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Geological and Geochemical Examination of Ground Water Resources in A Small Tropical Coral Island of Amini, Union Territory of Lakshadweep, India

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Abstract

The Geological and Geochemical Examination of Ground Water Resources in a Small Tropical Coral Island of Amini, Union Territory of Lakshadweep, India has carried out. The Map Info 6.5 techniques have been used for preparation of various layers and ground water resource of Amini has been computed based on the methodology recommended by the GEC 1997. The various hydrogeological parameters collected during the field study and water level data observed during low and high tide. The pre-monsoon (PRM) and post-monsoon (PSM) groundwater samples analysed for pH, EC, F^-, Cl^-, NO^{3-}, HCO^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+ as per standard procedures and the in-situ measurements of EC and pH were carried out by using EC and pH meters. At 16 sites Vertical Electrical Soundings (VES) had carried out by Wenner electrode spacing up to a maximum spread length (AB) of 120 m and IPI2 Win v2.0 used for the interpretation of the VES data. The purpose of the study is to examine geological and geochemical characteristics of ground water resources of the Amini. In Amini ground water occurs under phreatic condition and floats as lens over the marine water and the principal aquifers in the area are coral sands and coral limestones.

The depth of the wells is 1.6 - 5.5 meters below ground level (mbgl) and depth to the water table 1.20 - 4.80 mbgl. The ground water is under Na+-SO42- type, shallow to deep meteoric percolation types and alkaline (EC variation 465 - 999 micromhos /cm at 25o C). The water samples are Ca-HCO3 (recharge type) to Ca-Mg-Cl type (reverse ion exchange water type).The hydrochemistry in the area is mainly controlled by evaporation, water–rock interaction and aquifer materials. The evaporation process played major role in the evolution of water chemistry. The ground water in the study area is suitable for irrigation in all types of soil.

Keywords: Fresh water lens; Chloro alkali indices; Base Exchange indices; Irrigation; Sustainability

Abbreviations: PRM: Pre-Monsoon; PSM: Post-Monsoon; VES: Vertical Electrical Soundings; LD: Lakshadweep; PI: Permeability Index; KI: Kelley's Index; SSP: Soluble Sodium Percentage; MR: Magnesium Ratio; MBGL: Meters Below Ground Level

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Introduction

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 organic 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 limestones. The Amini Island has a delicate ecosystem receiving high rainfall, lack of surface storage and the limited ground water storage capacity, where fresh water occurs as a small lens floating over marine water. High porosity of the aquifers allows mixing of freshwater with sea water and due to high population density; waste water gets mixed with the fresh water in the aquifer.

The island hydrogeological and hydrochemical studies were carried out by many authors and these include Aris AZ et al. [1] on evaluation of factors influencing the groundwater chemistry in a Small Tropical Island of Malaysia, Kura NU et al. [2] applied factor analysis tool to the hydrochemical 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. VS Joji [4] on sustainable water development and suitability of ground water for irrigation purposes in a small coral Island of Minicoy, Vs Joji [5] on major ion chemistry and identification of hydrogeochemical processes of evolution of ground water in a small tropical coral island of Minicoy, on groundwater resources appraisal in the tropical coral island of Kalpeni, used application of multivariate statistical techniques in the assessment of groundwater quality in seawater intrusion area in Bafra Plain, Turkey, carried out assessment of groundwater quality for Veppanthattai taluk, Perambalur district, Tamil Nadu using Remote Sensing and GIS, on fresh water – salt water relation, appraisal of groundwater resources in an island condition and many others. The present study is an attempt to highlight hydro geological geochemical processes of evolution ground water in the Amini [6-10].

Study area

Amini Island having an aerial extent of 2.50 km^2 is elliptical in shape, located between Kadmath and Kavarati islands (in the N-S direction) and between Agathi and Androth islands (in the E-W direction) in a NE-SW alignment. The island is 58 km SW of Kiltan Island, 294 km from Mangalore, 324 km Kozhikode and 407 km Kochi. It lies between north latitudes 11^0 07’ 00” and 11^{0}08’00” and east longitude 72^0 44’ 00” and 72^0 45’ 00”. March to May is the hottest period of the year. The temperature ranges from 25^{o}C to 35^{o}C and humidity 70 - 76 per cent for most of the year. The area receives an average annual rainfall of 1600 mm and monsoon experiences from 15th May to 15th September.

