Water Policy for Andaman & Nicobar Islands:

A Scientific Perspective

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Preface

Although India as a whole has reached to threshold level of stress in terms of per capita water availability, but the eastern and north eastern region are surplus in water. The Andaman and Nicobar (A&N) Islands are even more lucky as they receive an average annual rainfall of about 3080 mm. About 95 percent of annual rainfall is received during May-December of which nearly 75 percent is lost as runoff to the sea due to undulated terrains and steep slopes. The Islands have a width of 15 to 40 km east to west and the slopes are from centre to either towards east or west due to which the length of drainage line to the sea is short. Because of this, there is only one perennial river Kalpong in North Andaman Island. Thus the actual water availability is much less and Islands faces severe problem of water scarcity even for drinking water. The Islands have become a major tourist destination not only for the national but also international tourists. In order to support the tourist driven economy of the Islands, the emphasis should be to produce adequate perishable items in these Islands rather than transporting from mainland. However, the irrigation potential created is just 3% and actual irrigated area is about 1%. Therefore, the focus of water development should be irrigation to crops apart from drinking water. As rainwater is the only source of the fresh water availability in these Islands, its harvesting, storage and recycling is the most important strategy for water resource management.

Studies at CARI has shown that if only 3% of the water which flows out is stored in surface and underground storage, the requirement of domestic and agriculture can be met. To achieve the goals of providing sufficient water for domestic purpose and irrigation to cultivated area, a policy is required to develop and manage water resources on a sustainable basis without endangering the fragile Island ecosystem. This document is a step in this direction and is based on open discussion with stakeholders during brainstorming session held at CARI Port Blair on 7th and 8th July, 2009.

We express our heartiest gratitude to Dr. Mangala Rai, DG (ICAR) and Secretary (DARE), Government of India for providing effective leadership and guidance for taking up this task. We are grateful to Dr. H.P. Singh, Deputy Director General (Horticulture) for encouragement and inspiration. We extend our special thanks to Shri Vivek Rae, Chief Secretary, A&N Administration for chairing the special theme session and suggesting valuable comments on the draft paper. We are highly thankful to Dr. S.S. Magar, Chairman, Research Advisory Committee of CARI for his encouragement and support. We also wish to extend our sincere thanks to Shri S.S. Chaudhury, PCCF, Shri Khajan Singh, PCCF (Wild life), Shri G.C. Saxena, Secretary, IP&T, Shri Alok Saxena, CCF, Shri R.K. Ghosh, Chief Engineer, APWD, Colonel S.S. Multani, ANC, Sh. S.N. Jha, Dy. Commissioner, South Andaman and other officials of A&N Administration for knowledge sharing during the special theme session. We also place on record our special thanks to Dr. M.S. Gill, Director, PDCSR, Modipuram, Dr. M.A. Khan, Director, ICAR-RCER, Patna, participants of the brainstorming session and the faculty members of CARI for their active and constructive suggestions.

We hope that this publication would serve as a useful document to the planners, policy makers and researchers involved with development of water resources in the Union Territory of A&N Islands.

Authors

CONTENTS

1. The Andaman and Nicobar Islands

The Andaman and Nicobar (A&N) archipelago comprises of about 556 small and big Islands covering an area of 8,249 sq km with a coastline of 1,962 km between 92-94 ^{0}E longitude and 6-14 ^{0}N latitude in the Bay of Bengal (Fig.1). The northern group of Islands form the Andaman Islands, while the southern group of Islands form the Nicobar Islands, which is separated by 10 ^{0} channel. The North Andaman, Middle Andaman and South Andaman Islands occupy major land mass. The A&N group of Islands fall under hot humid to par humid Island eco-region designated as Agro-ecological Region 21. The tropical ecosystem of the A&N Islands is very unique having diverse species with wide range of genetic diversity in varying density. High rainfall, extremely humid climate, undulating terrain and backwater creeks are very conducive for faunal and floral diversity. Evergreen and littoral forests, mangroves and coral reefs are important components of the existing ecosystems prevailing in the Islands.

