52	52.30	34.36	1785	1.38
	Mean	2.76	42.24	0.73	64.05	40.02	1309.00	0.60
	Min.	1.01	27.37	0.35	52.30	25.72	592.00	0.33
	Max.	5.70	60.44	1.36	73.74	57.61	2130.00	1.38
	SD	1.53	11.71	0.36	7.20	11.34	488.71	0.32

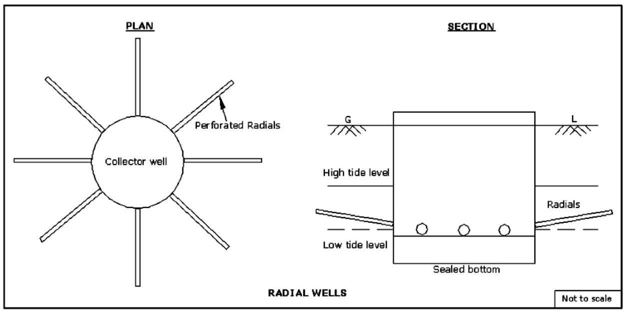

Fig. 7. Schematic representation of Radial well

Backer, 1964; Todd, 2005). 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. 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; Blake, 1989; Cerling *et al.,* 1989; Foster, 1950.)About 82% KI values are below 1, the water in the study area is suitable for irrigation.

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 (Lloyd and Heathcote, 1985). In the study area all the water samples except one water sample with MR value less than 50.

Water problems in minicoy

The increase in population and change in life style of the population leads to a non-injudicious exploitation of groundwater. The community ponds are gradually getting out of use and people prefer piped water supply. The withdrawal of water by bucket and rope is being replaced by pump sets and it resultants stress on the fresh water lens. The groundwater pollution from unprotected toilet system causing water quality issue deserving immediate attention. The potential for groundwater contamination has increased many folds because of the scattered toilet system. The water analysis show high on nitrate concentration (50 - 120 mg l^{-1}) in many dug wells indicating sewage contamination. This may lead to many water born diseases in the island.

Groundwater management

The important aspect of groundwater management in the island is maintaining an optimum dimension of the fresh water lens so as to avoid deterioration of water quality by saline water intrusion and to regulate the ground water draft in these islands. Conservation of fresh water through rainwater harvesting and desalination of brackish water can be adopted to meet future enhanced requirements as well as to reduce stress over the fresh water lens. Proper sanitation facilities are to be developed to protect the fresh water resources from contamination especially from bacteriological sources.

Regulation of water draft

The adverse effects of pumping can be minimized (to avoid upconing) if the pumped wells are shallow and pumped at low rates. Wherever the fresh water lens is very thin, infiltration galleries are obviously preferable to wells (Barker, 1984). Skimming wells are ideal for those parts of the island where the thickness of the lens is less. Skimming wells are constructed with vertical or inclined shaft with a sealed bottom connected to several small diameter perforated pipes placed at the bottom of trenches filled with gravel. The pipes lay just below the mean water table such that they follow the lens thickness contour. For better efficiency the galleries are to be oriented parallel to longer axis of the island (Petersen, 1984) and depth of the well should be less than 1/3 of the depth to the interface for homogenous isotropic aquifer (Chandler and Wherter, 1975).

Water conservation

The traditional water conservation practices in the main land have little application in these small Islands. Rainfall is the only source of recharge and the highly permeable coral sands allow the entire rainfall to reach the fresh water lens and get adjusted by way of diffusion leaving no scope for surface run off. The ponds and tanks in the islands minimise the use of fresh water by collective use of it for washing and bathing purposes. These ponds and tanks are water conservation structures and cannot be considered as effective recharge structures as the lateral movement of these mostly polluted pond waters are seldom noticed.The shape and size of islands influence the dimension of fresh water lens formed and the excess rainfall received in these islands gets adjusted by diffusion. The rainfall recharged beyond the optimum dimension of the fresh water lens is adjusted in the zone of diffusion and is not retrievable. Hence, the excess rainfall is to be harvested in a large way in the island. The fresh water lens is dynamic with an active vertical component and a restricted lateral component. Because of this situation the lateral movement of pollutants reaching the fresh water lens is very low. This is evident from the coloured polluted water restricted around the bathing ponds in these islands. Proper sanitation with a centralized sewage processing is very essential for maintaining the microbial quality standards for the fresh water in these islands.

