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Groundwater Resources Appraisal in the Tropical Coral Island of Kalpeni, U T of Lakshadweep, India

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Abstract

Groundwater resources appraisal in the Tropical Coral Island of Kalpeni, U T of Lakshadweep, India has been carried out by studying general hydrogeological conditions, hydrochemistry, evolution of ground water and the management of ground water resources. In the Island of Kalpeni ground water occurs under phreatic condition and is a thin lens floating over the saline water and coral sands and coral limestone form the principal aquifers. As the fresh water floats over saline water, it has got hydraulic continuity with sea water. Ground water is developed by open dug wells and to a limited extent through shallow filter point wells and the depth to the water level (DTW) in the Island varies 1.31 to about 2.9 mbgl and the depth of the wells varies from 1.9 to 3.5mbgl. The DTW is highly influenced by the tides. The base map of Kalpeni and various layers were prepared by using Map Info 6.5 techniques and in the ground water resource of Kalpeni has been computed based on the methodology recommended by the GEC 1997. The pre- and post-monsoon ground water samples collected from shallow aquifers (dug wells) in polyethylene bottles and analyzed for pH, EC, F^-, Cl^-, NO^{3-}, HCO^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+ as per standard procedures (APHA, 1995) and the in-situ measurement of electrical conductivity and pH carried out by using EC and pH meters. The ground water in the Island is generally alkaline and EC varies from 380 to 1204 micromhos /cm 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 Pre-monsoon groundwater samples of different areas of Ca-Mg-Cl Type and post monsoon $Ca-HCO_3$ Type and recharge has played major role in the evolution of ground water. The hydrochemistry is mainly controlled by evaporation, partly influenced by water–rock interaction and aquifer material.

Keywords

Phreatic, Ghyben-Hertzberg Relation, Chadha’s Diagram, Hydrograph, Hydrochemical Evolution

1. Introduction

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 300 km, consists of 36 coral atoll Islands (with low elevation above mean sea level) and many sunken banks, open 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 limestone. Kalpeni Islands have a delicate ecosystem with very limited fresh water resources. Though the Islands receive high rainfall, the lack of surface storage and the limited 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 allows mixing of freshwater with sea water and due to the thick population 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 development and management of ground water resources are needed to be scientific and integrated approach for solving present problems and future planning and delicate balance existing between fresh water resources and saline water must be maintained. Any disturbance to the equilibrium will lead to salinity. It is to analyze the present water demand based on recent population and other related data with the present climatological, rainfall and soil patterns and geomorphology of the Islands and their influence to ground water. It is to understand the present ground water scenario and reassess the groundwater resource in terms of quantity and quality. Further it is recommending different types of artificial recharge method suitable to different areas of geomorphic units. This is to propose and recommend the necessary scientific guidelines to the local administration to conserve protect and improve the ground water resources. The small Island hydrogeological studies were carried out many authors at international and regional levels. These include Barker (1984) on Freshwater – Saltwater relation, Frank (1984) groundwater recharge, storage and development on atoll Islands, Chapman (1985) the use of water balances for Water Resource Estimation with Special Reference to Small Islands, Dale et al(1986) Coral Island Hydrology, UNESCO (1991) on Hydrology and Water Resources of Small Island, Fackland (1992) Review of Ground water Resources of Home and West Island, Cocos (Keeling) Islands, Furness and Gingerich (1993)Estimation of Recharge to the Fresh water Lens of Tongatapu, Kingdom of Tonga, Ajaykumar and Ramachandran (1996) Resistivity survey for describing the fresh water lenses of Agatti atoll, Lakshadweep, Ajaykumar et al (1995) Groundwater resource potential in the union territory of Lakshadweep, Mondal et al (2009) Appraisal of groundwater resources in an Island condition, Revichandran et al (2001) Monitoring beach stability and littoral processes at Androth and Kalpeni Islands, Lakshadweep. The present study on Ground water resource and development potential of Kalpeni Island, U T of Lakshadweep is an attempt to highlight the various parameters affecting water resources of the Island of Kalpeni, water management aspects and ground water scenario of these small Islands based on various hydrogeological information gathered during hydrogeological surveys including the participatory water level monitoring among various Islands of Lakshadweep.