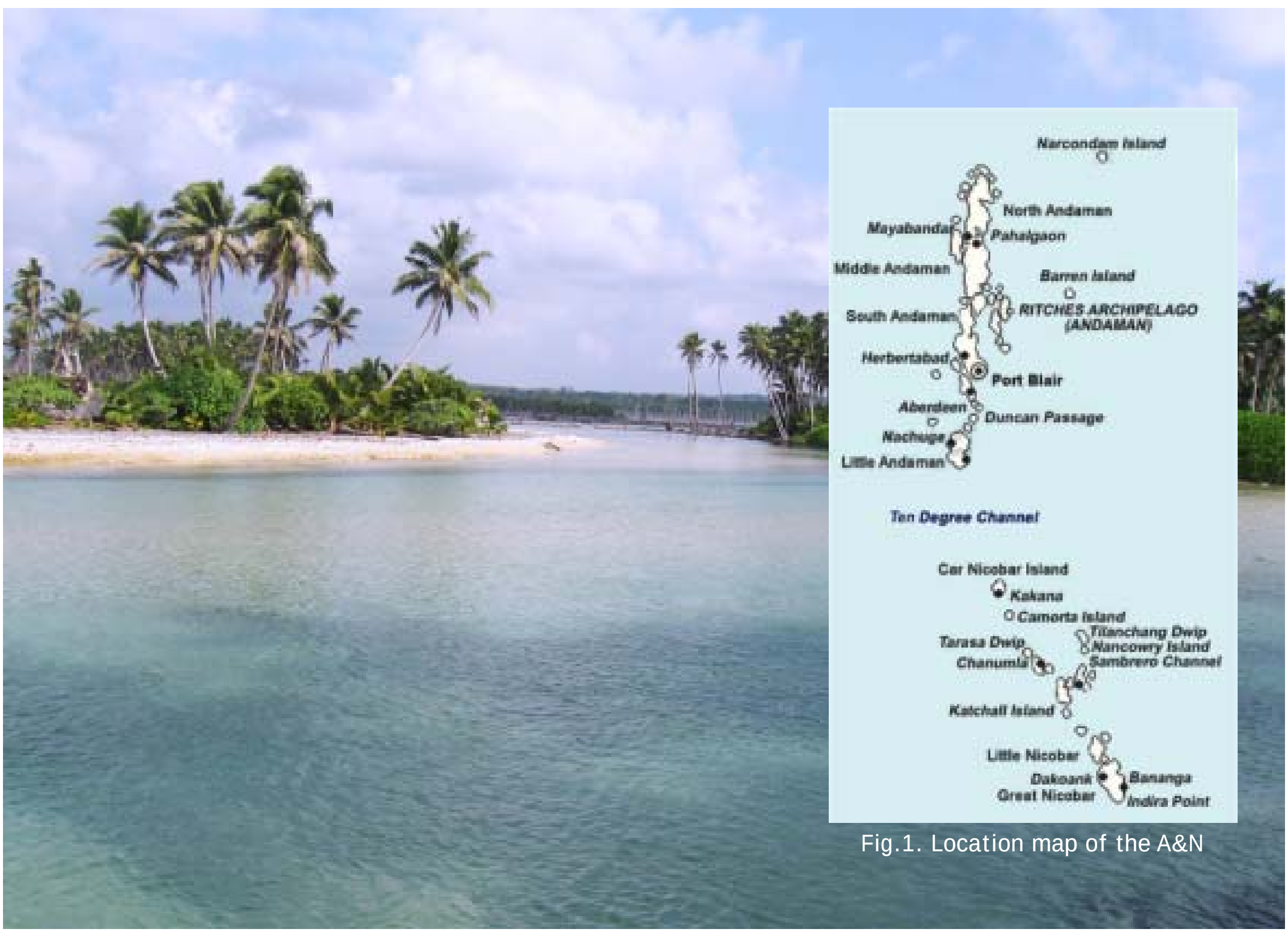


Fig.1. Location map of the A&N

2. Area and Population

The total geographical area of A&N Islands is 8,249 sq km. The forests in A&N Islands occupy about 92.2 percent of the total geographical area in which about 87 percent area is under legally notified forest. Remaining area is available for agriculture and allied activities. The area of Andaman group of Islands is 6,408 sq km whereas the Nicobar group of Islands is 1,841 sq km. The statistical details of area and population of different districts and blocks of the A&N Islands are given in Table 1. The total population in these Islands is about 3,56,152 (Population Census, 2001) with a growth rate of about 26.9 percent in the last decade. Assuming the population growth rate as in the last decade, it is projected that the population in these Islands will increase to nearly 5,73,500 in 2021 (Fig.2), with nearly 55 percent population living in rural areas. Out of 556 Islands, 38 are inhabited in which 25 are in Andaman group and 13 are in Nicobar group of Islands. The area and population of the inhabited Islands of the Andaman and Nicobar group of Islands are given in Table 2 and 3, respectively. It is interesting to note that inhabited Islands encompass about 94 percent of the geographical area of A&N Islands.

Table 1. Area and population in different districts and blocks in A&N Islands

Districts	Blocks	Area (km^2)	Population (2001 Census)
Andaman	Port Blair	2,021	1,42,317
	Ferrargunj	1,085	48,626
	Little Andaman	_ _	17,528
Nicobar	Car Nicobar	129	20,292
	Nancowry	1,712	13,472
	Campbell bay		8,214
North & Middle Andaman	Diglipur	884	42,877
	Mayabunder	1,348	23,912
	Rangat	1,070	38,824

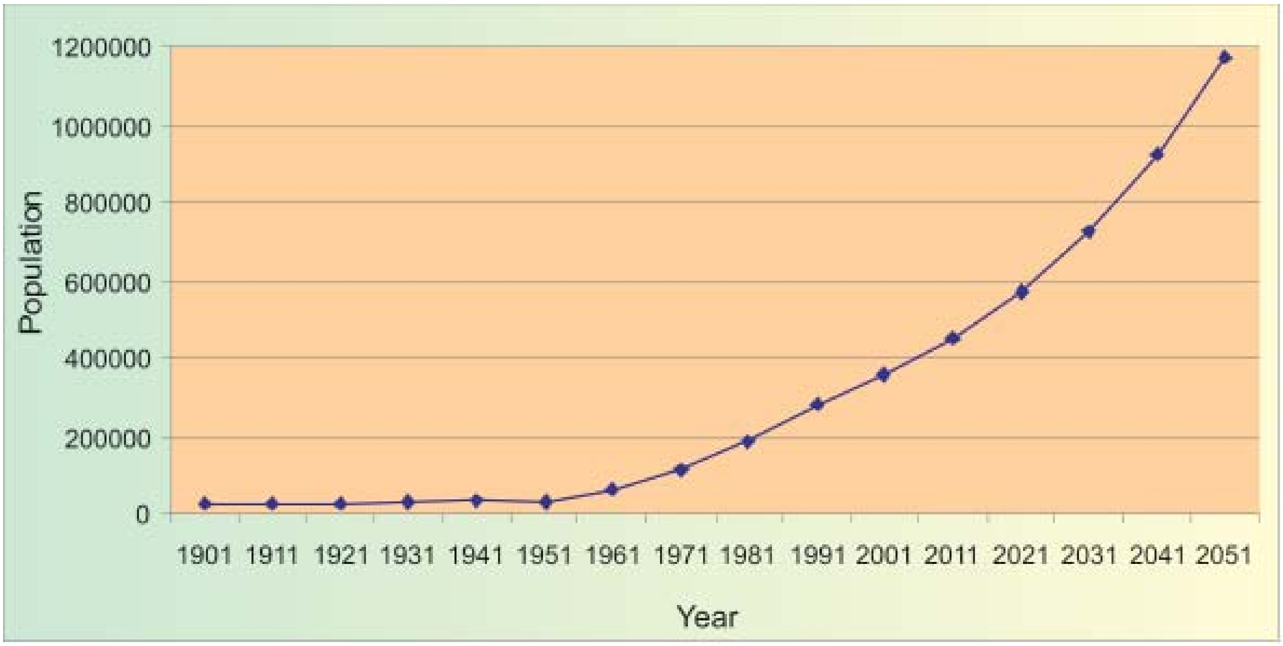


Fig.2. Trend of population growth and projected population in A&N Islands

Table 2. Area, population and density in inhabited islands of the Andaman group

Sl. No.	Geographical Name	Area(km^2)	Population (2001 census)	Density (person/km^2)
1.	Aves	0.20	2	10.0
2.	Baratang	297.80	6,062	20.4
3.	Cinque	9.53	6	0.6
4.	Curlew	0.03*	2	66.7
5.	East	6.10	17	2.8
6.	Flat Bay	0.14	10	71.4
7.	Havelock	113.90	5,354	47.0
8.	Interview	133.40	16	0.1
9.	John Lawrance	41.98*	25	0.6
10.	Little Andaman	731.60	17,528	23.9
11.	Long	17.90	2,199	122.8
12.	Middle Andaman	1535.50	54,385	35.4
13.	Narcondam	6.80	17	2.5
14.	Neil	18.90	2,868	151.7
15.	North Andaman	1376.00	42,163	30.6
16.	North Passage	22.00	11	0.5
17.	North Sentinal	59.67*	39	0.7
18.	Ross	0.65*	Nil	-
19.	Rutland	137.20	688	5.0
20.	Smith	24.70	676	27.3
21.	South Andaman	1347.97*	1,81,949	134.9
22.	Spike	11.70	19	1.6
23.	Stewart	7.20	2	0.3
24.	Strait	6.00	42	7.0
25.	Viper	0.50	4	8.0
	Total	5907.37	3,14,084	53.1

(Forest Statistics, 2000-01)*

Table 3. Area, population and density in inhabited islands of the Nicobar group

Sl. No.	Geographical Name	Area(km^2)	Population (2001 census)	Density (person/km^2)
1.	Car Nicobar	126.9	20,292	159.9
2.	Chowra	8.2	1,385	168.9
3.	Teressa	101.4	2,026	20.0
4.	Bompuka	13.3	55	4.1
5.	Katchal	174.4	5,312	30.5
6.	Kamorta	188.2	3,412	18.1
7.	Nancowry	66.9	927	13.8
8.	Trinket	86.3	432	5.0
9.	Little Nicobar	159.1	348	2.1
10.	Pillomilo	1.3	150	115.4
11.	Kondul	4.6	150	32.6
12.	Great Nicobar	1045.1	7,566	7.2
13.	Thillangchong	16.8	-	-
	Total	1841	42,068	22.9

Besides local population, the water requirement of the armed forces also needs to be accounted while planning and development of water resources in A&N Islands.