Roof water harvesting

The rainfall distribution pattern of the islands show that the average monthly rainfall is more than 40 mm for eight months a year, from May to December. Most of the buildings are tiled roof or RCC roofs and hence ideal for roof water harvesting. The commonly adopted practice in these islands is by providing eve gutters for the roof water collection and leading the same to surface level collection tanks. Just at the inlet points of this roof water to the storage tanks, filter beds are provided and filter bed is composed of coir fibre, charcoal, fine sand and gravel. During December there is an average rainfall of 45mm, about 80 percent of which is available for harvesting. The roof water harvesting will suffice to meet the drinking water demand for another 120 days at the rate of 8 lpcd for individual households, even if the rainfall during the other four months is not harvested. The advantage of roof water harvesting scheme over the other schemes is that it is self-contained and once implemented the individual beneficiary can manage, maintain, regulate and operate according to the requirements.

Desalination using waste heat

In all the inhabited islands as well as in the tourist island of Bangaram electricity is being produced by diesel generators. The heat generation potential is estimated based on the consumption of HSD. The average load is assumed to be about 75 percent of the peak load. These generators produce a large quantity of heat as a by-product. The same can be utilised for desalination of seawater. This helps in containing the temperature pollution also. It is estimated based on the experience from the existing plant at Kavaratti that on a conservative estimate 730 lpd of pure water with a TDS of about 10-15 ppm can be produced utilising the heat recovery system for every 100 lrs of diesel used. Considering an efficiency of 80 percent, the freshwater that can be produced through desalination by waste heat recovery system is worked out for the islands.

Solar desalination

For solar desalination, construction of solar desalination plants at community level needs availability of large open area. Hence solar desalination of seawater can be thought of only in those islands like Bitra, if the water produced by waste heat recovery system is not sufficient.

Integrated water management schemes

It is observed in the island that there are large areas under freshwater lens as well as brackish water lens. The development of the same should be done judiciously with slow and steady draft so that there is no upconing of the saline water from below and intermittent pumping with high discharge results in higher level of fluctuation and resultant expansion of transition zone. Wherever essential pumping should be done from radial wells and thses consist of a central well with six to eight galleries. Galleries are horizontal, permeable conduits constructed using slotted PVC pipe, porous concrete pipes or non-jointed hollow concrete blocks. The layouts of the galleries should be parallel to the longer axes of lenses and not perpendicular to them, except near the centre.

The total allowable draft from the freshwater lens in small island condition is important for management of the groundwater resource which may be expressed as $R = O + Q + Dv$, where R = recharge into the lens estimated from water balance after taking in to account all evapotranspiration losses. O = flow through the lens (or 'flux') which either flows out at the edge of the lens or mixes with the transition zone at the base of the lens. Q = total amount of water pumped from the lens, and dV = long-term change in freshwater volume, being negligible and can be ignored. In relatively large and stable lenses, the sustainable yields might be about 30 to 40 percent of the average recharge. For thin and fragile lenses, it is considered prudent to maintain the pumping at less than 20 percent of average recharge, until further groundwater quality-monitoring data has been collected and studied.

Measures to be adopted for sustainable development of ground water

The sustainable development of ground water in the island of Minicoy can be adopted by understanding of the saline-fresh water interface behavior and management of the ground water resource, Rain water harvesting should be mandatory for all future civil constructions, individual and community roof top rain water harvesting is an ideal decentralized system for providing safe drinking water generating awareness and capacity building of community towards promoting eco-sanitation, rain water harvesting, water conservation, recycling and re-use should be done on a large scale.

The sustainability of traditional open wells can enhanced by laying filter pipes (collector pipes) horizontally in the fresh water layers and connecting in to the wells and 50 to 60 m horizontal distances can be collected in the open wells constructed with the RCC ring, proper sewage disposal are to be given top priority to protect thin floating lens of ground water which is easily prone to contamination, composting toilet should be promoted particularly in places where water table is shallow to safe guard against ground water contamination from sewage, low temperature thermal desalination water treatment technology successfully implemented at Kavaratti can be replicated in Minicoy also.

CONCLUSIONS

Sustainable water development and suitability of ground water for irrigation purposes in the small coral Island of Minicoy have been examined. The major influences on the small Islands hydrological characteristics are climate, humidity, temperature, evapotranspiration, physiography, hydrogeological aspects, soil, vegetation, population and human interference, hydrogeology, ground water major ion chemistry and hydrogeochemical processes of ground water, hydrogeochemical evaluation are studied. The irrigation suitability parameters viz. 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 and Wilcox classification of irrigation water and U S Salinity diagram for irrigation water were examined. The water problems in minicoy, groundwater management, regulation of water draft, water conservation measures, roof water harvesting, desalination using waste heat, solar desalination and measures to be adopted for sustainable development of ground water are also examined.

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