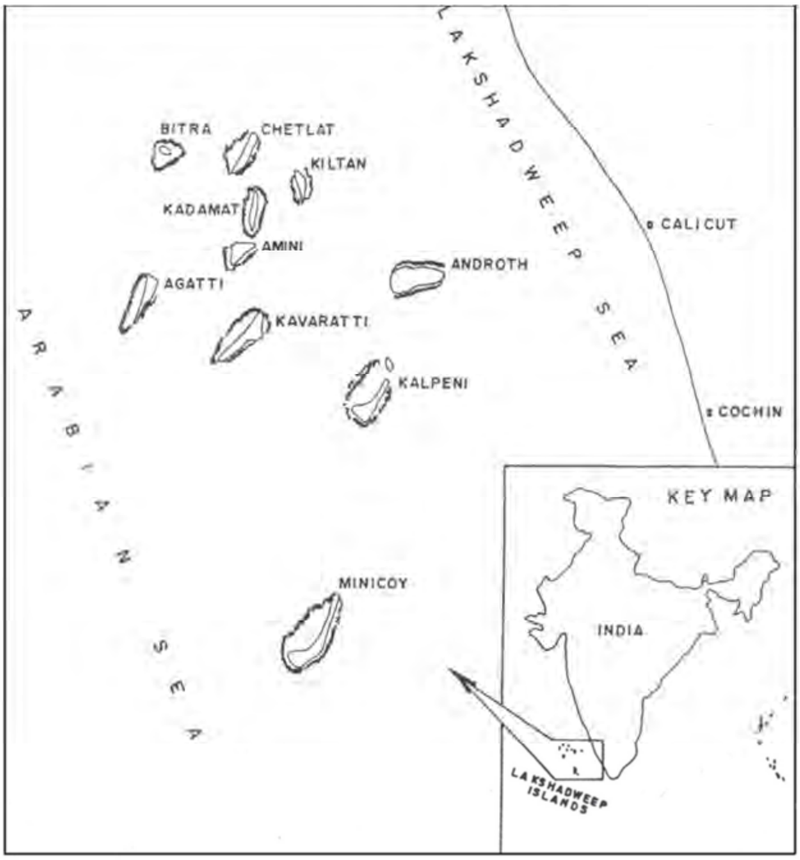

Figure 1. *Location Map of Kalpeni and other islands among Lakshadweep Islands.*

2. Study Area

U.T. of Lakshadweep (LD) 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 Islands Agatti, Kavaratti, Amini and Androth are the important and bigger size than others. The Bitra Island is a very small one, the residence of tourist staff. Kalpeni is on the east central part of the group and is in the southernmost part of the group and far away from the other Islands. Kalpeni is on the east central part of the group and located in the southernmost part of the group and far away from the other Islands. It has three satellite islands named Tilakkam, Pitti, and Cheriyam. The island is 2.8 Km in length and 1.2 Km in width with Cheriyam Island on the north, and Tilakkam & Pitti on the south-western side of the island. It lies between 10°05’ north latitude and $73^0 39$’ east longitude. The location map of LD Islands including Kalpeni Island is compiled (Figure 1). 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 geographical location details of Lakshadweep Islands are compiled (Table 1). Coral Islands are 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 a substance resembling limestone, 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). The coral reef is composed of calcareous and material derived from atoll and has very high % of $CaCO_3$ (87%). The beach rock consists of moderately well cemented calc arenites. The beach sediments of lagoon consist of various types of coral material of fine sand to cobble size. Although overall geology of an atoll is interesting, its significance is limited to few meters from mean sea level. 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. If the fresh ground water flux is high the transition zone will be thin. In small Islands due to high permeability almost all the rain falling onto the ground seeps below and a part about 7.15%of the rainfall is intercepted and evaporated before reaching the ground.

Table 1. *Salient features of Kalpeni.*

#	Item	Detail
1	Latitudes	10° 03' and 10° 07' N
2	Longitudes	73° 37' and 73° 39' E
3	Total geographical area	2.79 sq.km
4	Population (as per 2011 census)	4319
5	Average annual rainfall	1600 mm
6	Annual range of temperature	25 - 30°C
7	Major geological formation	Coral
8	Net ground water availability	0.16 MCM/Yr.
9	Stage of ground water development	50 %
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	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

3. Materials and Methods

The base map of Kalpeni and various layers were prepared by using Map Info 6.5 techniques and in the ground water resource of Kalpeni 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 utilization = 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 25 000 – 35000 sq. km 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) in polyethylene bottles and analyzed for pH, EC, F^-, Cl^-, NO^{3-}, HCO^{3-}, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+ as per standard procedures (APHA, 1995) and the in-situ measurement of electrical conductivity and pH 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 Fritz and Yamamura (1955) and Haartz et al (1979); 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 (Huh et al. 1998). The analytical precision was such that the ion charge balance was little above ±5% forth samples. The quality of the analysis was measured by standardization using blank, spike, and duplicate samples. The hydro chemical characteristics of ground water of shallow aquifers of the area have been briefly discussed.

The various hydrogeological aspects in the small Island of Kalpeni, LD islands are discussed in detail and as the Inland and small Island features are different comparison between Inland and Small Island features are compiled (Table 2). The major influences on the small Islands hydrological characteristics are climate, humidity, temperature, evapotranspiration; physiography, hydrogeological aspects, soil, vegetation, population and human interference are also discussed.

4. Results and Discussion

Table 2. *The comparison between inland and small island features.*

#	Controlling Factors	Inland	Island
1	Lithology	Crystallines, Sedimentaries, met sediments, lithified rocks	Coralline sand and coral lime stones
2	Geomorphology	Coastal plains, mid lands and high ranges	Low lands, plains and sand dunes
3	Drainage	Perennial surface water bodies and drainage	Surface water bodies and rivers generally absent or are ephemeral.
4	Meteorology	Tropical humid climate, average RF500-3500mm	Tropical humid average RF 1500-2500mm
5	Infiltration	About 10-25%of RF	About 70-85%RF
6	Proximity to water bodies	Limited	Surrounded by saline water on all sides
7	Aquifer geometry	Well defined litho units	Not well defined by coral colonies & eustatic changes
8	Ground water	Phreatic, semi-confined to confined	As lens, in hydraulic continuity with sea water
9	Depth to water table	Deep, beyond root penetration zone	Shallow, within root penetration Zone
10	Tidal influence	Limited	Highly influenced by tidal fluctuations
11	Effect of over draft of ground water	Depletion in water levels and dries up	Upcoming of saline water from bottom
12	Effect of recharge	Water level rises proportionately	Fresh water lens expands &fractional rise in levels
13	Quality change with time	No marked change	Improves during high tides and monsoon, deteriorates during summer.
14	Water level fluctuations	0.5-8.0 m fluctuation between pre- and post-monsoon	Less than a meter between pre- and post-monsoon
15	Pumping tests	For determining aquifer parameters	Limited applicability as it is highly influenced by lens readjustments & tides
16	Ground water estimation	By water level fluctuation rainfall recharge or chloride budgeting	By water balance or chloride budgeting
17	Ground water potential	Higher the permeability, higher the potential	Lower the per permeability, higher the potential

4.1. Climate

The climate of a small Island is one of the major influences on the availability of naturally occurring freshwater resources (UNESCO, 1991, Hay 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 temporal variation is usually high in small Islands whereas the spatial variation is a function of the Island physiography. The maximum, mean and minimum annual rainfall on Minicoy for the period 1961-91 are respectively 2634 mm (1961), 1555 mm, and 945 mm (1980). The standard deviation is 350.9 and the coefficient of variation is 23%. The status of extreme annual rainfall and the frequency of annual rainfall are given in Table 3&4.

