Hurdles in Framing Groundwater Management Strategies in A&N Islands in the Aftermath of Tsunami

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Abstract: In spite of copious rainfall, complex geology and hydrogeology are mainly responsible for the formation of un-ubiquitous potential groundwater reservoirs in the Andaman and Nicobar islands. Dearth of good catchment is causing non-availability of surfacewater projects. Thus, development of ground water and its management in island situation has been a perennial problem in the archipelago. The research and development work have revealed good prospect of development of ground water through artificial recharge and conservation, watershed development through conjunctive water use and rainwater harvesting. There was stupendous impact of the 26.12.2004 killer tsunami and devastating earthquake (Magnitude of 9.3 in ritcher scale) on groundwater resources in the islands. Currently the groundwater availability, its assessment, development and management in post-tsunami is more tricky in the changed environment. To combat with this situation, a regular monitoring of hydro-geological environment would be highly necessary for successful construction of groundwater augmentation structures during the rebuilding period and to adopt right and site/ island specific recommendation keeping in view the harmony with ecology and forestry for environmental sustainability. In this regard the detailed knowledge on the pre-tsunami situation and the recent changes in hydro-geoenvironment would be imperative to arrive at successful implementation of the projects.

INTRODUCTION

The Andaman and Nicobar groups of islands receive on an average 3000 mm of rainfall annually. Rugged topography, steep slope, low infiltration capacity and close proximity of hill to sea disallow creation of potential groundwater reservoirs in major parts of the archipelago. Simultaneously favourable catchments, channel width, perenniality, occurrence of frequent deep and shallow focus tremors and above all the environmental regulations hinder formation of medium dam projects in the islands. However, because of localization of the Islands (6°N to 14°N) near the equator, the annual evaporation loss is also high and it is to the tune of 1500-1800 mm. Nearly for a decade it is being observed that in most of the years the rainfall is below normal and in the lean period (i.e., December to May) the islands receive scanty rainfall. This had been creating the evacuation or drying up of the surface water in the reservoirs.

For these reasons during the past fifty years irrigation system, as also dependable major drinking water supply projects, could not be developed in the islands. Extensive field studies carried out by the author and his colleagues (Kar, 2001, 2002, 2003, 2004, 2005, 2006; Adyalkar et al., 1981, Banerjee et al., 1988; Bhattacharya, 1997) in Andaman and Nicobar Islands, had unraveled the hydro-geological set up of the islands. The studies carried out by the author since 2000 has helped the A&N Administration to formulate and start water harvesting schemes for tapping the surplus runoff through multiple check dams, subsurface dams/dykes, tidal bar for augmentation of both drinking water and irrigated agriculture. Besides, these, the other suitable conservation structures like, ponds and wells were also successfully constructed in the islands to tap ground water and the bountiful rainfall. To augment the soil mass of the land and the fresh groundwater resources, the integrated Rural Development Plan envisaging provision for drinking water and irrigation along with fisheries and livestock development through construction of water development projects (i.e, wells, ponds, check dams), islands were posing to achieve sustainability in drinking water supply, irrigation and agriculture. The pervasive devastating tsunami and earthquake on 26.12.2004 had damaged the land and water resources in many of the islands to a great extent. Amongst the 572 islands in the A & N Islands, only 36 were inhabited. Because of recent devastation by tsunami, the inhabitants of Chowra, Bambooka, Trinket, Kondul, Pulomilo and Little Nicobar are evacuated to Teressa, Kamorta and Great Nicobar (Campbell Bay) respectively. Recently the Chowra people have returned to their island from Teressa. Out of 50,000 hectares of land under agriculture, nearly 10,837 hectares were damaged by tsunami as well as by the permanent saline water ingress. In many islands due to the land subsidence (Jain et al., 2005), the agricultural lands are ingress by saline water. The earthquake has hit the water resources in the entire A & N Islands. In several islands, especially in southern group of islands and in south Andaman and Little Andaman, during tsunami the saline water has contaminated the freshwater resources. Government of India is taking utmost interest to rebuild the islands along with sustainable drinking water supply after the disaster. To rehabilitate agriculture in A&N islands, Ministry of Agriculture has taken a very big plan under Rajiv Gandhi Rehabilitation package, where development of water resources is a prime component for a sustainable agricultural production. Hence, strategies adopting an integrated water resources development plan incorporating tapping of groundwater, rainwater harvesting and watershed development are formulated (Kar, 2005, 2006). It is observed that after the recent calamity, qualitatively and quantitatively there has been some change in the fresh groundwater resources.

LOCATION

The Andaman & Nicobar Group of Islands are forming an arcuate chain in the Bay of Bengal within the geographical coordinates of 6°N to 14°N latitude and 88°E to 92°E longitude. There are 572 small to large picturesque islands, which are situated nearly 1190 ms. from the Indian mainland (both from Chennai and Kolkata) and are approachable by air and sea routes (Fig. 1).

AVAILABILITY OF FRESH GROUND WATER IN THE ISLANDS

Fresh groundwater availability in island environment is always interesting and problematic as many of the islands around the globe are suffering from water supply problems and sea water ingress due to over development (CGWB, 1999; Virgilio et al., 2001; Woodhall, 1974; Peterson, 1972, 1993). Consequent with the rise in population of the islands since independence and its strategic importance, the demand of water has been increased by leaps and bounds. In spite of copious rainfall, the availability situation of fresh ground water as also surface water is a perennial problem. The calamity of 26th December 2004 has further aggravated the situation. Currently Government of India is taking up a rebuilding operation in the islands where arrangement of sustainable water supply is one of the main items. In the following sections various aspects of ground water in the islands, especially the development and management problems in the post-tsunami are discussed.

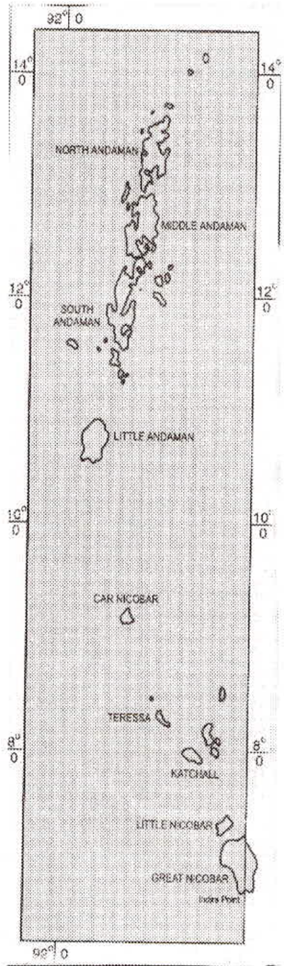


Fig. 1. Location map.