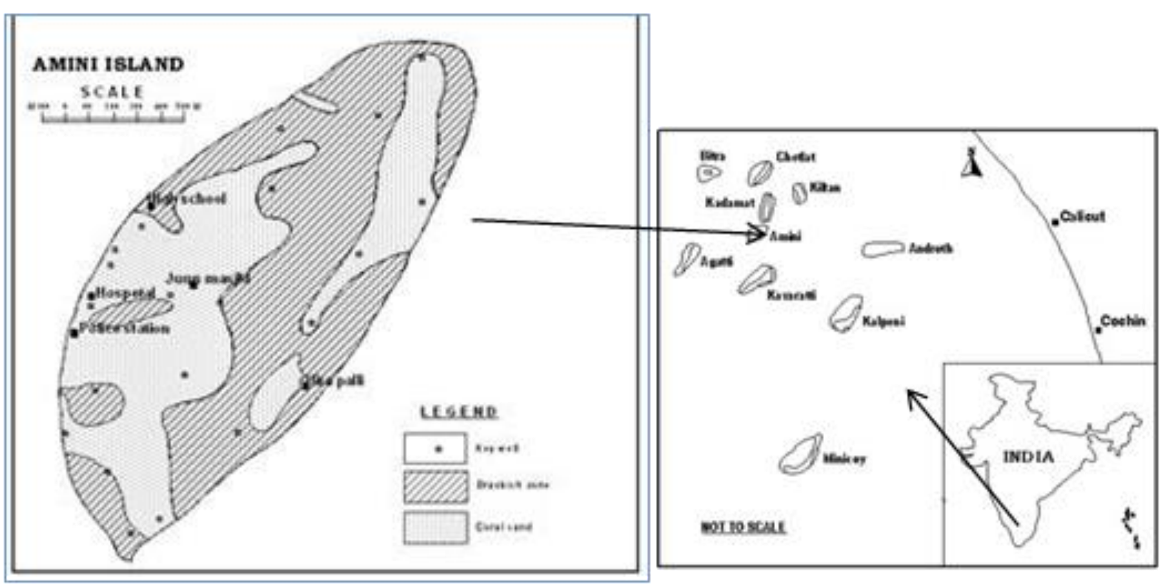

Figure 1: Location Map of Amini including other Lakshadweep Islands.

#	Item	Detail
1	Latitudes	110 07' 00" and 11008'00" N
2	Longitudes	720 44' 00" and 720 45' 00" E
3	Total geographical area	2.50 sq.km
4	Population (as per 2011 census)	7661
5	Average annual rainfall	1660 mm
6	Annual range of temperature	24.00C - 31.10C
7	Major geological formation	Coral
8	Net ground water availability	0.55 MCM/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	Upconing 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	Ground water	As lens, in hydraulic continuity with sea water
18	Effect of over draft of ground water	Upcoming of saline water from bottom

Table 1: Salient features of Amini Island.

The location map of LD islands including Amini Island is compiled (Figure 1) and various salient features of Amini are compiled (Table 1). Thecoral island of Amini is formed by coral polyps and they congregate in large colonies. 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 shape and movement of interface and may be controlled by 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.

Materials and Methods

The Map Info 6.5 techniques have been used for preparation of base map of Amini and various layers and ground water resource of Amini has been computed based on the methodology recommended by the GEC 1997. The recharge to ground water lens = rain fall – 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 consumption of ground water is coconut palms because one coconut tree consumes 40 lpd and density of coconut trees is 25 000 – 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-monsoon (PRM) and post-monsoon (PSM) 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 [11]. 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; $HCO3^-$ by potentiometric titration; SO_4^{2-} by modified titration method after [12,13]. 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 [14].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.

The subsurface conditions to recommend sites for ground water exploration at 16 sites Vertical Electrical Soundings (VES) were carried out by Wenner electrode spacing up to a maximum spread length (AB) of 120 m depending on the availability of space and signal sensitivity. The IPI2 Win v2.0 software has been used for the interpretation of the VES data.

Results and Discussion

The various factors controlling geological and geochemical examination of ground water resources of the island are discussed.

Geological aspects

General physical set up: The availability of the freshwater in the area is mainly controlled by intensity of rainfall and evapotranspiration. Tropical monsoonal climate exists in Amini and March to May is the hottest period of the year. The temperature ranges from 25°C to 35°C and humidity 70 -76 %. The monsoonal showers experience from 15th May to 15th September. The coral reefs maintain calm environment within the lagoon. The evapotranspiration is high and, in some months, even more than rainfall. There is no surface run off as the area is occupied mainly by coarse sandy soil of high porosity and permeability. The coconut trees, bushes and grasses are the main flora in the study area. The typical atoll of Amini with an elevation of 1-2 m above msl and the water bearing formations are coral sands and coral limestones. The depth of interface in the island can be determined by using Ghyben-Herzberg law.

Hydrogeology of amini: The Amini Island is made up of coral reefs and coral sands, generally enclosing a lagoon and coral limestone is exposed along the beaches of islands during low tides and in well cuttings. Below the coral sand is compact crust of fine conglomerate looking like coarse oolitic limestone with embedded bits and shell, and beneath this crust there is another layer of sand. The principal aquifers are the coral sands and the coral limestones. The depth of wells and water level ranges from 1.6 to 5.5 and 1.2 to 4.8 mbgl respectively with water level fluctuation due to tides in the range of 0 to 80 cms. The ground water is seen as a thin lens floating over marine water and in hydraulic continuity with the marine water (Figure 2). The Islanders use large diameter open dug wells as common ground water abstraction structures in addition to filter point wells. The hard-coral limestones are seen at the bottom of the majority of wells.