Table 3. *Status of Extreme Annual Rainfall among Lakshadweep Islands.*

Station	Highest Annual % of Normal & Year (mm)	Lowest Annual % of Normal & Year (mm)	Heaviest in 24 hrs	
			Amount (mm)	Date
Minicoy	127 (1902)	64 (1939)	224.9	8.12.1965

Table 4. *Frequency of Annual Rainfall.*

Range in mm	No. of Years	Range in mm	No. of Years
Minicoy (Data 1901 - 1950)			
1001 - 1100	1	1601 -1700	11
1101 - 1200	1	1701 - 1800	1
1201 -1300	3	1801 -1900	5
1301 -1400	2	1901 - 2000	3
1401 - 1500	6	2001 - 2100	3
1501 - 1600	6		

4.1.1. Humidity

The Humidity is high throughout the year and is generally higher in the morning hours compared to the evening hours. 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.

4.1.2. Temperature

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.

4.1.3. Evapotranspiration

It has a vital role on the hydrological cycle of tropical small Islands. 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. The Kalpeni Island is invariably low Island with ground elevation above mean sea level rarely going up to 6m. There are no streams or major surface water bodies in the Island. 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. PET is high due to shallow water table conditions.

4.2. Physiography, Soil, Vegetation and Human Impact

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 eastern flanks of this ridge appear to be steeper compared to the western portion. It has got many gaps, the prominent being the Nine-degree channel. Generally, in the Islands the atolls are widest on the South-Western side. The growth of the reef might have been facilitated by the continuous supply of nutrients. Echo sounding on the reefs of these atolls show that the first break in the profile of the reefs occurs at a depth of about 4-8 m, which extends to about 12 m on the south-west windward reef representing a wave-cut platform of Recent origin. The depth falls off steeply to about 50 m and in several Islands before the depth is reached, well-marked submerged terraces are observed at 7-12, 15, 21-36 and 43-47 m depths. It is considered that these terraces were cut during the Pleistocene period when the sea level was lower.

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 fine-grained soils with high retention capacities favor evapotranspiration, thus reducing recharge. Coarse soils with low water retention capacities allow rainfall to quickly infiltrate below the root zone decreasing evapotranspiration losses but increasing recharge.

The vegetation of LD Islands consists of coconut trees and a range of bushes and grasses. This vegetation is adapted to the local climatic conditions and receives adequate moisture for growth from rainfall and it rarely requires irrigation. Depending on the depth to the water table (DTW) and type of vegetation direct transpiration losses from the aquifer can increase. 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 both the availability of freshwater and water quality. In LD Islands consumption of water for domestic purposes is a major component in the water balance. Now a day with the popularization of pump sets the domestic consumption has increased significantly.

4.3. Geomorphology

The Kalpeni Island is flat, rarely rising more than two meters, and consists of fine coral sand and boulders compacted into sandstone. All the LD Islands are of coral origin and some of them like Minicoy and Kalpeni are typical atolls. The height of the land above msl is about 1-2 m.

The Islands on these atolls are invariably situated on the eastern reef margin except Bangaram and Cheriyakara which lie in the centre of the lagoon. The atolls show various stages of development of the Islands, the reefs at Cheriya Panniyam, Perumalpar and Suheli represent the earliest stage while Kalpeni is in an advanced or mature stage of development. A gradual accretion of sediments by this process has led to the growth of the Islands. Even the atolls where the Islands are not yet fully developed (Suheli, Valiyapanniyam and Bitra) sandy bays occur on the eastern reef margin.

4.4. Geology

The Kalpeni Island lies on a roughly north south aligned submarine ridge known as the Lakshadweep-Chagos ridge. Each atoll consists of a lagoon with an Island at the centre. However, in Androth Island the lagoon is absent and is oriented in an east-west direction unlike most of the other Islands which are oriented roughly in north-south direction.

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. The seismic profiling carried out by the ONGC in 1965 in the Lakshadweep Sea and the seismic survey conducted by a Soviet Research Vessel indicates sediments of 1.5 to 2.0 km. thick underlain by volcanic rocks. In the year 1972 the drilling vessel Glomar Challenger drilled a bore hole down to 411 mbgl on Lakshadweep ridge which is 1764 mbmsl in the Nine Degree channel. The sedimentary formations of Pleistocene to Upper Palaeocene were encountered in this bore hole down to a depth of 300 mbgl and below this depth volcanic tuffs were encountered.