FACTORS CONTROLLING GROUND WATER AVAILABILITY

Climate and Rainfall

The islands enjoy tropical humid climate because of their location in equatorial zone surrounded by the Andaman Sea. Because of paucity of climatic data from all over the islands, many of the metrological parameters are described based upon the data collected from the IMD station at Port Blair. The relative humidity varies from 79% to 89%, wind speed varies from 7 km/hr to 10 km/hr while the maximum and minimum temperature fluctuate between 27 to 33°C and 21 to 25°C. Daily evaporation rate in the island is fairly high which cumulatively ranges from 1500-1800 mm per annum (Fig. 2). The islands are mostly discrete. The topography, vegetation, forestry as also the geographical localizations of the islands, for being situated in a slender chain of nearly 740 km length are responsible for a varied rainfall distribution (Figs 3, 4, and 5). Simultaneously for couple of decades, to accommodate the galloping migration of people to the islands, the harmony is considerably distributed. Authorized/unauthorized deforestation to make room for the huge population in the last few decades to the present time may be having some cumulative effect on the rainfall pattern. This can be quite evident from the rainfall record in the islands.

In the current decade the rainfall distribution has become highly whimsical and dwindling. Prior to 1990 the rainfall used to commence from 1st week of May every year. Now in some years it is receded to the 1st week of June as happened in 2001, 2002 and 2003. In 2002 the situation was so worsened that Dhanikhari dam dried up (Fig. 6) and the Port Blair town water supply was totally shattered. Fortunately in 2004 the rainfall in Andaman District has been close to normal. In 2005 the rainfall in Andaman district was fairly high (3774 mm) and in 2006 also the rainfall recorded till August indicates it may surpass the normal. However, the Tsunami devastated Southern group of Islands were not receiving appreciable rainfall in 2005 while in December '05 itself a copious rainfall was received in the southern district which caused week long water logging situation in Car Nicobar island. The normal rainfall of Port Blair is 3180 mm whereas the mean annual rainfall of Andaman

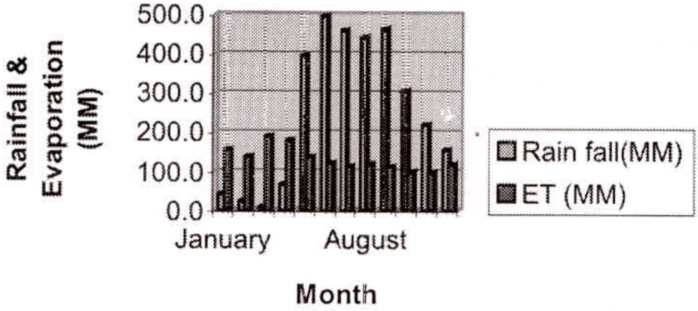


Fig. 2. Evaporation in Port Blair.

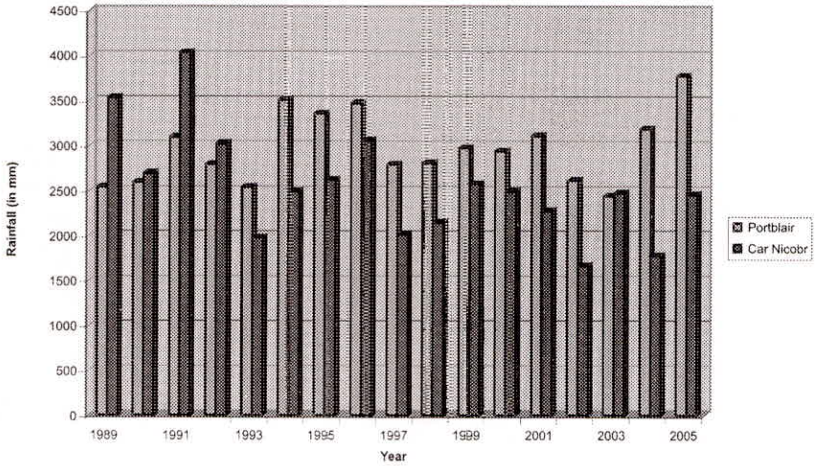


Fig. 3. Rainfall of Port Blair and Car Nicobar.

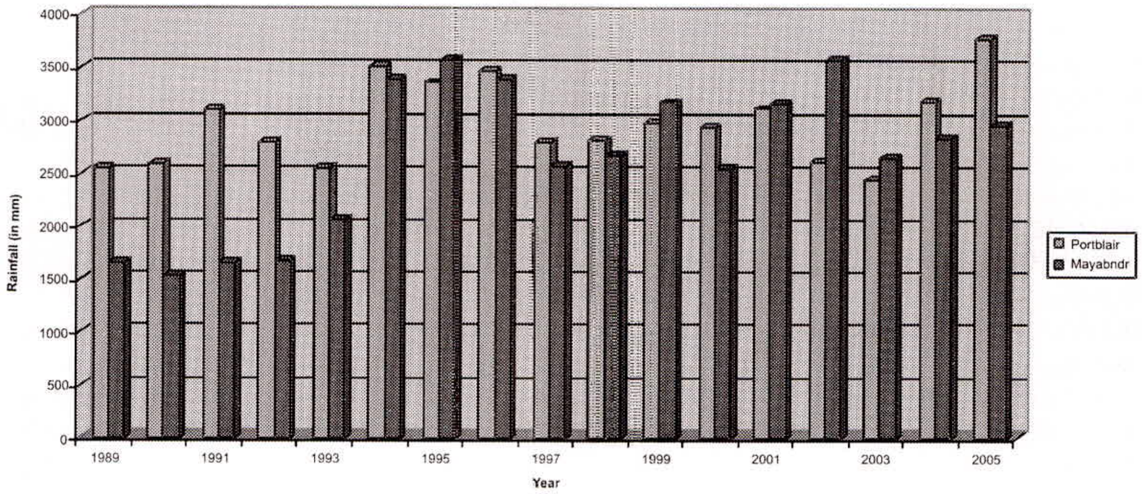


Fig. 4. Comparison of rainfall of Port Blair with Mayabunder.

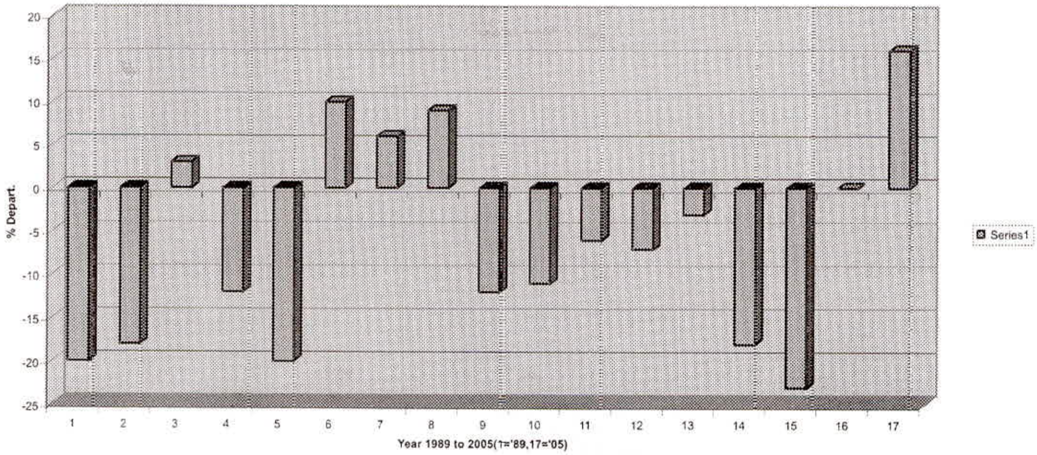


Fig. 5. Departure of Port Blair rainfall from normal.

and Nicobar districts are 2629.0 and 2624.0 mm respectively. In the islands the rainfall pattern is important for large-scale rainwater harvesting as also artificial recharge of ground water in specific areas.