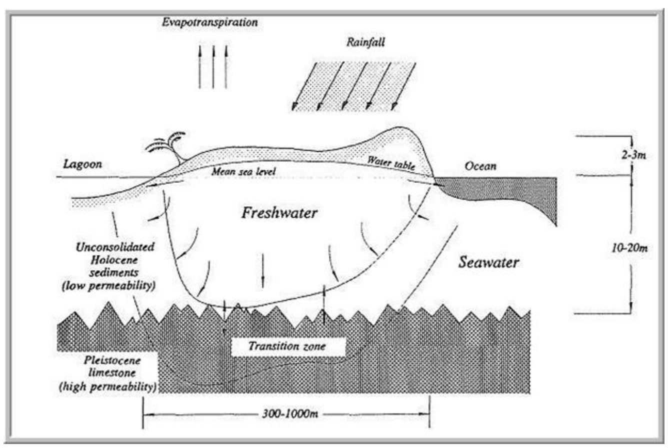

Figure 2: Freshwater lens in the small Island of Amini (Exaggerated vertical scale).

The calcareous sands are highly porous with high infiltrate rate and the infiltrating rainfall displaces the saline water to a freshwater lens due to density difference and the hydraulic continuity of ground water with seawater. About 18 to 51 per cent of the annual rainfall gets recharged into the ground water depending on the intensity, frequency and distribution of rainfall and the rise in water level due to recharge gets adjusted within the lens and hence appreciable increment in the water level is not observed. The coral atolls consist of a layer of Holocene sediments (coral sands and fragments of coral) on top of older limestones separated by unconformity at depths of 10 to 20 m below msl. The permeability greater than 1000 m/day in solution cavities of limestones. This extremely high permeability allows almost unrestricted mixing of freshwater and sea water which is less likely to occur in the upper sediments. The upper unconformity is one of the main controlling factors of the depth of freshwater lens. As the ground water is in hydraulic continuity with seawater, it is highly influenced by the diurnal tidal fluctuations of the sea. The magnitude of the water level fluctuation depends on permeability of the aquifer, proximity of the site to the sea and the magnitude of tidal variation. There is a time lag between tidal fluctuation in the sea and in the ground water levels, which is also dependent on the above factors.

The Amini is located on the north-central part of the Lakshadweep archipelago and is elliptical in shape with orientation in NE-SW direction. The freshwater availability in this island is limited to central part, while it is brackish in the south western and north eastern parts. The ground water from dug wells is the source of fresh water. The manually made dug wells are the extraction structures with diameter of 1 to 2 m width having a few meters depth are mainly used for domestic purposes, coconut seedlings or cattle rearing. The islanders conserving ground water by using water of step wells, ponds or tanks. The centrifugal pumps 1/2 HP capacity is increasingly used for the lifting of ground water. There are 1050 domestic dug wells with a density of about 420 wells / sq. km. The depths to the water table and hydrogeological maps have been prepared (Figure 3 and 4).

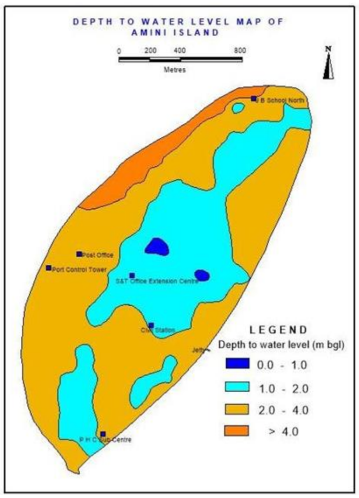

Figure 3: Depth to Water level map of the island (mbgl).

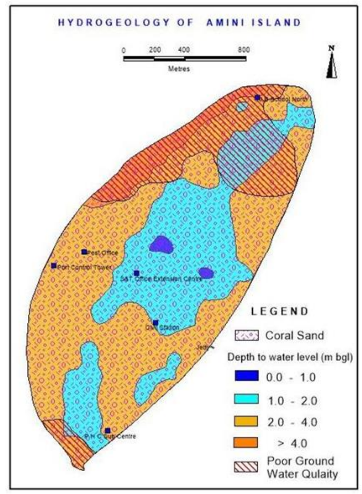

Figure 4: Hydrogeological map of the island.

Assessment of ground water resources: The dynamic ground water resources have been assessed by computing various components of recharge and draft. The main recharge component is rainfall but evapo-transpiration (consumptive use), outflow into the sea and domestic consumption are the components of draft. The 20% of the annual water surplus is reserved as buffer zone for reserve during delayed or deficit monsoon years and the other details are compiled (Table 2). The stage of ground water extraction in the island is 81.07 % and comes under Semi- Critical category.