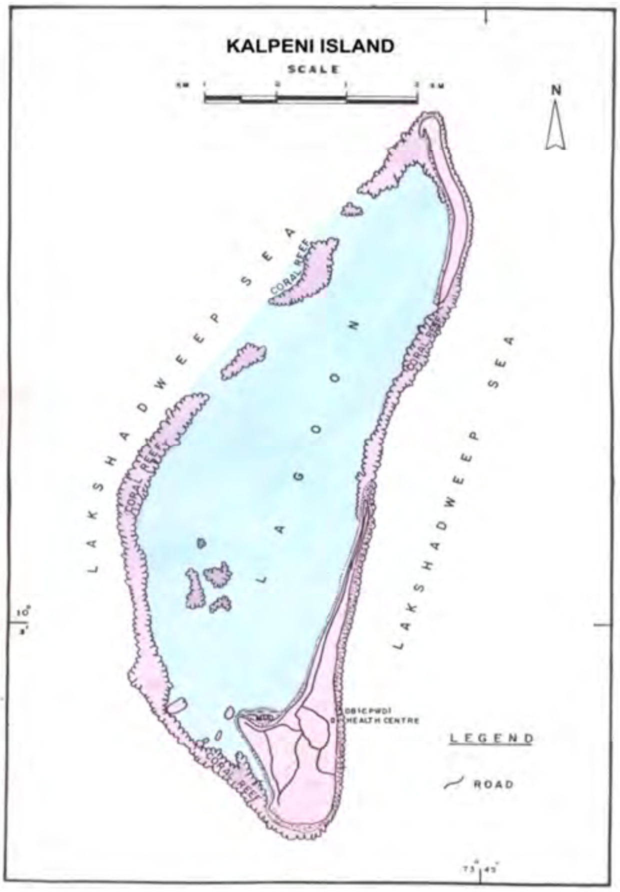

Figure 2. Location Map of Kalpeni (Hydrogeology) Island.

4.5. Hydrogeology

The Kalpeni 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. The hard pebbles of coral limestones along with coral sand are generally seen. Ground water occurs under phreatic condition and is a thin lens floating over the sea water. The coral sands and the coralline stone form the principal aquifer. The Ghyben-Herzberg relation determines the depth of the interface between fresh water and sea water. The Ghyben- Herzberg relation is applicable when the water is above mean sea level, it slopes towards the periphery and it is in hydraulic continuity with seawater. The position and the thickness of the interface / interface zone mainly depends on the diurnal tidal fluctuation, seasonal water level fluctuation, ground water recharge and draft, dispersion of the flow pattern, molecular diffusion and so on. Ground water is developed by open dug wells and to a limited extent through shallow filter point wells. Hydrograph for Kalpeni Island is prepared using the mean water level in selected wells and is compiled (Figure 3a &b).

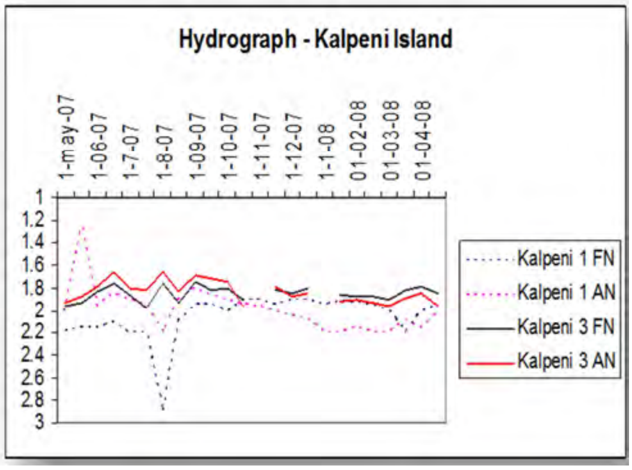

Figure 3a. Hydrograph of Kalpeni Island.

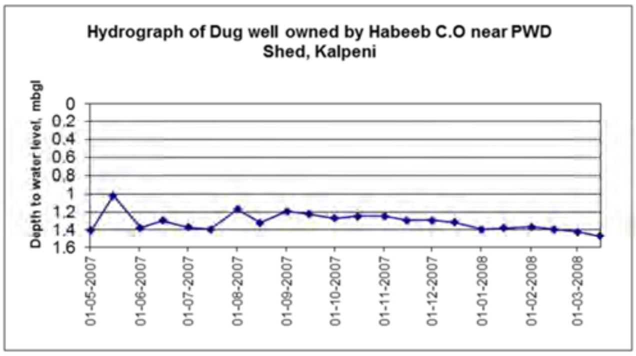

Figure 3b. Hydrograph of Kalpeni Island.

4.5.1. Water Level Scenario of Kalpeni Island

The water level data of monitoring wells in Kalpeni Island is compiled (Table -5) 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. The hydrogeology of Kalpeni Island is compiled (Figure 4).

Table 5. *Depth to the Water table (mbgl) Data of Monitoring wells in Kalpeni Island.*

	PWD Shed, Kalpeni 1		S.B School, Kalpeni 2		Ponnempalli, Kalpeni 3	
	FN	AN	FN	AN	FN	AN
1-05-07	2.18	2	1.93	1.88	1.97	1.94
15-05-07	2.15	1.25	1.87	1.82	1.93	1.88
1-06-07	2.15	1.96	1.70	1.67	1.83	1.79
15-06-07	2.11	1.85	1.72	1.80	1.76	1.66
1-7-07	2.2	1.9	1.82	1.90	1.86	1.81
15-7-07	2.2	1.95	1.92	1.84	1.98	1.82
1-8-07	2.9	2.2	1.71	1.65	1.76	1.65
15-08-07	2.1	1.9	1.89	1.73	1.94	1.83
1-09-07	1.95	1.8	1.35	1.31	1.75	1.69
15-09-07	1.95	1.86	1.45	1.38	1.82	1.71
1-10-07	2	1.9			1.8	1.75
15-10-07	1.91	1.95			1.9	1.96
1-11-07	1.9	1.96				
15-11-07	1.95	2			1.82	1.79
1-12-07	1.9	2.05			1.84	1.87
15-12-07	1.91	2.08			1.8	1.85
1-1-08	1.95	2.2				