3. Flora and Fauna

The forests in the A&N Islands occupy 7,606 sq km or 92.2 percent of the total geographical area of 8,249 sq km. Of this, 5,883 sq km forests are in the Andaman group and 1,723 sq km in the Nicobar group. Of the total forest cover, dense forests with crown density of 40 percent and above constitute 85.9 percent, open forests with crown density less than 40 percent constitute 1.7 percent and mangroves constitute 12.7 percent. The legally notified forest is 7170.69 sq km, (86.9 percent of the geographical area); of this, 4,242 sq km are protected forests and 2,929 sq km are reserved forests (ANDE&F, 2001).

Ecologically, high level of endemism prevails in these Islands. Overall, 9 percent of the fauna is endemic, 40 percent of the 244 species and subspecies of birds are endemic. In mammals, 60 percent of the 58 species are endemic. The A&N Islands supports a significant diversity of reptile and amphibians with a high level of endemism. Currently seven amphibians and 16 reptile species are endemic to the Andamans and two amphibians and 15 reptiles are endemic to the Nicobars. About 14 percent of the angiosperm species, representing 700 genera and belonging to 140 families, are endemic to the Islands. Among the non-endemic angiosperms about 40 percent are not found in mainland India, but have only extra-Indian distribution in South East Asia. The butterfly diversity and endemism is also very high, of the 214 species and 236 subspecies in 116 genera, over 50 percent are endemic.

4. Climate and Topography

These Islands fall under agro-climatic zone XV and have a true maritime climate with least variation in maximum and minimum temperatures throughout the year. The Islands receive an average annual rainfall of about 3180 mm with the highest rainfall experienced in 1961 (4300 mm) and the lowest in 1979 (1550 mm). About 95 percent of annual rainfall is received during May-December (2250 mm in May-September during southwest monsoon and 685 mm in October-December during northeast monsoon) but due to the erratic nature of rainfall the intermittent dry spells during the monsoon result in moisture stress and poor crop harvest. A surplus of about 1530 mm rainwater from mid-May to mid-December and a deficit of about 610 mm are experienced during January-April (Fig.3), when numbers of rainy days in each month hardly exceed three. Historical weekly rainfall (1970-2003) for Port Blair were analyzed using RAINSIM software to estimate weekly probable rainfall (Fig.4), which at normal probability distribution function fitted at 1% level of significance except for 24, 36, and 45 standard meteorological weeks. The fortnightly dry days and length of dry spell is given in Table 4, indicating length of dry spell about 7 days during June to November.

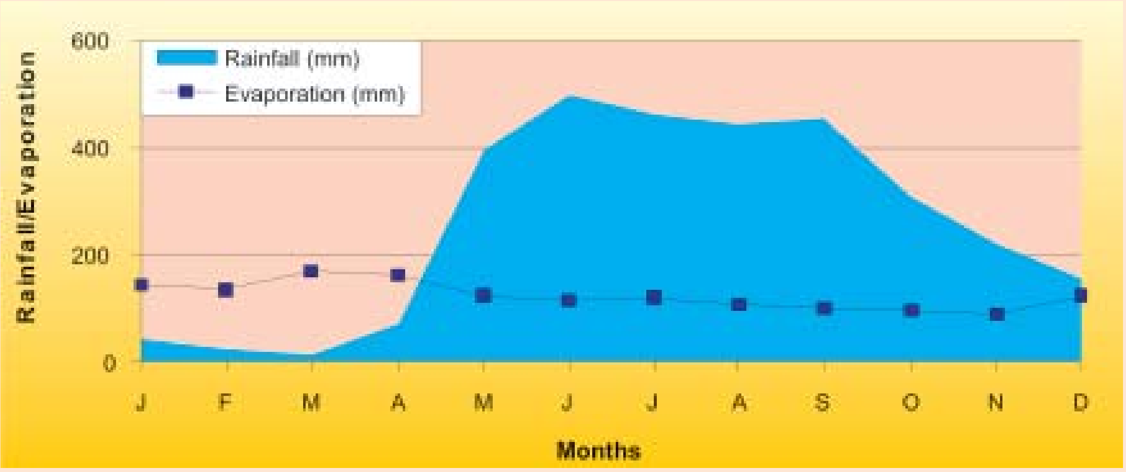


Fig.3. Monthly average rainfall and evaporation at Port Blair, South Andaman

The topography of the Islands is rolling with low range hills to narrow valleys at the foothills resulting in an undulating terrain ranging from steep slopes (>45°) to coastal plains (<10°). Physiographically, the land in these Islands can be subdivided into: (i) moderate to steep hill ranges (ii) intermountain narrow valley and (iii) coastal tracts including swamps. The huge hill ranges are generally covered by dense forest. Except the Kalpong river in the North Andaman, perennial streams of the status of river are absent in these Islands. Nearly 75 percent of the rainfall received in the Islands is lost due to undulated terrains, steep slopes, porous soil stratum and its proximity to the sea. As rainwater is the only source of the fresh water availability, its harvesting, storage and recycling forms the most important strategy for natural resource management in these Islands.