S.no	Annual components of Water Balance	Amini
1	Population (As on 2013)	7719
2	Area (Ha)	259
3	Normal Monsoon Rainfall (m)	1.326
4	Rainfall Infiltration Factor (%)	30
5	Total Resource (Water Surplus) (Ha.m)) [2*3*4]	103.0
6	ET loss from Trees for 6 non-monsoon months (Ha.m)	27.8
7	Water loss due to outflow to sea [20% of (3) (Ha.m)]	20.6
8	Buffer zone for reserve during delayed or lesser monsoon period [20% of (3)](Ha.m)	20.6
9	Balance available resource (Ha.m)	34.1
10	Domestic draft @100 lpcd [1*100*365](Ha.m)	28.2
11	Gross Annual GW Draft (Ha.m)	28.2

Table 2: Dynamic Ground Water Resources of Amini (As in March 2013).

Subsurface conditions of coral Island: In order to know the subsurface conditions to recommend sites for ground water exploration at 16 sites Vertical Electrical Soundings (VES) had carried out by Wenner configuration up to a maximum spread length (AB) of 120 m depending on the availability of space and signal sensitivity and the data analysed. There were 3 to 4 layered geoelectric sections in the interpreted VES. In all the VES, the last geoelectric layer was showing decreasing trend due to salinity and the types of the curve obtained were Q & QQ. The first geoelectric layer resistivity was varying in the range of 20-5483 ohm.m, and the thickness of the layer is varying in the range of 0.4-3.4 m. The second geoelectric layer resistivity was varying in the range of 4-788 ohm.m, and the thickness of this geoelectric layer is varying in the range of 0.8-8.3 m., at about 1 VES (Amini10) the geoelectric layer was extending in nature. The third layer resistivity was varying in the range of 1-122 ohm.m with thickness 1.2-3.3 m., at about 11 VES the geoelectric layer was extending in nature. The fourth geoelectric layer resistivity was varying in the range of 3-5 ohm.m., at about 3 VES the layer was extending in nature and the interpreted results were compiled (Table 3).

S.no	VES No	Interpreted Results								AB, m
		Resistivity, Ohm.m				Thickness, m				
		r1	r2	r3	r4	h1	h2	h3	Total, H	
1	1	29	9	4	-	0.8	3.3	Ext.	4.1	60
2	2	3866	788	122	3	0.8	1.9	1.2	4.0	60
3	3	5483	574	74	4	1.6	1.3	3.3	6.1	60
4	4	982	250	23	5	1.7	0.8	1.7	4.2	60
5	5	2075	62	5	-	2.1	1.8	Ext.	3.9	60
6	6	20	8	3	-	0.9	5.7	Ext.	6.7	60
7	7	1035	22	5	-	1.5	8.3	Ext.	9.9	60
8	8	953	10	2	-	1.6	1.5	Ext.	3.1	80
9	9	1588	94	4	-	1.8	4.8	Ext.	6.6	90
10	10	1212	4	-	-	2.3		Ext.	2.3	90
11	11	920	75	4	-	3.4	4.5	Ext.	7.9	90
12	12	Not Interpretable								90
13	13	1961	33	2	-	1.5	4.9	Ext.	6.4	90
14	14	532	13	1	-	1.1	4.9	Ext.	6.0	60
15	15	146	19	2	-	0.4	3.2	Ext.	3.5	60
16	16	1354	40	3	-	1.2	2.9	Ext.	4.1	60

Table 3: Interpreted results of VES in Amini Island.

ρ1: First layer resistivity in ohm.m; h1: First layer thickness in m; Ext.: Extending with depth; VH: Very High.

By considering the type of VES curves, resistivity, thickness of the geoelectric layers, Amini1, Amini 6, Amini 7, Amini 8, Amini 10, Amini 14 and Amini 15 sites are represented that those are showing the resistivity of <22 ohm.m up to a depth of 3 mbgl. The location map of VES has been prepared (Figure 5). Some of the examples of field curves at Amini-9 and Amini-13 have been shown in Figure 6 & 7. The resistivity of the curves reveals that the resistivity decreasing with increasing electrode separation.

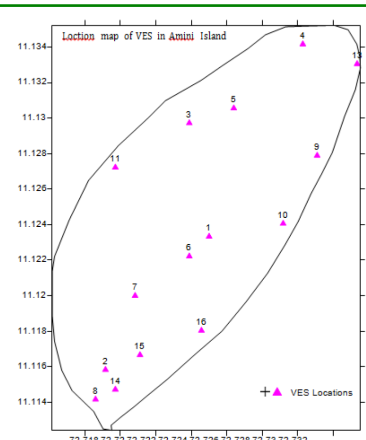

Figure 5: Location map of VES at Amini Island.