	PWD Shed, Kalpeni 1		S.B School, Kalpeni 2		Ponnempalli, Kalpeni 3	
	FN	AN	FN	AN	FN	AN
15-01-08	1.92	2.2			1.86	1.92
01-02-08	1.93	2.16			1.87	1.91
15-02-08	1.95	2.2			1.88	1.93
01-03-08	2	2.2			1.91	1.97
15-03-08	2.2	2.1			1.82	1.89
01-04-08	2	2.15			1.79	1.85
15-04-08	1.95	2			1.85	1.96

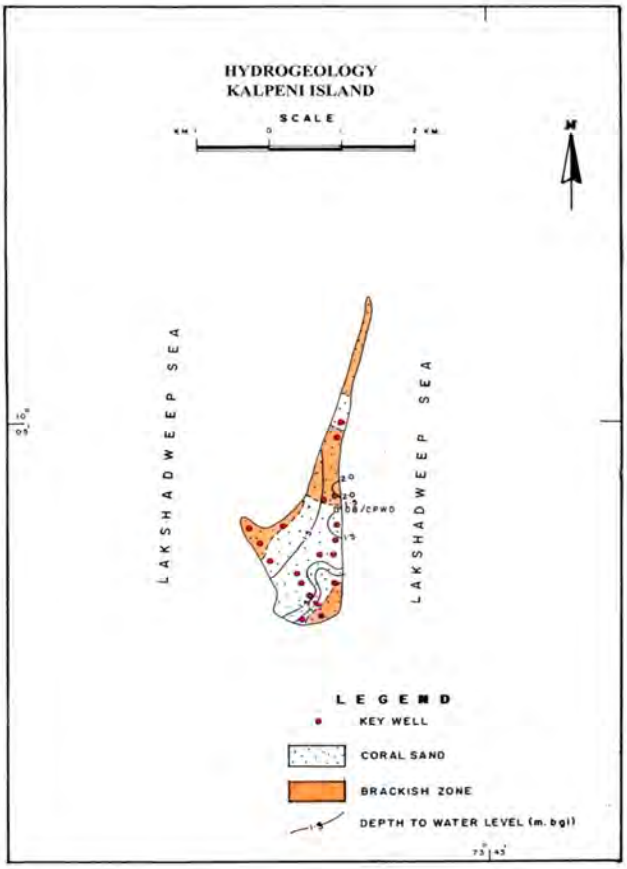

Figure 4. *Hydrogeology of Kalpeni Island.*

4.5.2. Ground Water Resources

Ground water draft is mainly used for domestic needs only. 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 Evapotranspiración, R Recharge to ground wáter and dV change in soil moisture. 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 Kalpeni has been computed based on the methodology recommended by the GEC 1997 given in Table 6.

Table 6. *Ground water resources of Kalpeni.*

#	Annual components of water balance	Kalpeni
1	Population	4321
2	Area (sq.km)	2.28
3	Total Resource (water surplus MCM)	1.08
4	ET loss from trees for 8 months (MCM)	0.33
5	Water loss due to outflow to sea {10% of (3) (MCM)	0.22
6	Buffer zone for reserve during delayed or lesser monsoon period {10% of (3) (MCM)	0.22
7	Balance available resource(MCM)	0.32
8	Domestic draft (100 lpcd) (MCM)	0.16
9	Gross annual draft(MCM)	0.16
10	Ground water balance(MCM)	0.16
11	Stage of development	50%
12	Category	Safe