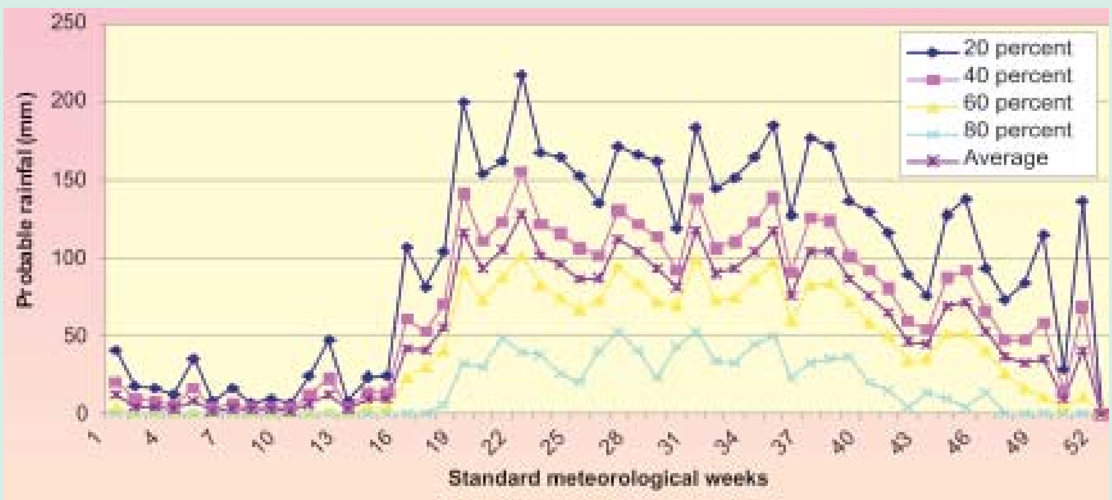


Fig.4. Probable rainfall at different probability levels for Port Blair

Table 4. Fortnightly average dry days and length of dry spell in A&N Islands

Month	1st Fortnight		2nd Fortnight	
	Dry days* (days)	Length of dry spell (days)	Dry days* (days)	Length of dry spell (days)
January	14.46	13.54	15.50	14.35
February	14.72	14.60	13.00	12.48
March	18.80	14.40	15.52	14.48
April	14.64	14.44	13.52	11.68
May	12.08	9.64	9.68	5.56
June	8.76	5.08	10.72	7.48
July	9.52	5.96	10.20	6.12
August	9.32	5.20	10.12	6.44
September	9.12	5.00	9.16	5.68
October	2.04	6.12	12.24	7.92
November	11.20	7.24	12.08	8.76
December	13.24	10.96	15.12	13.20

5. Agriculture and Food Requirement

The crop wise land utilisation pattern in these Islands is given in Table 5 and the major crops grown in different Islands are given in Table 6. The land distribution system, in general, allowed each settler 4.4 ha of land consisting of 2 ha of low-lying paddy land, 2 ha of hilly land generally planted with coconut, arecanut, banana, papaya and spices and 0.4 ha land for the homestead. However with time, the land holdings have been fragmented. Approximately 46,000 ha land is under agricultural crops that include about 30,000 ha land under fruits and plantation crops, about 10,000 ha land under field crops (about 8000 ha paddy land after tsunami) and about 461 ha land as fallow land. The current annual production of rice in the A&N Islands is 16790 tonnes with an average productivity of only 2.2 tonnes/ha necessitating an import of about 54310 tonnes of rice from the mainland to feed a projected population of 4.4 lakhs in 2011. The commodity wise projected requirement of food articles in A&N Islands is given in Table 7. Therefore, it is a challenge to close the yield gaps and diversify crops to meet the food demand. Though the potential for raising output by expanding the area cultivated is meagre, there is scope for introducing long duration high yielding tall rice varieties and increasing the cropping intensity. Although the production of food grain in the Island is less than the local demands, organic farming based crop intensification/diversification towards vegetable, spice and fruit crops are considered better options of farm income. Considering the growing importance of agriculture in A&N Islands, macro-management of agriculture is necessary for proper planning and evaluating options for possible interventions for improvements.

Table 5. Land utilization pattern in A&N Islands (2006-07)

Crops	Area (ha)
Paddy and other field crops	9,186
Coconut	21,416
Arecanut	4,056
Cashew	570
Fruits	2,950
Spices	1,611
Red oil palm	1,593
Rubber	1,500
Fallow Land	461
Reclaimable area	2451
Total	45,794
Permanently submerged land	4,206
Total (including intercrops also)	50,000

Table 6. Major agricultural crops grown in different inhabited islands

Islands	Main Crops
Andaman Group	
1. Narcondum	Coconut
2. East Island	Coconut, arecanut
3. North Andaman	Paddy, pulses, oilseeds, vegetables, coconut, arecanut, fruits, spices
4. Smith	Paddy, coconut, arecanut, fruits
5. Stewart	Coconut
6. Curlew	Nil
7. Aves	Coconut
8. Interview	Coconut, arecanut
9. Middle Andaman	Paddy, pulses, oilseeds, vegetables, coconut, arecanut, fruits
10. Porlob	Coconut
11. Long	Paddy, vegetables, coconut, arecanut
12. North Passage	Coconut, arecanut
13. Strait	Vegetables, coconut, fruits
14. Baratang	Paddy, vegetables, coconut, horticultural crops, spices

15. Peel	Nil
16. Havelock	Paddy, pulses, oilseeds, vegetables, coconut, arecanut, fruits, root crops
17. John Lawrence	Nil
18. Neil	Paddy, vegetables, coconut, arecanut, fruits, root crops.
19. South Andaman	Paddy, vegetables,coconut, arecanut, fruits, spices, sugarcane
20. Rutland	Paddy, vegetables, coconut, arecanut, ginger, sugarcane
21. North Sentinel	Nil
22. Little Andaman	Paddy, red oil palm, vegetables, coconut, arecanut, fruits
23. Flat Bay	Vegetables, coconut, arecanut, spices
24. Viper	Coconut
25. Chatham	Not available
Nicobar Group	
1. Car Nicobar	Coconut, aecanut, fruits, tuber cops, vegetables
2. Chowra	Coconut, tuber crops
3. Teressa	Coconut, arecanut, cashew, fruits, tuber crops
4. Bampooka	Coconut, tuber crops
5. Katchal	Paddy, red oil palm, vegetables, coconut, arecanut, spices
6. Nancowry	Coconut, arecanut, fruits, tuber crops
7. Kamorta	Coconut, arecanut, cashewnut, banana
8. Trinket	Coconut
9. Little Nicobar	Coconut, arecanut, colocasia, dioscoria
10. Pilomilo	Coconut, colocasia
11. Kondul	Dioscoria
12. Great Nicobar	Paddy, vegetables, coconut, arecanut, fruits
13. Thillachong	Nil

Table 7. Projected requirement of food items (as per ICMR standards) in A&N Islands

Commodity	Production requirement* (t/yr)		
	2011	2021	2031
Cereals	76,596	96,746	1,19,682
Pulses	4,666	5,832	7,290
Roots and tuber	23,692	29,616	37,020
Vegetables	27,519	34,399	42,998
Fruits	16,249	20,312	25,390
Fat and oils	6,427	8,033	10,042
Milk	27,683	34,603	43,254
Meat/fish	13,741	17,177	21,471

** Based on projected population which include armed forces, migrant labours & tourists*

6. Water Resources Potential and Requirements

The water resource potential of A&N Islands and its districts are given in Table 8. The projected population and per capita water availability in the years 2011, 2021 and 2051 for different districts and A&N Islands are given in Table 7. It indicates very high per capita water availability of 22,380 m^3/year in these Islands even in the year 2051 compared to the national availability and availability in other countries (Table 9).