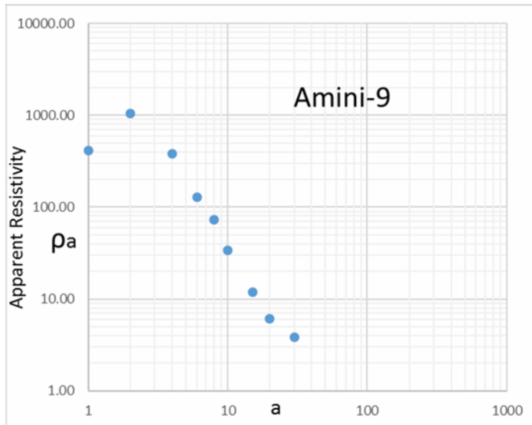

Figure 6: Representation of field curve at location Amini-9.

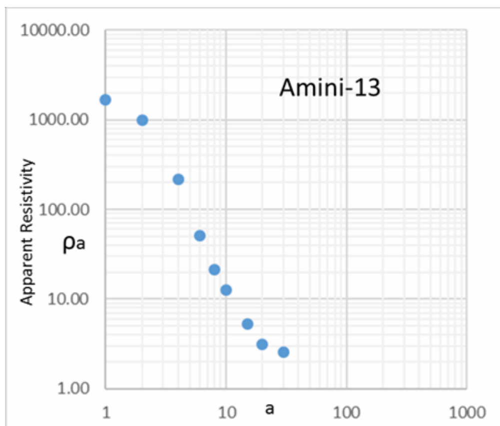

Figure 7: Representation of field curve at location Amini-13.

Geochemical aspects

Geochemical process: The geochemical processes of evolution of ground water have been examined classified ground water based on ionic strength of select anions of Cl-, $SO_4$2-and HCO_3- as Normal chloride type (Cl− <15 meq/l), Normal sulphate (SO42− <6 meq/l) and Normal bicarbonate type (HCO_3- 2-7 meq/l). The study reveals that majority of the samples are of Normal chloride type, followed by Normal bicarbonate type and concentration depends on geology, environment, and movement of water [13,15,16]. 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 could be used for further classification and groundwater may be Na^+ − HCO_3-type if r1 > 1 and Na+-SO^{4-} type with r1 < 1; r2 < 1- groundwater is of shallow meteoric percolation type and >1, shallow meteoric percolation type. The groundwater in Amini comes under Na^+- $SO_4{}^-$ type and shallow meteoric percolation type and the chemical analysis details are compiled (Table 4 & 5).

Pre-monsoon (PRM) 2010																
S.no	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	SAR	RSC	TDS	%Na
1	8.12	492	244	58	24	6.7	0.3	0	317	13	10	0.57	1.47	0.19	0.32	344	5.78
2	8.12	657	315	80	28	14	1.1	0	397	32	20	3.4	0.75	0.34	0.20	460	9.17
3	8.14	822	330	66	40	34	2.9	0	409	71	25	5.3	0.9	0.81	0.11	575	19.06
4	8.1	999	335	60	45	67	4.1	0	287	167	31	11	0.64	1.59	-2.00	699	31.05
5	8.23	741	295	52	40	30	1.5	0	354	75	21	4.8	0.68	0.76	-0.09	519	18.56
Min	8.10	492	244	52	24	7	0	0	287	13	10	1	0.64				

Max	8.23	999	335	80	45	67	4	0	409	167	31	11	1.47				
Mean	8.14	742	304	63	35	30	2	0	353	72	21	5	0.89				
SD	0.05	189	37	11	9	23	2	0	52	59	8	4	0.34				
BIS DWS - MDL	8.50	750	300	75	30	NR	NR	NR	500	250	200	45	1.00				
Post-monsoon (PSM) 2010																	
S.no	**pH**	**EC**	**TH**	**Ca**	**Mg**	**Na**	**K**	**CO3**	**HCO3**	**Cl**	**SO4**	**NO3**	**F**	**SAR**	**RSC**	**TDS**	**%Na**
1	8.04	465	268	70	23	7.4	0.5	0	342	11	7.1	0.7	1.3	0.20	0.21	326	5.84
2	8.04	555	285	74	24	16	0.6	0	372	21	14	1.5	0.2	0.41	0.42	389	11.13
3	8.24	835	340	62	45	52	1.1	0	433	75	26	1.1	0.45	1.23	0.30	585	25.18
4	7.68	572	195	42	22	38	5.1	0	214	60	19	12	0.44	1.18	-0.40	400	31.31
5	7.79	725	335	88	28	23	0.6	0	451	36	15	2	0.44	0.55	0.69	508	13.15
Min	7.68	465	195	42	22	7	1	0	214	11	7	1	0.20				
Max	8.24	835	340	88	45	52	5	0	451	75	26	12	1.30				
Mean	7.96	630	285	67	28	27	2	0	362	41	16	3	0.57				
SD	0.22	148	59	17	10	18	2	0	94	27	7	5	0.42				
BIS DWS - MDL	8.50	750	300	75	30	NR	NR	NR	500	250	200	45	1.00				