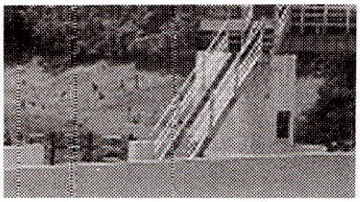


Fig. 6. Dried up Dhanikhari Dam, 2002.

Geomorphology

Geomorphologically the Andaman and Nicobar islands can be divided into three distinct units:

Fig. 7. Hill range near Billi-Ground Middle Andaman.

1. Low to moderately high and steep hill ranges (Fig. 7). These tracts generally act as the recharge areas for groundwater. However, fracture springs in the high altitudes form also pockets of free flowing discharge and form the main source of water supply in the Rural Andaman. A prominent North-South trending hill range of both the igneous and sedimentary rocks extends along the east coast from North Andaman to South Andaman. Numerous ridges in Great Nicobar Island represent the counterpart of this chain. Most of the islands are characterized by undulating and rugged topography. The highest peak in Andaman is the Saddle peak (732 m, amsl) in the N.Andaman, and Mount Thullier (642 m, amsl) in the Great Nicobar island.
2. Narrow intermontane valley. These are (Fig. 8) especially the discharge areas but lot of recharge also takes place through such units in the higher altitudes above msl.

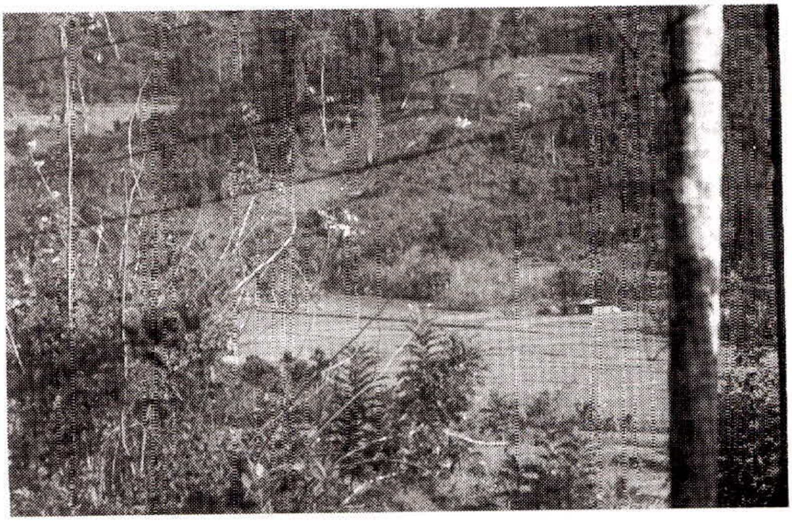


Fig. 8. Narrow intermontane valley near Rangat, M. Andaman.

3. Gently sloping slender coastal tracts with swamps. These are (Fig. 9) the discharge areas of ground water. The character of the coastal tract is dependent on the provenance/host rock in the upland, the size of the streams meeting the sea as also the geology of the country rocks in their courses and coastal geology. In general, well-sorted sand size particles are not abundant in the beaches. Good sandy beaches are available in the areas with good coral growth in the shallow sea and of course in the coral islands (atolls). In general, huge fresh water is discharged along the coasts of coral islands than in other inorganic sedimentary terrains in Andaman and Nicobar islands. The

Fig. 9. Slender coastal stretch near Middle Strait, S. Andaman.

coastal plain fringing the hilly terrain in South Andaman is 0.2 to 1.0 km wide with occasional coastal mounds, rocky shorelines, narrow sandy beaches and mud flats with mangroves. The narrow undulating coastal plain fringing the eastern coast is usually 0.2 to 0.5 km wide rising upto 10 m above the high water line with a rocky fractured shore line. It is nearly a flat in coral islands having width of 0.5 to 1.0 km.

Drainage

The islands are devoid of (Fig. 10) any big river system with vast catchment. However, a few perennial streams, such as Mithakhari, Protheropore nala, Burma nala, Pema nala, Karmatang, Betapur (Fig. 11), Korang, Rangat, Dhanikhari, etc. drain the Andaman group of islands. The Great Nicobar is the only island of the Nicobar group with five perennial rivers.

Originating from Mount Thulier, among them the Galathea river, is the longest and widest and flows southwards to the Galathea Bay. The general drainage pattern of the islands varies between dendritic to sub-dendritic. However, in some places in S. Andaman, rectangular drainage is also characteristic. However, the salinity ingress along the creeks are changed to a great extent after the tsunami, at least in the streams of the entire Nicobar district and the streams of Andaman district atleast upto Rangat area of Middle Andaman. The streams of north Andaman especially in Diglipur zone have declined in the tidal level after the disaster.

Fig. 10. Small nala near Nayagaon, Port Blair.

Fig. 11. Highly perennial Betapur nala near Swadesh Nagar, M.Andaman.

Geology

Geologically inorganic marine sedimentary group of rocks comprising shale, sandstone, grit and conglomerate; extrusive and intrusive igneous rocks (volcanics and ultramafics) and organic limestones (coralline atolls) occupy the entire geographical areas. Amongst these the inorganic sedimentary group is the most pervasive and occupies nearly 70% of the entire area of the islands. The Igneous group covers nearly 15%, while the rest 15% goes to the organic coralline (limestone) formations. All these rock formations are brought under tectonism because of their alignment in a tectonically active zone, evident from the occurrence of shallow and deep focus earthquakes in the islands. The current devastation of tsunami is also developed due to tectonic setting of this archipelago in a converging plate margin. Because of tectonicity, the igneous and sedimentary group of rocks are highly fractured and fissured. The fracturing in hard rocks form conduits for movement of ground water in the deeper horizon. The geology of the islands is highly varied and even changes within a small distance. The hydrological behaviours of the rock formations occurring in the islands are controlled by the above factors. For taking up groundwater development, post tsunami, it is very much urgent to know the details of hydrogeology of the islands in the pre-tsunami and the current changes in the water availability after the disaster. In the following text it is discussed with field observations.

Hydrogeological Situation (Pre-tsunami)

Hydrogeologically (Fig. 12), in general, the sedimentary rocks are very poor water yielders both in shallow and deeper horizons because of preponderance of clayey materials in them. As mentioned earlier although the sedimentary rocks possess fractures developed in them but these are highly clogged by the clayey residue. Hence in majority of the cases the exploratory boreholes drilled in the sedimentary formations did not yield water. The weathered horizon of such rock formations where dug wells are constructed also yield ground water in meagre quantity.