The water resource of the selected Islands where population is more than 1000 has been estimated and given in Table 10. It has been observed that per capita water resource potential in Long, Neil, South Andaman, Car Nicobar and Chowra Islands are far below in comparison to their district average. The per capita water availability

Table 8. Water resource potential and projected per capita water availability

UT / Districts (Area)	Water resource potential (BCM)	Projected population			Projected per capita water availability(m^3/yr)		
		2011	2021	2051	2011	2021	2051
A&N Islands (8249 km^2)	26.2	4,51,957	5,73,533	1,172,050	57,970	45,740	22,380
Andaman (3106 km^2)	9.9	2,64,550	3,35,713	6,86,050	37,422	29,420	14,400
Nicobar (1841 km^2)	5.9	53,270	67,745	1,38,450	1,10,756	86,420	42,285
N&M Andaman (3302 km^2)	10.5	1,34,023	1,70,075	3,47,550	78,345	61,740	30,210

(BCM - billion cubic meter)

Table 9. Per capita water availability in selected countries

Country	Per capita water availability (m^3/yr)		
	1975	2000	2025
India	3100	1900	1400
China	3000	2200	1900
Pakistan	5600	2700	1600
Bangladesh	15800	9400	6800
UK	1300	1200	1200
USA	11300	8900	7600

in all the Islands is quite high in comparison to 1700 cu m national per capita water availability (less than 1700 cu m and 1000 cu m are termed as water stress and water scarce conditions). However, these figures are illusory as the amount of water available for harvesting is far below due to topography and high intensity of rainfall.

It is important to estimate future water demands for different Islands taking in to account its projected population and food requirements. The average crop water requirement to produce different commodity in India is given in Table 11, which has been used to estimate the water requirement for producing different commodities in the A&N Islands.

The amount of water involved in agriculture is significant and most of it is provided directly by rainfall particularly to produce rice crop during monsoon season. An estimation of Island water needs for food production can be based on the specific water requirements to produce food per capita. The present average

Table 10. Projected water availability in selected islands (population more than 1000)

Island Name	Area (km^2)	Projected population		Projected water availability (m^3/capita)	
		2021	2051	2021	2051
Baratang	297.80	9762	19949	97009	47471
Havelock	113.90	8622	17619	42010	20557
Little Andaman	731.60	28226	57681	82422	40334
Long	17.90	3541	7236	16074	7866

Middle Andaman	1535.50	87580	178974	55754	27283
Neil	18.90	4619	9439	13013	6367
North Andaman	1376.00	67898	138753	64445	31536
South Andaman	1347.97	293004	598768	14630	7159
Car Nicobar	126.9	32677	66777	12349	6043
Chowra	8.2	2230	4557	11691	5722
Teressa	101.4	3263	6668	98833	48357
Katchal	174.4	8554	17481	64832	31726
Kamorta	188.2	5495	11229	108922	53296
Great Nicobar	1045.1	12184	24899	272769	133478

Table 11. Projected water requirement to produce different commodity for A&N Islands

Commodity	Crop water requirement (m^3/t)	Total water requirement (BCM)		
		2011	2021	2031
Cereals (Rice)	4254	0.326	0.412	0.509
Pulses	1000	0.005	0.006	0.007
Roots & tuber	1000	0.023	0.029	0.037
Vegetables	1000	0.027	0.034	0.043
Fruits	1000	0.016	0.020	0.025
Fat & oils	2000	0.013	0.016	0.020
Milk	1369	0.038	0.047	0.059
Meat	5187	0.071	0.089	0.111
Coconut+arecanut	*	0.048	0.048	0.048

**Estimated @1780 m^3/ha for coconut + 2222 m^3/ha for arecanut for 100 days during dry period*

food ingest 2800 kcal/person/day may require 1000 m^3 per annum to be produced. The Island population is going to be about 4.5 lakhs in 2011 and 5.7 lakhs in 2021, so water needed to produce the necessary food, excluding water losses due to the irrigation system, is 0.47 BCM and 0.61 BCM (including the requirement of armed forces), respectively. Most of it is provided by rainfall stored in the soil profile and only 1% is provided through ponds created under minor irrigation. Irrigation therefore needs 0.4 BCM of water per annum for food crops. Although, on an average about 25% of water can be withdrawn from rivers, lakes and aquifers for agriculture to effectively contribute for crop production (the rest is lost through overland flow, evaporation and deep infiltration) but considering the typical topographic conditions, high intensity rainfall and narrow

Table 12. Projected water demand in selected islands

Island Name	Water availability (BCM)	Projected population			Projected water demand* (BCM)		
		2011	2021	2051	2011	2021	2051
Long	0.055	2790	3541	7236	0.003	0.004	0.008
Neil	0.058	3639	4619	9439	0.004	0.005	0.010
South Andaman	4.178	230893	293004	598768	0.242	0.307	0.629
Car Nicobar	0.393	25750	32677	66777	0.027	0.034	0.070
Chowra	0.025	1758	2230	4557	0.002	0.002	0.005

** Includes demand of drinking water and food requirements* breadth of the land mass in A&N Islands, only 20% of the water resources can be potentially developed. Consequently, the water withdrawals in Island for irrigation are estimated to be about 5.2 BCM per annum. The water demands for selected critical Islands are given in Table 12. It indicated that development of 5-7% by 2011, 7-10% by 2021 and 15-20% by 2051 of the available Island water resources could meet their requirements.