Table 4: Chemical analysis data of ground water in Amini.
BIS DWS – MDL - Bureau of Indian Standards Drinking Water Standards; NR - Not recommended

Well Nos	**Cl–**	**SO4 2–**	**HCO3–**	**Base exchangex, (r1)**	**Base exchange index, (r2)**	**Na/Cl**	**Ca/Mg**	**Chloroalk ali indices for cations,**	**Chloroalka li indices for anions, CAI-2**
Pre-monsoon, 2010 (PRM)									
1	0.37	0.21	5.2	-1.5	-0.3	0.52	1.47	0.18	0.01
2	0.9	0.42	6.51	-1.6	-0.6	0.44	1.74	0.29	0.04
3	2	0.52	6.7	-2.4	-0.9	0.48	1	0.22	0.06
4	4.71	0.65	4.7	-4.4	-2.6	0.4	0.81	0.36	0.31
5	2.12	0.44	5.8	-3.5	-1.8	0.4	0.79	0.37	0.12
Mean	2.02	0.45	5.78	-2.66	-1.24	0.69	0.74	0.29	0.11
Min	0.37	0.21	4.7	-4.38	-2.62	0.62	0.51	0.18	0.01
Max	4.71	0.65	6.7	-1.47	-0.33	0.79	6.58	0.37	0.31
SD	1.68	0.16	0.85	1.27	0.94	0.08	1.26	0.08	0.12
Post monsoon, 2010 (PSM)									
1	0.31	0.15	5.61	-1.78	0.16	0.67	1.85	-0.08	0
2	0.59	0.29	6.1	-1.34	0.41	0.76	1.87	-0.2	-0.02
3	2.12	0.54	7.1	-1.64	0.32	0.69	0.84	-0.08	-0.02
4	1.69	0.4	3.51	-2.62	0.23	0.63	1.16	-0.05	-0.02
5	1.02	0.31	7.39	-2.25	0	0.64	1.91	0	0
Mean	1.15	0.34	5.94	-1.93	0.22	0.68	1.53	-0.08	-0.01
Min	0.31	0.15	3.51	-2.62	0	0.63	0.84	-0.2	-0.02
Max	2.12	0.54	7.39	-1.34	0.41	0.76	1.91	0	0
SD	0.75	0.14	1.54	0.51	0.16	0.05	0.5	0.07	0.01

(# Concentration, meq/l)
Table 5: Different parameters of Pre and Post monsoon water samples.

The Na^+ / Cl^- molar ratio will be 1 if halite dissolution responsible for sodium dominance in groundwater and >1 Na^+ is released from silicate weathering process [17]. The Na^+ / Cl^- molar ratio is <1 in all samples of the seasons indicating that halite dissolution was the primary process responsible for the release of Na^+ into the groundwater.

Modified piper diagram: The Modified Piper diagram has been utilised to know the facies and nature of the water samples. The PRS water samples fall within the fields 5 and 6 of the Chadha's diagram (Figure 8 a & b) and are characterized by alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively i.e. (Ca+Mg)+ (CO_3+HCO_3)> (Na + K) +(Cl+SO_4) and the sample at Amini - Sidiqui Palli with alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions ie (Ca+Mg)>(Na+K)>(Cl+SO_4)>(CO_3+HCO_3). The PSM samples fall under field 5. All the samples except Ammini - Sidiqui Palli falling under Sub-field I and are Ca-HCO_3 Type / recharge type water but that of Ammini - Sidiqui Palli falling under Sub-field II and is Ca-Mg-Cl type, reverse ion exchange type. The diagram revealed that Ca^+ and Na^+ (cations) and HCO_3– and Cl–(anions) dominate in groundwater [18].

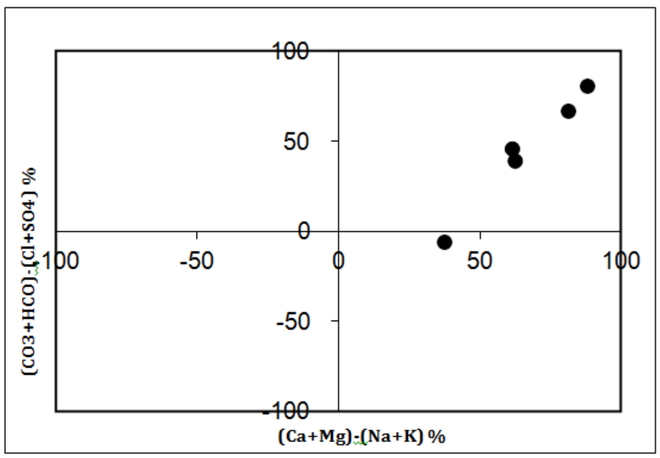

Figure 8a: Modified Piper Diagram-PRM 2010.