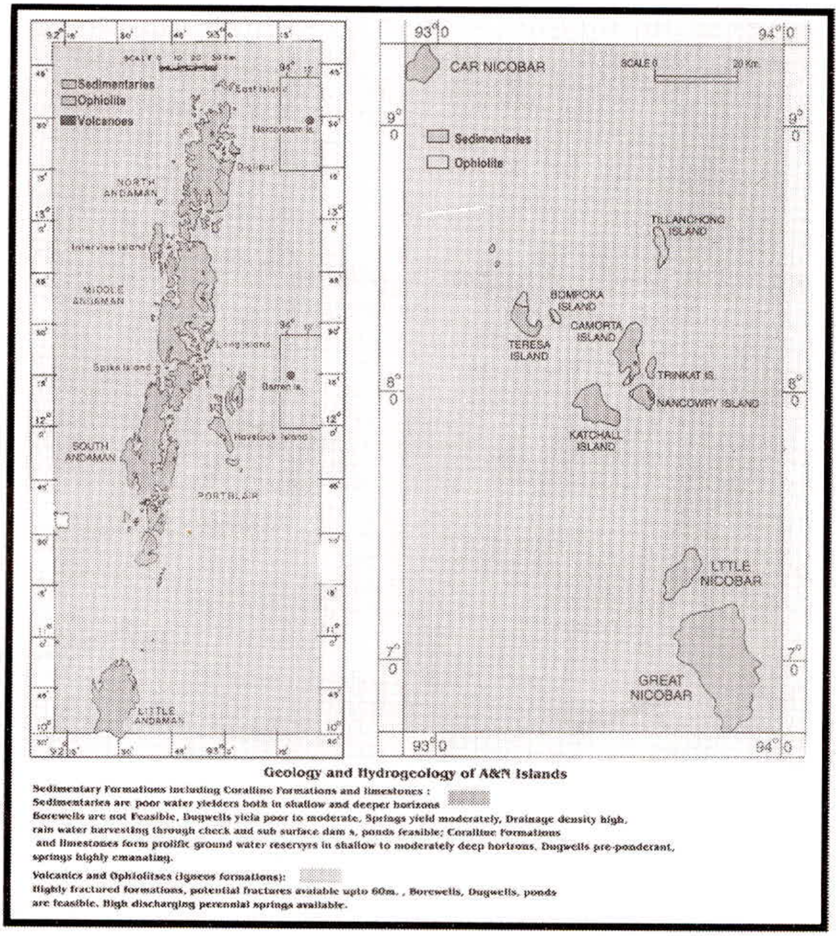


Fig. 12. Hydrgeological map of A&N Islands.

A dug well having 5 m diameter and 6 m depth constructed in valley areas may yield maximum 4000-5000 litres/day, while the igneous suite of rocks sustain good amount of water both in shallow and deeper horizons. Borewells were being successfully constructed in these formations. A dug well 5 m diameter and 6 m depth used to yield to the tune of 10,000 to 15,000 litres/day, while a bore well 60 m deep and 6 inch diameter was yielding 25,000 to 30,000 litres/day. However, in island situation always the ground water development should be done judiciously as per the availability of mineral water otherwise it may cause environmental degradations through seawater ingress. Amongst all these rock formations the coralline formations are the most potential and yield very high amount of water because of good porosity and permeability. In such terrains dug wells were constructed (Ex-Carnicobar, Neil island, Little Andaman Islands). One dug well with the specification of 5 m diameter and 6 m depth may even yield 1,00,000-1,50,000 litres/day. Geology and topography facilitated origin of springs abundantly in all the three major geological formations (i.e., marine sedimentary group of rocks, volcanic and other igneous rocks and coralline limestone). The rural water supply in the entire A&N Islands except Neil and Car Nicobar islands (Water supply is done in these islands only from the wells) is maintained either directly from the springs or spring-fed perennial streams. These springs are generally formed in high altitudes because of good fracturing in the rocks. For this they also may be termed as fracture springs. However, the springs are highly yielding and sustainable in igneous rocks and limestone as seen in Rutland (Kalapahar), Panchavati Hills (near Rangat) and Saddlepeak (all in igneous rocks) and in little Andaman and Havelock islands (limestone).

Following an exploration programme, total 47 exploratory boreholes were drilled in the islands during 1984-90 (CGWB, unpub.). Amongst these wells 18 were drilled in South Andaman, 11 were drilled in Middle Andaman, two in North Andaman, nine in Great Nicobar, three in Nancowry and four in Katchal Island. It was observed that the boreholes drilled in Sedimentary formations throughout did not yield except one near Prothrapur Jail Junction, which yielded brackish water (EC – 5500 microsiemens/cm) to the tune of 9000 litres/hr. However, the valley fill deposits in the islands were seen to yield copiously. The well drilled at Beadnabad is the main supply source in parts of South Andaman adjoining Beadnabad-Rangachang-Burmanala sector. The yield of the well was as high as 44,000 litres/hr; igneous rocks yield moderate to good. Up to 60 m depths potential fractures were noticed. The yield range of the boreholes in these formations was found to vary from 10,000 to 25,000 litres/hr. There was no exploration in the coralline and limestone formation.

From the studies the following observations were made:

- Geology of the islands are highly varied (Roy et al., 1988; Vohra et al., 1989) and complex. Each island is having separate geological characteristics, which may vary with the contiguous islands and even within the same island.
- Except in the areas underlain by the valley fill deposits and the pockets underlain by the igneous rocks and coralline formation, the prospect of groundwater development is bleak.
- Unproductive sedimentary rocks cover major parts of the islands.
- Out of 47 exploratory wells, only two were highly successful (Beadnabad and at Calicut) and four others in Middle Andaman were partially successful.

In the light of the above facts the research studies (Fig. 13) by the author revealed that lot of fresh ground water is flowing below the streams as base flow, besides the surplus runoff water move to the sea along the streams. Considering the deviation of rainfall as also the prolonged dry spell, artificial recharge and conservation studies of ground water were carried out utilizing the huge rainfall in

A&N islands. The basic geological and hydro-geological factors favouring such type of studies in the islands are:

- Islands receive copious rainfall
- Areas are drained by numerous small, medium and major streams/rivers (exist in North, Middle Andamans and Great Nicobar).
- Even in the terrains underlain by unproductive sedimentary rocks, a good thickness of porous valley fill deposits could be seen in many areas which carry huge quantity of base flow throughout the year.
- Generally big boulders, gravels and porous pebbles are laid in the stream courses.
- The base flow could be restricted by means of sub-surface dams (Fig. 13) and lot of surplus run-off may be conserved through check dams/weirs as also can be utilised for recharging the subsurface reservoir even in lean period (if there is any stray rainfall). The recharged and conserved water may be utilized by means of dug well and dug-cum-bore well.

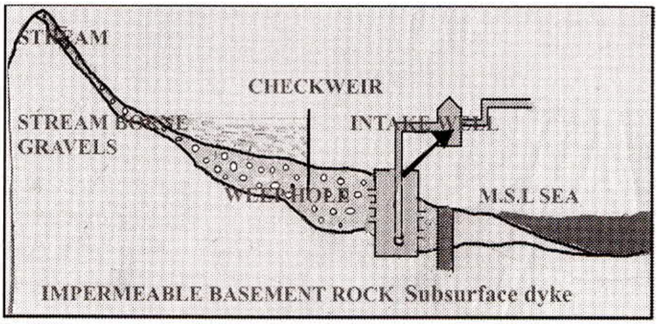
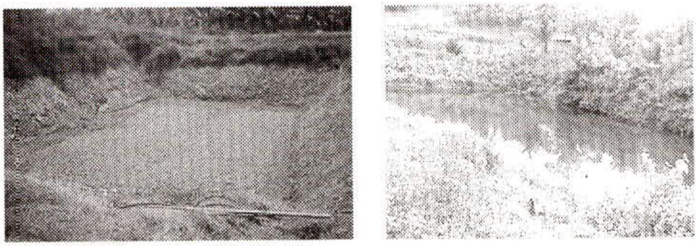


Fig. 13. Model of artificial recharge, conservation and utilization of ground water in A&N islands.