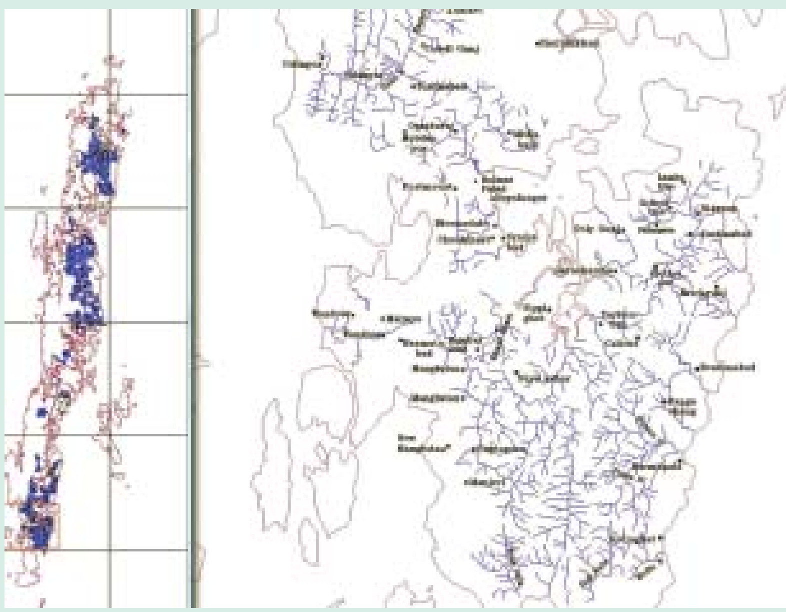
7. Water Resource Development

Surface water: The present development and availability of water resource in the urban area of Port Blair is 17.79 million litres per day (MLD), which is only 0.007 billion cubic meter (BCM) per annum. This is mainly by storage in Dhanikhari dam, Jawahar Sarovar, Lambaline diggi, Dilthaman, Nayagaon and Chakkargaon diggi. As per the status of water supply (Economic Survey of A&N Islands, 2007-08), the available water supply in A&N Islands is 49.62 MLD indicating an excess of 10.27 MLD whereas the projected demand for 2020 is 53.91 MLD showing a shortfall of 4.56 MLD. It is interesting to note that the present and projected (by 2020) shortfall in water supply in urban Port Blair alone are 9.38 MLD and 19.67 MLD, respectively. For development of water resources in the urban and rural Port Blair, raising of Dhanikhari dam by 5 m, sweet water lake at Sippighat, Rutland water supply project, desalinisation plant at Port Blair, Tylerabad weir, 14 m high earthen dam on Indira nallah, Karupaswamy nallah and procurement of barges in urban area and, 14 m high dam on Kamsrat Nallah, 13 m high dam on Koila Nallah, Mithakhari and reservoir for 100 day storage in rural areas have been taken up. Further, the present irrigated area (2007-08) in A&N Islands is 409.2 ha by pond, 985.5 ha by Nallah (out of this, the main project at R K Pur in Little Andaman is non-functional from the very beginning) and 116.5 ha by wells, which is less than 5 percent of the cropped land (excluding rainfed paddy area) suggesting adoption of a pragmatic approach and policies for water resource development for irrigation in these Islands.

Ground water: Groundwater is the main source of drinking water supply in rural areas in A&N Islands. These Islands are underlain by Late Cretaceous igneous rocks - the 'Ophiolite Suite', marine sedimentary group of Palaeocene to Oligocene age and Recent to Subrecent beach sand, mangrove clay, alluvium and coralline formations (CGWB, 2009). The Ophiolite suite comprises a wide variety of acidic to ultrabasic plutonic rocks and their serpentinised equivalents and essentially basic volcanicrocks occur in South, Middle and North Andaman, in sporadic patches of Little Andaman, Kamorta and Bampooka Islands in Nicobar group. The marine sedimantaries comprise greywakes, graded sandstones, siltsones, black shales and volcanogenic sediments. These fine grained deep see deposits are generally having predominantly clayey particles. The coralline formations are observable in coral Islands and also occur in the fringe areas of the sedimentary and igneous formations and form the narrow beaches encircling the Islands. The ophiolite and marine sedimentaries have undergone different phases of folding, faulting and upliftment which is responsible for the development of fractures and fissures as a result infiltrated rainwater percolates downwards. Marine sedimentary rocks are located to an anomalous admixture of sand and clay where clayey residue are predominating and do not form well developed potential aquifer system both in shallow and deeper horizons. Bore wells are not feasible in marine sedimenatary formations whereas dug wells of 4-5 m diameter to 6 m depth may yield 3000-5000 litres/day water. The igneous rocks also do not form potential aquifers but in comparison to the sedimentaries they yield moderately. These rocks form aquifer both in weathered mantle and fractured basement rocks which are generally developed through dugwell, ponds and borewells. The fracture conduit is observed up to 45 m depth with discharge varying between 30000-45000 litres/hour. The coralline limestone formations form potential aquifer in shallow horizon and can be developed as 4-5 diameter dug wells to 6 m depth in many Islands like Car Nicobar, Katchal, Neil, Havelock etc. with a yield varying between 15000-90000 litres/ day. There are approximately 2000 bore wells on the Islands. About 220 bore wells were surveyed and reported that 90% of the freshwater bore wells were drilled to less than 18 m. About 90% of the dry bore wells (13% of the total bore wells surveyed) were in compressed sedimentary deposits, which acts as aquiclude or even as aquitard whereas rocky subsoil formation was found to be more successful (Kumar et al., 2009). It was also reported that a majority of the bore wells surveyed were within one kilometre of the coastline but saline aquifer was not found.

8. Technologies for Water Resource Development

The water resource scenario presented earlier clearly shows that water resource development in A&N Islands should be based on utilization of rainwater either through surface storage or enhanced groundwater recharges. Considering the topographical constraints, surface storages at different inhabitation area/cultivated land instead of centralized location should be preferred. The drainage network of A&N Islands (Fig.5) should be used for developing the water resource plan. For surface water development on a drainage line, a three tier water resource development plan should be developed. This will include development of plastic film lined tanks on the top of the hills, recharge structure cum well system in the mid-hills and development of open dug wells in the valley areas. The recharge structure cum well system in mid hills can be both dugout or



(a) (b)

Fig.5. Drainage network in (a) North, Middle and South Andaman Islands and in (b) enlarged part of South Andaman Islands

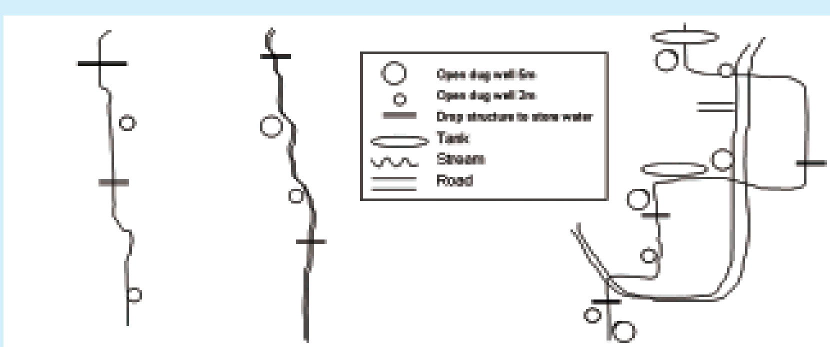


Fig.6. A schematic diagram showing different systems implemented at CARI, Port Blair

impounded type or combination of both depending up on the topography of a location. These technologies have been successfully demonstrated at CARI, Port Blair and have been linked to supply of water for drinking and irrigation purposes, which can serve as a model of extending these technologies to other parts of the Islands. A line diagram presenting these systems is shown in Fig.6.

In order to develop water resources at hill tops, lined tanks can be constructed. The lining technique has been standardized at CARI Port Blair, which involves lining by silpauline covered by reinforced plaster (1:6) on sides and 15 cm thick soil layer at bottom. Although the annual cost of water in lined tank is high (about Rs.30/m^3, varies from Rs 27/m^3 for 350 cu m capacity tank to Rs 81/m^3 for 80 cu m capacity tank) after accounting evaporation losses, the returns from expected yield increase of about 1-2 kg/tree in case of arecanut due to irrigation during five dry months of December to April will make it cost effective. The water requirement of arecanut per tree is about 1200 litres. Assuming even minimum enhancement, the economic gain will be about Rs.70/tree and thus a benefit-cost ratio of more than 2. For one hectare of arecanut, a tank of about 1500 m^3 will suffice. This size need not be created at one site but can be distributed in the whole area. For wide spaced crops like coconut and cashew, the tank size requirement will be further less. The lining process is shown in Fig.7.