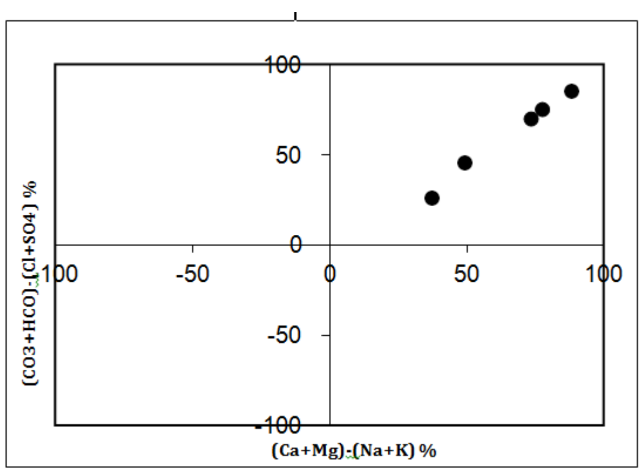

Figure 8b: Modified Piper Diagram-PSM 2010.

Hydrogeochemical evaluation: The high sodium content among cations in the ground water for the period could be due to halite dissolution which was further enhanced by evaporation 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 [17]. The Na^+/Cl^- molar ratio is>1inthesamples 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 Amini.

Evolution of groundwater: The plots, in which TDS vs. $Na^+/(Na^+ + Ca^{2+})$ for cations and TDS Vs $Cl^-/(Cl^- + HCO_3^-)$ for anions were plotted to know evolution process of the ground water and the influence of host rock on ground water chemistry. It is revealed that the samples occupied the evaporation dominance field. The rock water interaction played minimum role in the evolution of water chemistry, which was dominated by evaporation process during PRM and PSM. The geological location is one of the most important factors affecting the ground water quality [20,21].

Chloro alkali indices: The role of aquifer material in the evolution of ground water 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 [22], relates the ion exchange process between ground water and aquifer material. TheCAI-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 [23]. 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 when different geological formations are encountered in river basins [24]. As CAI-1 and CAI-2 are negative in the samples of PSM indicating the ion exchange predominance in the study area during PSM and positive values during PRM shown lesser role of ion exchange during PRM.

Irrigation suitability

The irrigation suitability examined based on 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 6) and the analytical results are compiled (Table 7).

Aspect	Formula	Range	Classification	Reference
EC, µS/c m at 25oC		<250	Excellent	[25]
		250-750	Good	
		750-2000	Permissible	
		2000-3000	Doubtful	
		>3000	Unsuitable	
SAR	SAR = Na / √ (Ca+Mg) / 2	<10	Excellent	[26]
		10–18	Good	
		18–26	Doubtful	
		>26	Unsuitable	
%Na	%Na = ((Na+K) / (Ca+Mg+Na+K))*100	<20	Excellent	[25]
		20–40	Good	
		40–60	Permissible	
		60-80	Doubtful	
		> 80	Unsuitable	
PI	PI = ((Na+ (√HCO3) / (Ca+Mg+Na))*100	>75	Class I	[27]
		25- 75	Class II	
		<25	Class III	
KI	KI= Na/Ca+Mg	>	Unsuitable	[28]
		1-2	Poor	
		< 1	Suitable	
SSP	SSP= Na*100/ Ca+Mg+Na	>50	Unsuitable	[29]
		< 50	suitable	
Mg Ratio	MR = (Mg*100) / (Ca+Mg)	>50	Unsuitable	[30]
		< 50	suitable	

Table 6: Methodology adopted for computations of Irrigation Suitability

S.no	Location	SAR	%Na	KI	P I	SSP	EC, µ S/cm	Mg Ratio
PRM water samples, 2010								
1	Ammini - UJRA Palli	0.19	5.78	0.06	49.76	5.64	492	40.51
2	Ammini - Maidanul Islam Madrassa	0.34	9.17	0.10	45.71	8.81	657	36.55
3	Ammini - Nercha Palli	0.81	19.06	0.22	50.41	18.32	822	49.94
4	Ammini - Sidiqui Palli	1.59	31.05	0.43	52.85	30.29	999	55.24
5	Ammini - Homeo Hospital	0.76	18.56	0.22	51.60	18.13	741	55.87
Mean		0.74	16.72	0.21	50.07	16	742	48
Min		0.19	5.78	0.06	45.71	6	492	37
Max		1.59	31.05	0.43	52.85	30	999	56
SD		0.55	9.88	0.15	2.71	10	189	9
PSM water samples, 2010								
1	Ammini - UJRA Palli	0.20	5.84	0.06	47.07	5.63	465	35.10
2	Ammini - Maidanul Islam Madrassa	0.41	11.13	0.12	49.68	10.92	555	34.80
3	Ammini - Nercha Palli	1.23	25.18	0.33	54.34	24.94	835	54.43
4	Ammini - Sidiqui Palli	1.18	31.31	0.42	63.37	29.70	572	46.30
5	Ammini - Homeo Hospital	0.55	13.15	0.15	48.27	12.98	725	34.37
Mean		0.71	17.32	0.22	52.55	17	630	41
Min		0.20	5.84	0.06	47.07	6	465	34
Max		1.23	31.31	0.42	63.37	30	835	54
SD		0.47	10.55	0.15	6.65	10	148	9

Table 7: Quality parameters of PRM & PSM water samples determined for Irrigation Suitability.