- Hence, as per the hydrogeological situation of the island, to tackle the water crisis, conservation of rain water in the form of surplus runoff by multiple check dams, sub surface dam and wells, roof top rain water harvesting for its conservation as also recharge, harvesting of rain water in ponds would be highly necessary.
- Conservation of spring water and judicious groundwater development through construction of dug well, bore well had been conjectured as per the pre-tsunami situation. The present situation post-tsunami does not favour construction of bore wells (Table 4). However, environment friendly borewells/tubewells fitted with hand pump may be constructed in specific areas.
- For groundwater pumping cautious regulations should be adopted in the islands keeping in view the fragile geo-environmental condition of the islands.
- Since 2000, more than 75 recommendations were given (CGWB, 2002) for augmentation of drinking water supply of which 20 were implemented and promising results were obtained.
- The minor irrigation development plan for the major part of Andaman district was prepared in 2003 and 101 check dams were constructed by the Agriculture Dept., A&N Admn. This plan envisaged both development of ground water and combined water shed development through rainwater harvesting and recharge.

- With the available data, the groundwater resources of the island (pre-tsunami) was assessed and it was reconciled with the A&N Administration just before the tsunami.



Post-tsunami Same pond (Pre-tsunami)

Fig. 14. Pond dried up at high altitude near Calicut, S. Andaman.

Fig. 15. Check dam dried up at high altitude near Calicut, S. Andaman.

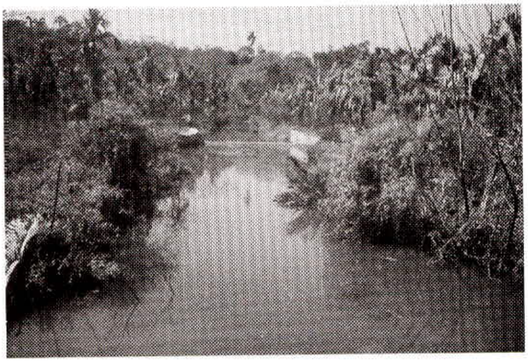


Fig. 16. Check dam affected by tsunami at Chouldari, S. Andaman.

Fig. 17. Well dried up at high altitude, R.K. Pur, Little Andaman.

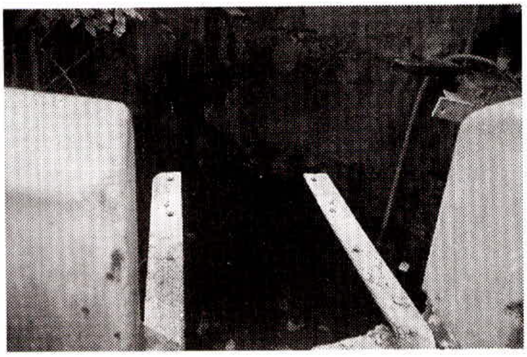


Fig. 18. Water level rise in well at low altitude near Gandhi Bhawan, Port Blair.

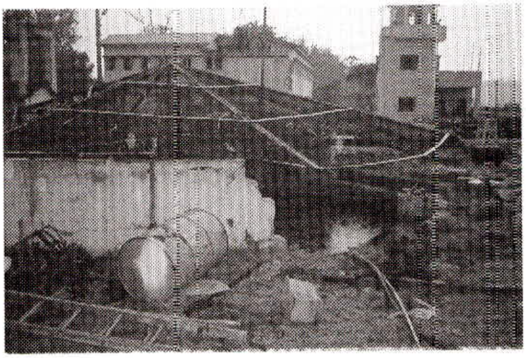


Fig. 19. Supply well affected by tsunami at Navy Airport, Campbell Bay (Great Nicobar).

Table 1. Change in aquifer characteristics of select wells in low altitude of A&N islands, post-tsunami

Island name	*Location*	*SWL(m) pre-tsunami with date*	*SWL(m) Post-tsunami with date*	*Yield, duration of pumping, pump capacity, drawdown, recuperation (Pre-tsunami)*	*Yield, pump capacity, drawdown, recuperation, (Post-tsunami)*	*Remarks*
1. South Andaman, Port Blair	Peerless Beach Resort Hotel	Depth-6.3m Dia-2.65m S.W.L. 4.76 m (07.2.04)	S.W.L. 1. G.L. (26.12.04) 2. 1.89 m (4.1.05) 3. 3.69 m (22.4.05) 4. 2.8 m (22.2.06)	1. Yield (per day)-7000 liters/day(290 lit/hr) 2. Duration of pumping per day - 2 hrs 3. Pump capacity 5 hp (diesel) 4. Drawdown 1.3 m 5. Recuperation 1.3 m in 24 hrs	1. Yield(Per day)-40500 lit/day(1690 lit/hr) 2. Duration of pumping per day 3. Pump capacity 5 hp (diesel) 4. Drawdown 3.24 m 5. Recuperation 2.15 m in 7 hrs	S.W.L.&Yield increased
2. Car Nicobar	Head Qtrs. Pumping Well, APWD	Depth 10.94 m Dia. 6.42 m S.W.L. 1. 10.24 m as on 28.4.02 2. 9.44 m as on 6.6.04 3. 10.09 m reported s.w.l. before earthquake	S.W.L. 1. 7.86 m (7.1.05) 2. 8.7 m (10.2.05) 3. 9.35 m (11.2.05) 4. 9.28 m (28.7.05) 5. 8.46 m (6.2.06) 6. 8.63 m (18.7.06)	1. Yield (Per day) 1,60000 litres per day 2. Duration of pumping per day 6 hrs 3. Pump capacity 20 H.P (one pump) 4. Drawdown 0.33 m in 6 hrs 5. Recuperation 0.33 m in 40 m	1. Yield (Per day) 540000 lit per day, 40000 lit/hr 2. Duration of pumping per day 9 hrs 3. Pump capacity 20 H.P. (Elec), 10 H.P. (Elec), 25 H.P. (Diesel) [3 pumps run] 4. Drawdown - 0.2 m in 6 hrs 5. Recuperation - 0.2 m in 25 min	S.W.L.&Yield increased *Sea water stagnation was contg. after tsunami high tide time low tide started 1&2 cases of tidal variation Two post-tsunami records in '05 &'06 in July. Change in water level of this well with tide has become very much prominent after tsunami

Table 2. Rise in water level in select dug wells in low altitude in Andaman districts