Fig.7. Process of lining of tank (a) dug out tank (b) laying of silpauline (c) reinforced plastering and (d) finished lined tank

In mid-hill areas, recharge structure cum well system can be adopted for water resource development. A series of recharge structures in the form of small pond or check dam can be constructed in the stream itself at appropriate sites where storage of about 1000 to 5000 m^3 can be created. These storages, besides storing water will also recharge shallow aquifer. Open dug wells of 4-5 m diameter in the downstream of the recharge structure can recover back the recharged water. The surface storages can be used for providing water for initial period of dry season whereas water from dug well can meet the water requirement in rest of the season. This system has been constructed and evaluated at Garacharma farm, CARI where a series of tanks and wells have been constructed along with the course of stream which are providing adequate water to residential colony, demand of laboratories and animal farm, and to irrigate about 20 ha of plantation and 1.5 ha of vegetable crops (Fig. 8). At Sippighat farm, CARI, two such drainage lines have been treated with structures and wells where irrigation will be provided to about 20 ha of plantation crops (Fig.9). In Manjeri village, gabion structures in the stream has enhanced ground water recharge and thus made water availability to domestic use and irrigate 7 ha vegetables land through three open dug wells on the sides of stream (Fig.10). At Manjery, development of water resource process was unique as all the stakeholders formed a registered water user association and participated for creation of infrastructure.

A B C D

Fig.8. Construction of (a) pond and (b) open well downstream of pond and (c) check dam and (d) well downstream of check dam in Kaju Nallah at Garacharma farm

For valley areas, the paddy fields should be properly bunded to store the rain water. The stored rainwater will slowly percolate down and can be harvested back through open dug wells in downstream. One ha of paddy land, if bunded properly by 22.5 cm high bunds with provision of draining excess water, will facilitate slow percolation of about 6000 m^3 of water (@4 mm/day for 150 days). Assuming that about 50% of the percolated water can be harvested back through downstream open dug well, which should not be deeper than 8 m, about 3000 m^3 of water will be available per ha of paddy land which will be sufficient for providing 300 mm irrigation water in the following dry season crops. This will be in addition to the normal recharge received from the forested catchment on both sides of valley. This practice can be adopted for the valley lands which are at more than 10 m elevation than sea level to avoid the risk of sea water intrusion. Using

Fig.9. Tank-cum-well system at Sippighat farm

Fig.10. Gabions constructed through water user association in Manjeri village

this principle, three open dug well of 2 m diameter each have been dug at Bloomsdale farm, CARI to irrigate 3 ha area. The cost of each well is about Rs. 80,000. The pumping test of the well indicated that about 20 m^3 water can be pumped per day from the well which will provide about 24 cm of water to 1 ha land in 120 days of the crop, sufficient for irrigating at IW/CPE of 0.5.

Since the cost of developing water resources by above mentioned systems is high, application of water should be practiced to achieve high irrigation efficiency. Micro irrigation system allows precise application of water with an application efficiency of 95% or even more. In addition, it reduces fertilizer use and increases crop yield. Since most of the farmers in these Islands are small and marginal, the high initial cost of drip irrigation and economy of scale in its operation makes adoption of drip irrigation difficult for the farmers. In view of topography, gravity-fed drip irrigation can be adopted successfully which if properly designed can be very useful for the farmers. Design methodology for such systems has been developed and successfully demonstrated. Even for small farms of less than 0.1 ha and low head availability (< 2.0 m), low cost low-head filter has been designed. This filter costs just about 1/5th of conventional screen filter with a head loss of only 0.13 m compared to 1.2 m by conventional filter.

Thus, the available rainfall in A&N Islands can be harnessed for providing irrigation to plantation and spice crops, which will increase the productivity by at least 100 percent. The fallow paddy land can be effectively used for vegetables and flower cultivation. As the initial investment of creation of water resource is high, but in view of higher returns, these systems are cost effective. However, efficient utilization of water through micro irrigation system should be practiced. This will not only increase water productivity but will also save labour and fertilizer. These systems can also be linked to domestic water supply in rural areas by putting requisite water filtering systems.

9. Water Policy for A&N Islands

Unlike other parts of the country, Union Territory of A&N Islands is a non-contiguous group of Islands. Therefore, each Island should be treated as single entity for water resource planning and development. The important Islands should have a comprehensive land and water resource management plan, keeping in view the environmental and ecological impacts. However, the general water policies for A&N Islands are given below:

Hydrological database

- Island wise hydrological database on area, land use, soil, topography, drainage network, geology, groundwater hydrology, water quality is pre-requisite for development of macro scale plans for surface and groundwater resources. These data need to be collected for future planning.
- Since 86% of the area is under forest, those drainage lines need to be identified which are near to habitats as well as cropped area. Data for these drainage lines should be collected for reliable estimate of total water availability present use, present and projected and required amount of water which could be harnessed for use given topographical constraints. This information should be collected using remote sensing and GIS to facilitate its continuous updates. This will also help in adopting a holistic approach to collect, handle and analyse the necessary data sets as well as expanding our knowledge of the processes involved at the appropriate scales to manage water resources with objective thinking, planning and decision making.

Water allocation priorities

- Water allocation priority, in line of national priorities, should be accorded for drinking water to satisfy the basic human need followed by irrigation, industries including agro-industries and ecology. Limited but due priority should also be accorded to micro-level hydropower generation considering the lack of thermal based power generation in A&N Islands.
- The drainage network identified near habitats and cropped area should be exclusively marked for drinking and irrigation purpose in order of priority.
- As tourism is the backbone of the economy of the A&N Islands, due priority should also be given to the tourism industry. The importance of tourism in A&N Islands is borne out by the vision statement of administration which states that *the limited scope for industrial activity on the Islands coupled with the decline in the wood-based industry pursuant to the Supreme Court judgment has led to tourism being identified as a thrust sector for economic development, revenue and employment generation on the Islands. Keeping in view the fragile ecology and limited carrying capacity of the Islands, the objective of A&N administration is to strive for sustainable tourism.* Therefore, the requirement of tourism industry should be estimated. Drainage network near designated tourism points should be identified and exclusively earmarked for development of water resources considering the future requirements of the tourism industry.
- It has been observed as well as reported that construction sector and industries faces severe problem of non availability of water. To meet up water shortages, often public water system is encroached which creates conflict of interest and unrest in the society. To meet such challenges, drainage line/network should be identified near the prospective industrial area/construction sites which can be earmarked to provide water exclusively for these purposes.

Water resource planning

- Water resource development projects should as far as possible be planned and developed as multipurpose projects. Provision for drinking water should be a primary consideration. The study of the likely impact of a project on human lives, settlements, socio-economic conditions, environment and sustainability aspects shall form an essential component of project planning.
- Water resource development process should be inclusive in nature taking care of rights of all stakeholders. Special attention should be given to the needs of scheduled tribes and other weaker sections of the society at planning stage.

- Integrated and coordinated development of surface water and ground water resources and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of the project implementation.
- Realistic time, cost and realisation of benefits of a project should be planned to upgrade the quality of project preparation and management.
- The involvement and participation of *panchayats* and stakeholders should be encouraged right from the project planning stage.
- Minimum flow in the perennial streams should be ensured while planning a surface water resource development project for environment and ecological considerations.