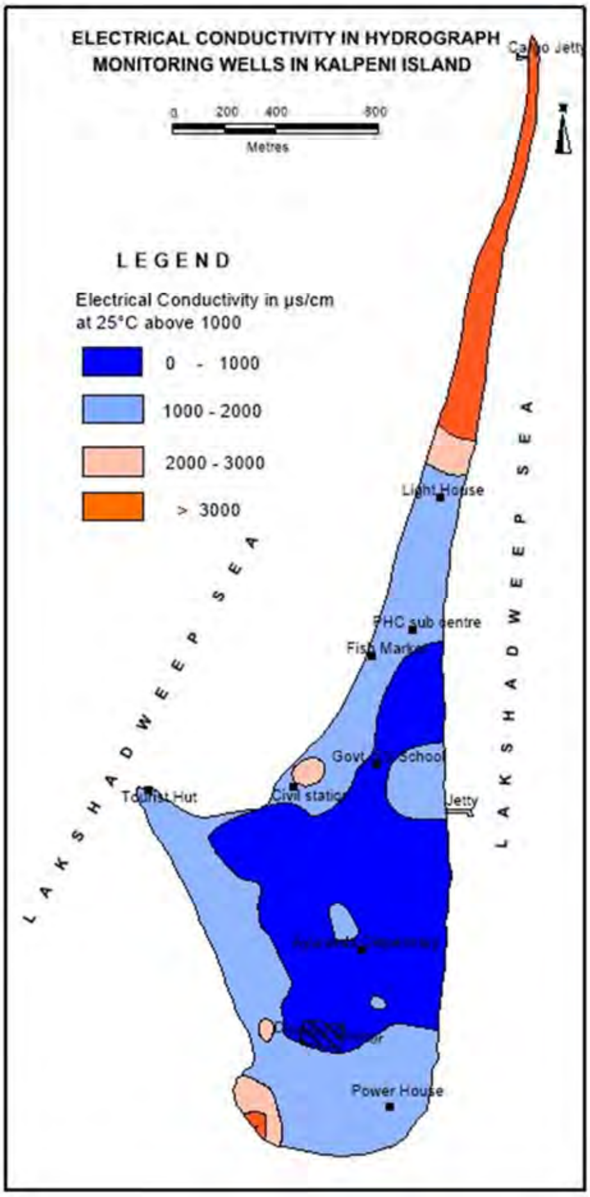

Figure 5. *EC contours of Kalpeni Island.*

4.5.3. Quality of Ground Water

The ground water in the Island is generally alkaline with few exceptions. The electrical conductivity ranges from 380 to 1204 micromhos /cm at 25°C and the EC contours are plotted (Figure 5). Higher concentrations of the dissolved solids are generally seen along the periphery of the Island and close to pumping centers. The factors affecting the quality are tides, ground water recharge and draft and pollution from human and animal waste, oil spills and fertilizers.

The geochemical evolution of the ground water samples of the area (pre- and post-monsoon 2010) has been examined. The groundwater of different geological horizons can be classified depending upon their ionic strength of select anions and Soltan (1998) categorized ground water based on the meq/l content of Cl^-, SO_4^{2-}, and HCO_3^-. The water is Normal Chloride type if $Cl^-$is <15 meq/l, Normal Sulphate type ifSO_4^{2-} is<6 meq / land Normal Bicarbonate type if HCO_3^- varies between 2 and 7 meq/l. Distribution of ground water samples based on the Soltan's classification has indicated that all the samples of pre and post monsoon 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 (Raghunath1982;Gopinathand Seralathan2006). 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, 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+- SO4 − 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+-SO_4^{2-} type and shallow meteoric percolation type.

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 ground water 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 halite dissolution is responsible for sodium dominance in groundwater.

(1). Chadha's Diagram

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 pre- monsoon season indicated distribution within the field 6 and that of post monsoon Field 5 (Figure 6a&b). The pre- monsoon groundwater samples of different areas of Ca-Mg-Cl Type and the alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. In the case of pre- monsoon samples (Ca+Mg) > (Na+K)> ($Cl+SO_4$)> (CO_3+HCO_3). As the water samples falls under Field II, they are of Ca-Mg-Cl Type and Reverse Ion exchange has played role in the genesis. It is to be noted that as the post monsoon samples fall under Field I of Chadha's diagram, they are of are of Ca-HCO3 Type and recharge has played major role in the genesis. In the case of post monsoon samples Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively and (Ca+Mg) +(CO_3+HCO_3)>(Na+K) +($Cl+SO_4$). 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 Mg+ and anions CO_3^-, HCO_3^- and Cl^- dominate the ionic concentration in groundwater.