The EC is a measure of ability to conduct electric current and classified into five major types and the samples in the area are under excellent, good, permissible and doubtful categories. The EC values range from 492 to 999 with a mean value of 742 µsiemens / cm at 25°C during PRM and those during PSM are 465 to 835 with mean value of 630 µsiemens / cm at 25 °C [25].

The sodium alkali hazard or sodium absorption ratio (SAR) of water is an indicator of sodium hazard in irrigation water and as per, the SAR values are excellent. The SAR values range from 0.19 to 1.59 with a mean value of 0.74 during PRM and those during PSM are 0.20 to 1.23 with mean value of 0.71 [26.31].

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 [7,32,33]. The samples come under excellent to good categories and can be used for irrigation on almost all types of soil. The %Na values range from 5.78 to 31.05 with a mean value of 16.72 during PRM and those during PSM are 5.84 to 31.31 with mean value of 17.32. Doneen LD [27] has classified the irrigation water quality into three classes based on permeability index (PI) – class I, II and III and all the samples come under Class II and suitable for irrigation in all types of soil. The PI values range from 45.71 to 52.85 with a mean value of 50.07 during PRM and those during PSM are 47.07 to 63.37 with mean value of 52.55.

Kelley WP, Paliwal KV [28,34] proposed suitability of irrigation water quality based on the sodium concentration against calcium and magnesium. The water is suitable for irrigation if Kelley's Index (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 water logged area, marshy / swampy land, creek, mud / tidal flat represented by Montmorillonite clays, which lead to the release of Na or Ca into the ground water and adsorption of Ca or Na, respectively [35]. All the values with KI values below 1 indicating the water is suitable for irrigation. The KI values range from 0.06 to 0.43 with a mean value of 0.21 during PRM and those during PSM are 0.06 to 0.42 with mean value of 0.22. Water with less than or equal to 50 Soluble Sodium Percentage (SSP) value is of good quality and more than 50 is not suitable for irrigation as permeability will be very low. The study reveals that the water samples with

SSP values less than 50 make them suitable for irrigation. The SSP values range from 6 to 30 with a mean value of 16 during PRM and those during PSM are 6 to 30 with mean value of 17.

Water with less than or equal to 50 Magnesium Ratio (MR) value is of good quality and >50 is considered unsuitable for irrigation [30]. Here all water samples except one with MR values less than 50. The MR values range from 37 to 56 with a mean value of 48 during PRM and those during PSM are 34 to 54 with mean value of 41.

Conclusion

The coral atoll of Amini having an elevation of 1-2 m above msl and the water bearing formations are coral sands and coral limestones. The depth of wells and water level ranges from 1.6 to 5.5 and 1.2 to 4.8 mbgl respectively with water level fluctuation due to tides in the range of 0 to 80 cms. The ground water is seen as a thin lens floating over marine water and in hydraulic continuity with the marine water and open dug wells and filter point wells are the common ground water abstraction structures. The stage of ground water extraction in Amini is 81.07 % and comes under Semi-Critical category.

Thr VES revealed 3 to 4 layered geoelectric sections and the types of the curve obtained were Q & QQ.

The ground water in the area is of Normal chloride type, followed by Normal bicarbonate type. The groundwater in Amini comes under Na^+- SO_4^- type and shallow meteoric percolation type. The Na^+ / Cl^- molar ratio is <1 in all samples of the seasons indicating that halite dissolution was the primary process responsible for the release of Na^+ into the groundwater. The PRS water samples are characterized by alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively and on the other hand the PSM samples are Ca-HCO_3 Type / recharge type water but that of Ammini - Sidiqui Palli falling under Sub-field II and is Ca-Mg-Cl type, reverse ion exchange type. As all the groundwater samples with $Na+$/ $Cl-$molar ratio less than one or nearer to one and halite dissolution is responsible for sodium dominance in groundwater of the small coral island of Amini. The rock water interaction played minimum role in the evolution of water chemistry while evaporation process played major role during PRM and PSM. The chloro alkali indices for cations (CAI-1) and anions (CAI-2) are negative in the samples indicating the ion exchange between $Na+$– $K+$ in water and $Ca2+$– $Mg2+$ in rocks. The irrigation suitability revealed that Water samples are suitable for irrigation on almost all types of soil.

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