Island name	*Well location*	*Depth (m)*	*S.W.L. (Pre-tsunami with date)*	*S.W.L. (Post-tsunami with date)*	*Remarks*
Baratang I. (M.Andaman)	Near G.P. office	6.60	5.96(29.4.04) 1.26(6.12.04)	2.18(12.3.05) 1.54(19.5.05)	Rise in water level continuing
S.Andaman Port Blair	Near Gandhi Bhawan	4.74	4.39(03.5..04) 2.99(6.12.04)	1.14(9.1.05) 1.32(11.3.05) 1.30(23.2.06) 0.54(10.8.06)	Rise in water level continuing
S.Andaman Port Blair	Sampath Lodge	10.56	8.06(3.5.04) 5.56(9.12.04)	6.55(9.1.05) 1.28(11.3.05) 1.18(10.8.05) 1.64(12.12.05) 3.55(23.2.06) 4.10(10.8.06)	Well showed peculiarity in W.L. change. First no change after e.q. Then sudden rise. Continuation for some time again ..ning old situation
S.Andaman Port Blair	Dhobigat Near Power Hose	3.85	3.35(3.5.04) 2.69(9.12.04)	1.55(9.1.05) 2.23(11.3.05) 1.60(10.8.05) 2.70(23.2.06) 0.58(10.8.06)	Rise in water level continuing
Car Nicobar	Agril. farm	10.71	9.45 (6.6.04)	7.98 (7.1.05) 9.00(10.2.05) 8.90(28.7..05)	Rise in water level continuing

HYDROGEOLOGICAL SITUATION (POST TSUNAMI)

The disaster had a tremendous impact on the water resources as a whole and groundwater resources in particular and the following observations were made.

- In high altitude terrains, springs, check dams, ponds borewells (in South Andaman) are either dried up (Tables 3 and 4) or discharges are declined (Figs. 14, 15, 17, 21, 23).
- In lower topographic terrains especially in South Andaman the discharge of streams, springs, and water level (Tables 1 and 2) in wells are increased (Figs 18 and 20). In other places either the discharge is showing some rise or showing little decline or no change. However, in few cases the discharge ceased.
- In Havelock Island at Vijoynagar in the foothill region one good discharging spring generated. Pond was seen overflowing on 02.03.2005.
- On 26.12.2004, during the earthquake fresh water fountain (only reported from Car Nicobar) as well free flow on the ground surface was observed in Car Nicobar, Little Andaman, Neil, Havelock and in many places all along in South, Middle and North Andamans.

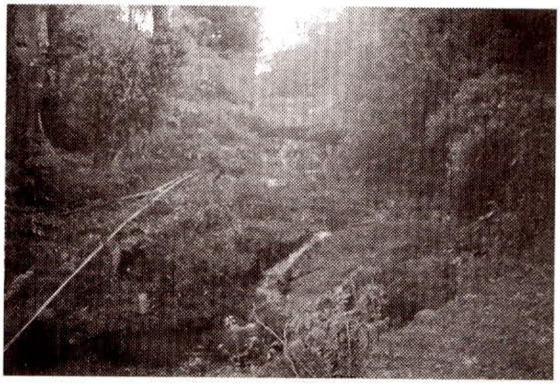


Fig. 20. Sudden rise in discharge of spring at low altitude near Brookshabad, Port Blair.

Fig. 21. Almost dried up pond at Kalipur, Diglipur, N. Andaman.

Pre-Tsunami

Post Tsunami

Fig. 22. Change in discharge in spring-fed waterfall at high altitude in Little Andaman.

Table 3. Water level decline in select dug wells in high lands of Andaman district

Island name	*Well location*	*Depth (m)*	*S.W.L(Pre-tsunami with date)*	*S.W.L(Post-tsunami with date)*	*Remarks*
North Andaman	Sitanagar, Diglipur Sub divn. Inside house of S.R. Mistry	4.21	4.06(30.4.04) 1.44(7.12.04)	4.18(11.3.05)# 3.90(18.5.05)* 1.73(25.1.06) 1.20(8.8.06)	# well dried up after tsunami * Rainfall during the measurement
Little Andaman	R.K. Pur. Inside house of Sh. Kalipada Bachhar	10.85	4.55(25.12.04) Reported	6.85(15.1.05) 2.85(28.8.06)	Water level in the entire area gone down. W.L. situation partially improved due to temporary grouting in the recharging reservoir.
Little Andaman	R.K. Pur. Inside house of Smt. Sarojini Mondal	7.63	7.20(25.12.04) Reported	Dry(15.1.05) 5.00(28.8.06) 3.85(Actual rainy time level reported)	Water level in the entire area gone down.
Little Andaman	Ravindra-Nagar Inside house of Sh. Asim Biswas	25.25	14.55(20.12.04) Reported	15.55(28.12.04) 18.00(3.1.05) 19.82(18.1.05) 19.36(29.8.06)	Water level in the entire area gone down.
Little Andaman	Ravindra Nagar Inside house of Sh. Selvaraj	9.82	8.50(25.12.04) Reported	Dry(18.1.05) 6.89(29.8.06)	Saline water ejected nearby. Water level in the entire area gone down.

- Saline water was ejected (Fig. 23) at several places as in R.K. Pur (22 km), Ravindranagar (28 km) in Little Andaman, near Pema Junction Calicut, South Andaman and near Jarawa Tikrey, Baratang, Middle Andaman. This probably happened with the huge aquatic pressure exerted by the tsunami and synchronous fracturing of the geological formations by the mega earth quake (M = 9.3).
- Two earthen medium dams at R.K.Pur (Fig. 24) and Ravindranagar were highly damaged during the earthquake and water was seeped through cracks and fissures developed on the dam bed.
- Cracks were generated in the aquifers, which are cropping out in the surface.
- In Andaman district, the arable lands and ponds are highly damaged during earthquake (especially in North and Middle Andaman) causing decline in soil moisture of the agricultural land and water-holding capacity of the ponds.

Table 4. Water level decline in the borewell of Calicut-Maccapahar area, S.Andaman during tsunami