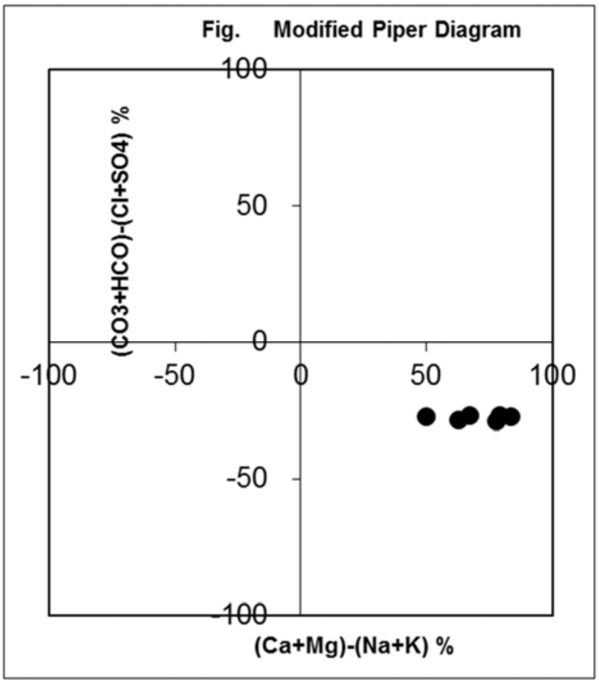

Figure 6a. *Modified Piper Diagram-Pre- monsoon, 2010.*

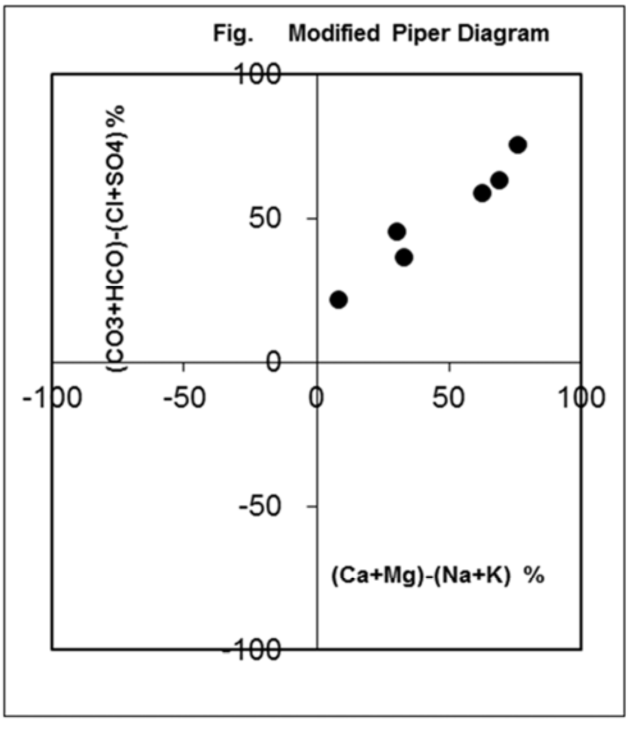

Figure 6b. *Modified Piper Diagram-Post monsoon, 2010.*

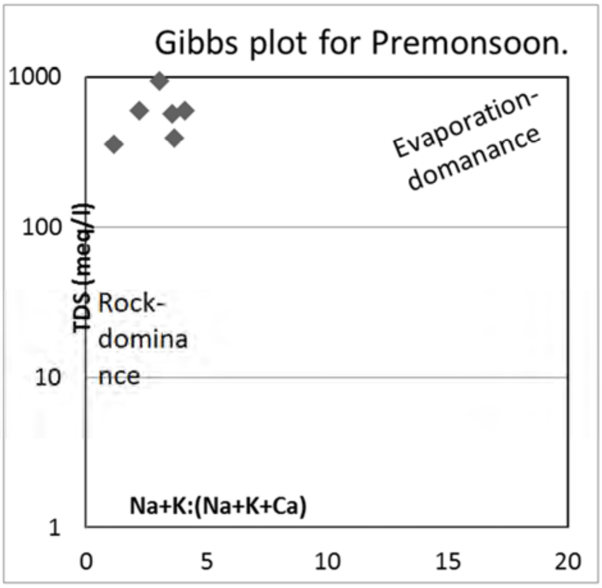

Figure 7a. *Gibb's plots for cation - Pre- monsoon, 2010.*

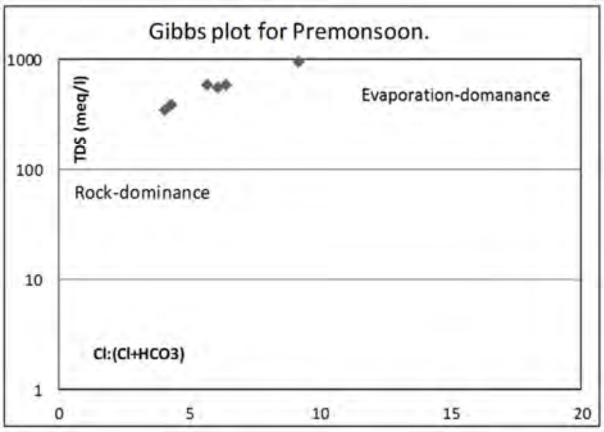

Figure 7b. *Gibbs plots for anion - Pre- monsoon, 2010.*

(2). Hydrogeochemical 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 evaporation dominance field during the both seasons and for the pre-monsoon is compiled (Figure 7a&b). The evaporation played major role in the evolution of water chemistry, which was partly influenced by water–rock interaction and aquifer material (Geological location is one of the most important factors affecting the groundwater quality (Beck etal1985).

4.5.4. Management of Ground Water Resources

The groundwater is the prime source of freshwater for all the domestic needs of the population. In these Islands the fresh groundwater occurs as a thin lens floating over the saline water. The size, shape and thickness of the freshwater lenses expand and contract seasonally depending on the intensity of rainfall and draft and there is no equitable distribution. Hence, even though the stage of development of freshwater of a given Island is within the safe limits, it may not have freshwater availability throughout the Island at least during the summer months. To tide over the situation in some of the Islands piped water supply is resorted to with groundwater from the freshwater part of the lens as the source. Heavy draft from a point source induces up coning of saline water from below and destabilizes the lens configuration. Proper management of the resource is essential to tide over such situations. Hence, to meet the ever-increasing freshwater demand in the Island, a scheme is prepared for meeting the freshwater requirements of individual Island, with four components viz. groundwater, roof top rainwater harvesting, desalination using waste heat and solar desalination.

4.6. Groundwater Potential

Dynamic groundwater potential is worked out based on the water surplus available on a daily water budgeting done for thirteen years (from 1987 to 1999) and the data is compiled (Table 6). The average of this water surplus was taken for computations. The rainwater recharge in freshwater lens areas and brackish areas were separately worked out for the water surplus. In brackish areas the groundwater turns brackish during summer months and freshwater is available for about four months a year. Draft by vegetation was estimated by appropriation of the coconut trees based on the density in the Island. The deep-rooted coconut plantation is one of the major consumers of groundwater. The requirement for plants for eight non-monsoon months a year barring monsoon month is accounted for the total freshwater requirement of each of the Islands is worked out for the projected population for the year 2025 based on the decadal growth rate of population and domestic needs of 401pd. The fresh water available in the brackish zone is not available for domestic consumption except for the monsoon season as the same is occurring as a very thin lens and is extracted by the plants. In brackish water area, about 20 percent of the recharge is available for consumption during the monsoon season. About 10 percent of the available freshwater in the lens is lost by mixing due to tidal fluctuation.

As per correlation worked out, for a 10 percent decrease in annual rainfall the water surplus will be reduced by 23 percent and a 30 percent decrease in annual rainfall from the 1577mm will result in 68 percent reduction in the water surplus. This means that the dynamic resource is very sensitive to the rainfall and hence there should be a standby system to meet the exigencies. To meet the shortfall in freshwater supply, alternate sources like roof water harvesting, desalination using waste heat and solar desalination must be tapped.

4.7. Roof Top Rainwater Harvesting

The rainfall distribution pattern of the Islands show that the average monthly rain fall 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. This 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.