Surface water development

- For surface water development in a drainage line, a three tier water resource development system should be created. This will involve construction of plastic film lined tanks on top of hill, tank-cum-well system in the mid-hills and open dug well in valley areas. The tanks in the mid-hills can be both dugout or impounded type or combination of both depending upon the topography.
- A drainage line should be treated as single entity for development of surface water resources on contiguous basis to realize the full potential of available water resources. The scheme may be named as micro-level water resource development scheme (MWRDS).
- In Island where soils are highly porous and ground water is saline due to proximity to sea, water resources should be developed through lined dug out ponds.
- Necessary provision for surface drainage should be made in the valley areas.

Ground water development

- Augmentation of groundwater resources is necessary where surface storage structures are inadequate to meet the demand or when annual exploitation of resources exceeds its replenishment in a given area. High runoff, lack of surface storages and reduction in natural recharge due to human interventions are the main reasons for groundwater augmentation in A&N Islands.
- There should be a periodical reassessment of the ground water potential on a scientific basis, taking into consideration the quality of the available water and techno-economic feasibility of its extraction.
- Ground water exploitation through bore wells should be exclusively used only for drinking purposes in view of typical confined aquifer characteristics. No bore well should be allowed to be used for irrigation/industry.
- Exploitation of ground water resources should be regulated to avoid detrimental environmental consequences of overexploitation by the Union Territory Authority.
- Over exploitation of ground water should be avoided especially near the coast to prevent ingress of seawater into sweet water aquifers.

Drinking Water

- Access to safe and adequate drinking water is a fundamental human need and needs to be provided to the entire population both in urban and rural areas.
- Micro-irrigation / micro-hydropower projects should invariably include drinking water component.
- Perennial streams, large diameter dug wells and bore wells (in safer zones) should be utilized for developing drinking water sources.
- Roof water harvesting in government and commercial premises should be made mandatory for use in non-drinking purposes.
- To maintain drinking water quality standards, water treatment plants / units should be established at village level.

Irrigation water

- Irrigation planning should be based on demand rather than supply. Irrigation intensity should aim to extend the benefits of irrigation to more farm families to maximise the production.

- Conjunctive use of surface and ground water through rainwater harvesting in farm ponds and wells located on seepage line should be promoted. In porous soil areas, lining of pond with silpauline/geo-membrane with covering material to protect from high daily insolation should be encouraged through subsidy.
- Efficient irrigation techniques such as drip irrigation for plantation/spices/fruit crops (coconut, arecanut, black pepper, clove, banana, watermelon etc.) and sprinkler for vegetables should be promoted.
- Water conservation measures such as, mulching, residue soil moisture management, minimising evaporation losses, promotion of low water requiring crops should be considered.

Water quality

- Both surface and ground water should be monitored regularly for its quality.
- Necessary legislation is to be made for preservation of existing water bodies by preventing encroachment and deterioration of water quality.

Energy considerations

- Feasibility of using renewable energy sources for pumping water specifically for irrigation should be explored. Solar energy based pumping system have a chance as the water requirement period and sunshine periods coincide.
- In A&N Islands, electricity generation is mostly through diesel which is quite expensive, thus efficiency of pumps should be given utmost attention in water resource development design parameter.

Participatory approach through water user association

- Management of the water resources for diverse uses should incorporate a participatory approach. As rainwater harvesting is linked with the watershed programs, involving water user associations (WUA) at village level will help ensure productivity and equity aspects. WUA and the local bodies such as *panchayats* should particularly be involved in the operation, maintenance and management of water infrastructures / facilities.

Regulation / enactment of law

- Regulation in the utilization of groundwater by way of legislation is important particularly in the fragile ecosystem like A&N Islands. At present, the groundwater development in A&N Islands is mostly done by private individuals. Hence virtually no groundwater discipline i.e. safer zone, spacing etc. is being followed. Hence, groundwater legislation is a must to regulate groundwater development.
- Presently A&N administration does not have an irrigation department, therefore a water resource development authority should be created for the planning, development and management of water resources with a multi-sectoral, multi-disciplinary and participatory approach as well as integrating quality, quantity and the environmental aspects. It will oversee the development of micro level water resources right from planning to operation in close collaboration with *Panchayati Raj Institutions*. All the rights of ownership of the water resources should be vested to this authority.

Role of NGO's

- NGOs could play a pivotal role in awareness building in communities, formation and capacity building of water users association (WUAs), design, construction and management of water harvesting and conservation structures in rural areas, sharing experiences and information with various stakeholders, and integration of information from various sources. Experienced NGO's should also find representation at the district and state level forums.

Research and development

- For effective and economical management of water resources of A&N Islands, promotion of frontier research and development efforts on surface and ground water hydrology, assessment of water resources, water harvesting and ground water recharge, use of remote sensing techniques in spatial database management, water quality, river morphology and hydraulics, evaporation and seepage losses, crops and cropping systems, water conservation and better water management practices, soils and material research, safety and longevity of water-related structures, economical designs for water resource projects, risk analysis and disaster management, sedimentation of reservoirs, use of sea water resources, prevention of salinity ingress, prevention/reclamation of water logged/saline lands, environmental flow requirements, equity and adequacy in water distribution and the upcoming impact of climate change on natural resources should be taken up.

10. Conclusions

The development of water resources in A&N Islands requires an approach that is regional in scale and holistic in scope. Planning and management of water resources at a regional scale will increasingly demand an integrated overview of different types of hydrological data gathered from different sources. Remote sensing could be used to define the representative sites, guide the field work and generate thematic layers such as surface hydrology, geomorphology, geology, vegetation, rainfall and human impact. It can be achieved by water resource planning at macro-scale, understanding, modelling and monitoring water bodies and their catchments at watershed scale and efficient management of augmented water in the command area. In addition to water resource development schemes (medium and minor projects including digging wells and ponds, constructing check dams and artificial groundwater recharge structures), environment aspects should be maintained with the prevailing socio-economic settings and fragile ecosystem of the Islands.

For valley areas, the paddy fields should be properly bunded to store the rain water. The stored rainwater will slowly percolate down and can be harvested back through open dug wells in downstream. One ha of paddy land, if bunded properly by 22.5 cm high bunds with provision of draining excess water, will facilitate slow percolation of about 6000 m^3 of water (@4 mm/day for 150 days). Assuming that about 50% of the percolated water can be harvested back through downstream open dug well, which should not be deeper than 8 m, about 3000 m^3 of water will be available per ha of paddy land which will be sufficient for providing 300 mm irrigation water in the following dry season crops. This will be in addition to the normal recharge received from the forested catchment on both sides of valley. This practice can be adopted for the valley lands which are at more than 10 m elevation than sea level to avoid the risk of sea water intrusion. Using this principle, three open dug well of 2 m diameter each have been dug at Bloomsdale farm, CARI to irrigate 3 ha area. The cost of each well is about Rs. 80,000. The pumping test of the well indicated that about 20 m^3 water can be pumped per day from the well which will provide about 24 cm of water to 1 ha land in 120 days of the crop, sufficient for irrigating at IW/CPE of 0.5.

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