Village Name	*Name of the owner*	*SubDivn.*	*District*	*Type*	*Total Depth(m)*	*Static water level(m) [in pre-tsu nami]*	*Static water level(m) [in post-tsunami]*	*Khasra no with affec-ted irrigable area in Hectare after tsu-Nami*	*Remarks*
Maccapahar	S/Sh. Sunderraj	S.Anda-	Andaman	Borewell	45.75	1.5	15	152/22,0.62 Hectare	This area lain by igneous rocks comprising pillow lava and various variants of ultramafic, mafic and acid volcanics. Because of britness of the rock formations, the fractures developed easily allowed quick evacuation of ground water. It may take long time for natural healing up by Clay cloGging.Studies are underway to find out the looosing fracture for cement grouting.
do	Ramaswamy	do	Do	do	34	3	12	152/28,0.6 Ha	
do	Bal Murugan	do	Do	do	54	0.6	24	152/20,0.70 Hectare 0 Ha	
do	Arumugam	do	Do	do	40	7.6	12.19	152/23,0.54 Hectare 4 Ha	
do	Rajendran	do	Do	do	33.5	3	15	152/29,0.6 Hectare HA	
do	N. Hamza	do	Do	do	33.5	7.6	12.19	203/6 &152/39,2.1 Ha	
do	R. Manoharan	do	Do	do	30.48	Auto flow	6	152/38,0.55 Ha	
do	R. Veluswamy	do	Do	do	30.48	1.2	9.14	152/35,0.65 Ha	
do	R. Ramaswamy	do	Do	do	33.5	3	12.19	152/86,0.56 Ha	
do	Muthuswamy	do	Do	do	44.2	3	6	152/52,Not available	
do	Ganeshan	do	Do	do	33.5	3	12.19	152/48,Not Available	
do	Arunachalam	do	Do	do	33.5	Auto flow	6	152/10,Not Available	
do	Guna Sekharan	do	Do	do	22.86	Auto flow	7.62	52,Not available	
do	Smt.Santha Laxmi	do	Do	do	32	3	Dried up	2/2,Not available	
do	N. Dharman	do	Do	do	39.69	6	15	253/203,Not available	
do	Subra Mani	do	Do	do	33.5	3	12.19	255/201/3 NA ,NA	
do	V. Kandaswami	do	Do	do	33.5	Auto flow	24	203/28,NA	
do	Masna Muthu	do	Do	do	33.5	6	12.19	152/9,NA	
do	S. Muthaiah	do	Do	do	30.48	3.35	15	203/18,NA	
Teylerabad	Vellakanni	do	Do	do	30.48	6	15	Not Available	
Calicut	P. Moideen	do	Do	do	30.48	3	Dried up	74,75/1,75/2,76/1,76/2,77	
do	Do	do	Do	do	45.73	24	Dried up	77,78,23,22/1,2.1Ha	
do	V. Subramanium	do	Do	do	30.48	2.43	18.29	Not Available	
do	K.Ali	do	Do	do	30.48	2.74	19.8	245,0.5 Ha	
do	M.Mohammed	do	Do	do	42.68	3	15.24	181,0.5 Ha	
do	N. Mohammed	do	Do	do	30.48	0.6	9.14	72,0.5 Ha	
do	C. Subbaiah	do	Do	do	45.75	6	13.71	160,0.5 Ha	
Calicut	Smt. K.Nabisha	do	Do	do	38.1	1.5	21.34	155/p,0.3550 Ha	
do	P. Mohammed	do	Do	do	40	2.43	19.8	156/p,0.45 Ha	
Teylerabad	P. Arunachalam	do	Do	do	45.75	1.5	18.29	203/93,1.0 Ha	
New B.Tan	K. Subbaiah	do	Do	do	33.5	4.57	Dried up	255,1.0 Ha	
do	Do	do	Do	do	38.1	6	Dried up	do	
do	A. Balaswamy	do	Do	do	36.58	7.62	Dried up	255/31,1.0 Ha	
do	Shri Casper	do	Do	do	38.1	4.57	Dried up	Not Available	
do	S. Gandhi	do	Do	do	42.68	3	15	255/p,0.25 Ha	
Teylerabad	Arumugam	do	Do	do	33.5	3	18.29	203/39,1.0 Ha	
do	Chella Mani	do	Do	do	33.5	4.57	27.43	203/116,0.93 Ha	
do	P.Aboo	do	Do	do	36.58	6	10.6	203/191,1.0 Ha	
Brichganj	Sheo Ram	do	Do	do	39.39	6.06	Dried up	76/1,78,1.07 Ha	
do	Jog Ram	do	Do	do	30.3	4.54	Dried up	33/2,0.45 Ha	
do	B.P. Tiwari	do	Do	do	45.45	6.06	Dried up	Not Available	
dd	Neelawati	do	Do	do	60.6	7.57	Dried up	36,0.72 Ha	

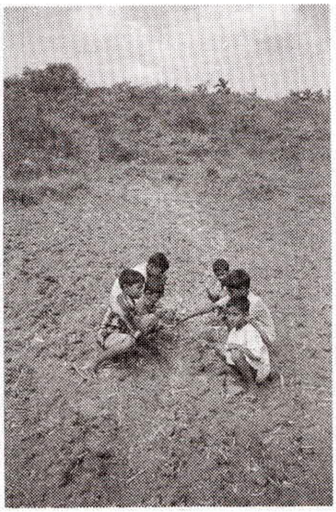


Fig. 23. Trail of high mineralized water flown at highland near Rabindra Nagar, Little Andaman.

Fig. 24. State of R.K. Pur Dam, Little Andaman after 26.12.04 earth quake.

- Field studies by various land survey departments as also the field observations reveal that in the areas from Campbell Bay to MiddleAndaman (upto the Sabari and Dasarathpur areas in and around Rangat) the land shows some subsidence, evident from the sea water ingress.
- The reported range of subsidence varies from 0.5 to 1.5 metre (Jain et al., 2005).
- Similarly there has been a reported upliftment especially in Diglipur Zone, North Andaman, evident from the lowering of creek water level during low and high tides. At places lowering of sea level has been reported to the tune of 1.0 to 1.38 m (Jain et al., 2005).
- The low lying areas in the entire Nicobar district and in parts of Andaman district upto Rampur in Mayabunder were inundated by tsunami waves whose height varied from 0.5 to nearly 10 metres.
- These waves contaminated the ponds, wells and all fresh water bodies along the coast (Figs 16 and 19).

After tsunami at various places in the affected islands, the contaminated wells were pumped out. At many places pumping was done cyclically. Following observations (Table 5) were noted:

- In many areas during the first phase the wells showed positive result (i.e gradual decrease in salinity). However, afterwards it started showing increase in salinity.
- In many places the salinity did not change at all even after evacuation or repeated pumping.
- At places the wells become naturally flushed without pumping.
- At places they are still saline.

From the above observation it may be conjectured that continuous quality monitoring should be undertaken to see the changes of quality of water through time. Regular geohydrological monitoring would be highly necessary in the islands for successful construction, proper design and site selection of the water development structures.

Table 5. Change in salinity of select dug wells in tsunami affected areas of Andaman and Nicobar districts