Table 7. *Chemical analysis data of ground water in Kalpeni.*

Pre - monsoon 2010																	
#	**pH**	**EC**	**TH**	**Ca**	**Mg**	**Na**	**K**	**CO3**	**HCO3**	**Cl**	**SO4**	**NO3**	**F**	**SAR**	**RSC**	**TDS**	**%Na**
1	8.35	432	162	3.2	37	14	0.9	2.4	188	188	10	1.1	1.4	0.48	-0.04	351	16.47
2	7.83	556	235	52	26	9.7	0.4	0	311	311	9.1	1	1.2	0.27	0.36	566	8.4
3	7.63	567	245	62	22	13	0.5	0	329	329	6.7	1.1	0.8	0.36	0.48	600	11
4	8.07	380	160	53	6.3	8.6	0.7	0	202	202	14	1.4	0.6	0.30	0.14	388	11
5	8.39	768	265	24	50	40	1.8	12	287	287	43	1	0.7	1.07	-0.21	597	25
6	8.06	918	435	40	81	43	3.9	0	500	500	30	1.2	0.9	0.90	-0.47	950	19
Min	7.63	380	160	3	6	9	0	0	188	188	7	1	0.57	0.27	-0.47	351	8
Max	8.39	918	435	62	81	43	4	12	500	500	43	1	1.35	1.07	0.48	950	25
Mean	8.06	604	250	39	37	21	1	2	303	303	19	1	0.92	0.56	0.04	575	15
SD	0.29	204	101	22	26	16	1	5	112	112	15	0	0.31	0.34	0.36	213	6
Post monsoon 2010																	
#	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	SAR	RSC	TDS	%Na
1	7.8	600	205	52	18	50	0.7	0	262	46	15	1	0.5	1.52	0.21	420	35
2	7.63	605	270	82	16	17	0.2	0	390	21	14	0.1	0.6	0.45	0.98	424	12
3	8.08	432	168	42	15	14	0.1	0	226	21	12	0.1	0.6	0.47	0.37	302	15
4	7.87	580	230	64	28	28	1.6	0	336	39	16	1.6	0.4	0.73	0	406	19
5	8.04	1204	390	78	47	88	2.8	0	549	114	46	0.3	0.4	1.94	1.23	843	33
6	8.35	1016	270	30	47	99	10	0	390	121	33	2	0.6	2.63	1.03	711	46
Min	7.63	432	168	30	15	14	0.1	0	226	21	12	0.1	0.37	0.4	0.0	302	12
Max	8.35	1204	390	82	47	99	10	0	549	121	46	2	0.58	2.6	1.2	843	46
Mean	7.962	740	255.5	58	28.5	49.3	2.57	0	359	60.3	22.7	0.85	0.51	1.3	0.6	518	27
SD	0.251	300	76.64	20.4	15.06	36.6	3.78	0	115	45.4	13.7	0.82	0.09	0.9	0.5	210	13

4.8. Desalination Using Waste Heat

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 utilizing the heat recovery system for every 100 lts of diesel used.

At the rate of 10 lpcd, freshwater supply can be assured for the entire projected population in the saline zone area in these Islands. At the rate of 40 lpcd 50 percent of the projected population in the saline zone area of Kalpeni Island respectively can be covered. However, the performance of the scheme must be evaluated for 2-3 years before embarking upon the scheme on a large scale. The running cost for these systems is negligible, as it is a by-product of power generation. The available water, being very low in dissolved solids, can be used for diluting the brackish groundwater of these Islands. The existing delivery system may be used to supply water through the pipelines to the brackish water area.

4.9. 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 if the water produced by waste heat recovery system is not sufficient.

4.10. Integrated Water Management Schemes

It is observed from Table 1 that in many of the Islands there are large areas under both freshwater lens as well as brackish water lens. Hence it is important to have a proper management scheme to meet the demands of different areas in these Islands. Wherever the fresh water lens is stable it makes the prime source. However, the development of the same should be done judiciously with slow and steady draft so that there is no up coning of the saline water from below. 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, the radial wells consist of a central well with six to eight galleries (Figure 6). 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. Linear systems are probably the best approach on Islands with limited lateral extent, and where the freshwater zone is relatively small. On wider Islands, radial or cruciform patterns may be appropriate. Conduits should be laid at a level to prevent dewatering during low tides and saltwater intrusion during high tides or periods of peak freshwater use. These problems arise if the conduits are too high or too low. It is suggested that the inverts of conduits should be set at between 100 and 300 mbmsl depending on the head of water above mean sea level. No allowance for possible long-term sea level changes is suggested because of uncertainty of the magnitude of changes.

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. The studies further indicated that 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.

5. Conclusions

The Kalpeni Island is made up of coral limestones and coral sand and the ground water occurs under phreatic condition and is a thin lens floating over the saline water. The coral sands and the coralline stone form the principal aquifer. The major parameters controlling the hydrological characteristics of the Kalpeni island are climate (especially rainfall), humidity, temperature, evapotranspiration; physiography, hydrogeological aspects, soil, vegetation, population and human interference. The 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. The available resource is 0.32 MCM and the gross draft is 0.16 MCM. The stage of development of ground water in the island is 50% and comes under safe category of stage of ground water development. The ground water in the area comes under Normal Chloride type, followed by Normal sulphate type and concentration of salts in natural waters depend on the geology, environment, and movement of water and groundwater of the area comes under $Na+-SO_4^{2-}$ type and shallow meteoric percolation type. The groundwater of the area comes under $Na+-SO_4^{2-}$ type and shallow meteoric percolation type. The evaporation played major role in the evolution of water chemistry, which was partly influenced by water–rock interaction and aquifer material. As fresh groundwater occurs as a thin lens floating over the saline water various types of ground water regulatory measure and artificial recharge technique must be adopted.

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