Island name	*Well location*	*Well depth(m)*	*S.W.L. (m) [Pre-tsunami with date and electrical conductivity in micro siemens/cm]*	*S.W.L. (m)[Post-tsunami with date and electrical conductivity in microsiemens per cm]*	*Remarks*
South Andaman, Port Blair	Inside Peerless Beach Resort	4.40	1. 3.20(3.5.04) EC-320 2. 1.74(9.12.04) E.C-330	1. 1.25(9.1.05) EC-6000 2. 1.32(11.3.05) EC-6050 3. 2.31(27.4.05) EC-5850 4. 1.13(10.8.05) EC-2390 5. 1.97(22.2.06) EC-1830 6. 0.74(9.8.06) EC-1230	Brackish condition still persist eve after two rainy seasons with copic downpour
South Andaman	Saitankhari adj. to road	5.15	1. 5.06(3.5.04) EC-1210 2. 1.86(9.12.04) E.C- 1000	1. 1.66(11.3.05) EC-7200 2. 0.88(28.4.05) EC-4590 3. 0.95(7.8.06) EC-1610	Brackish condition still persist eve after two rainy seasons with copic downpour
Car Nicobar	Tapoiming well of APWD	4.30	1. 2.57(22.2.02) EC-380 2. 2.16(6.6.04) E.C-330	1. 1.50(9.2.05) EC-3290 2. 1.45(18.2.05) EC-850 3. 1.55(15.7.05) EC-5060 4. 1.25(6.2.06) EC-1400	Well was dewatered
Car Nicobar	Chukchucha well inside the compound of Mr. I.A. Hussain	4.33	1. 2.50(6.6.04) EC-400	1. 2.65(10.2.05) EC-2130 2. 2.48(19.7.05) EC-3940 3. 2.59(6.2.06) EC-2200 4. 2.40(18.7.06) EC-1600	* Well was dewatered
Car Nicobar	Kinuka well of APWD		1. 1.14(6.6.04) EC-350	1. 2.06(9.2.05)* EC-1420 2. 1.48(15.7.05) EC-3500 3. 1.90(6.2.06) EC-2000 4. 1.55(18.7.06) EC-1300	* Well was dewatered
Cowry	Champin village well of MML	6.95	1. 1.50(2.2.01) EC-350	1. 2.03(20.6.05)* EC-3990 2. 2.17(7.2.06) EC-2500 3. 1.45(19.7.06) EC-1700	* Well was dewatered
Katchal Island Nicobar	Kapanga well near Shivs temple close to school	4.62	1. 1.14(5.2.01) EC-320	1. 2.64(4.7.05) EC-8390 2. 2.55(20.7.06) EC-1700	
Nancowry	Champin village well of MML	6.95	1. 1.50(2.2.01) EC-350	1. 2.03(20.6.05)* EC-3990 2. 2.17(7.2.06) EC-2500 3. 1.45(19.7.06) EC-1700	* Well was dewatered
Campbell Bay (Great Nicobar)	Supply well of Navy	3.27	1. 0.78(6.2.04) EC-400 Reported	1. 0.75(2.1.05)* EC-710 2. 0.35(4.7.05) EC-5630 3. 0.40(19.7.06) EC-2800	

Problems Associated with Development of Groundwater (Post-tsunami)

Immediately after the disaster, the government of India took a decision to go for faster rebuilding of the islands and to revitalize the basic requirements, like permanent shelter, water supply, communication etc. in a time-bound manner. Simultaneously for assisting the disaster affected people through livelihood generation, a programme named Rajeev Gandhi Rehabilitation Package for agriculture has been launched by Ministry of Agriculture, Govt. of India, where a main item was construction of various water development structures for agricultural revitalization. Based upon the previous activities of water resources development in the islands in the pre-tsunami, a tentative target was adopted by the Ministry of Agriculture (Table 6). However, based upon the experience of the administration after the disaster and the post-tsunami research studies carried out by the author (Kar, 2006) in liaison with the Agriculture Dept., A&N Administration and the post-tsunami terrain condition, the modified target is formulated and the developmental activities are underway (Table 7). From the foregoing discussion

Table 6. Target sources adopted in the action plan prepared by the Min. of Agriculture after the preliminary tsunami assessment in Andaman district as per pre-tsunami data

Sl. No.	*Island name/Zone*	*Check dam (nos)*	*Ponds/Wells (nos)*
1	South Andaman	100	500
2	Rangat Zone	19	347
3.	Mayabunder Zone	28	122
4.	Diglipur Zone	298	778
5.	Little Andaman Zone	5	46

Table 7. Target (based upon latest field data and observation) and achievements of construction of various groundwater resources augmentation structure under RGRPA in A&N islands, post-tsunami

Island Name	*Achievement during 2005-06*		*Target for 2006-07*		
	Ponds	*Wells*	*Ponds*	*Wells*	*Check dam*
S/Andaman	20	1	200	200	100
Rangat (Middle Andamans)	17	-	59	67	19
Mayabunder (North Andamans)	8	-	74	83	7
Diglipur (North Andamans)	83	-	53	53	235
Little Andaman	19	-	7	28	2
Car Nicobar	1	1	5	65	5
Katchal	1	-	4	6	
Kamorta	1	-	6	20	3
Teressa	1	-	2	15	3
Campbell Bay (Great Nicobar)	-	-	13	31	31
Total	151 nos completed and seven under progress	Two nos completed and 90 nos under progress	423 nos	568 nos	405 nos

(Source: Implementation Cell, Rajiv Gandhi Rehabilitation Project for Agriculture (RGRPA), A&N Admn.)

it is clear that there has been some qualitative and quantitative changes taking place particularly in the groundwater resources in the islands. Field observation carried out reveals that with the destruction of coast line by the tsunami, subsidence and progression of tidal line towards coast has caused sea water ingress both in the surface and subsurface. Because of this problem it appears that the former thickness of freshwater resources has been reduced, which has caused the changes in quality as being observed in the monitoring wells (Table 5) spread all over the islands. The observations are spectacularly matching with the models and observations made by the International Groundwater Resources Management Center (IGRAC, 2006). For this reason a problem in development of the drinking water supply sources in the islands is being faced by APWD, A&N Administration. Especially the depth criteria, availability and future sustainability is the main concern for them in the changed scenario. In the islands like Car Nicobar, Campbell Bay (Great Nicobar) where groundwater availability was not at all a problem in the pre-tsunami, there now it is a problem to extract water in abundance as before from the new sources. However, based upon detailed studies and prevailing hydro geological situation and terrain and aquifer conditions of the islands, the following structures are recommended in the post-tsunami to conserve, recharge and exploitation of ground water and rain water: 1. Ponds, 2. Check dams, 3. Sub surface dams, 4. Recharge shaft, 5. Intake wells, 6. Collector wells with infiltration gallery, 7. Lift irrigation points, 8. Roof top rain water harvesting and recharge.

CONCLUSION AND RECOMMENDATIONS

Islands of Andaman and Nicobar were developed by the British, only to deport the dreaded prisoners and subsequently for the freedom fighters. They intended to develop the islands optimally to run the administration over the far off maritime territory through penal settlements. However, after the independence through phase-by-phase resettlements and subsequently due to huge exodus of mainlanders in search of livelihood, in the last two decades the island population had a steep increase. Industry is almost absent in the islands while agriculture could not be developed in want of dependable irrigation water supply. For this besides the government job and the jobs related to the construction and government establishment expansion and management there is no other dependable way out in the islands to earn the bread and butter. At this juncture tourism development in these picturesque islands is the best option, which could give the economic sustenance to the islanders including good government revenue. In spite of construction of the Port Blair airport as per international standard, full-fledged tourism with rich foreign tourist could not be started mainly because of insufficient availability of fresh water in the islands. The recent tsunami disaster has also terrified the indigenous tourist and owing to the above reasons and current situation, tourism is practically handicapped. In this context the detailed studies on the present situation of water availability and associated problems as discussed above would be highly pertinent. To develop ecofriendly tourism as also for the drinking water requirement of the population, studies on availability of water resources is to be carried out. The groundwater resources in the changed geo environment after the tsunami and earthquake are to be worked out after the islands attain the hydro chemical equilibrium in the aquifers which is yet to be achieved after the disaster. For this regular hydrogeological monitoring is to be carried out. This will be very much necessary for the future sustainable, cautious and scientific withdrawal of ground water in the islands. Simultaneously the water user departments in the islands should not take up any such groundwater development projects involving unscientific withdrawal which may jeopardise the islands geoenvironment. Projects involving groundwater recharge, conservation and rain water harvesting should be prioritized.

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