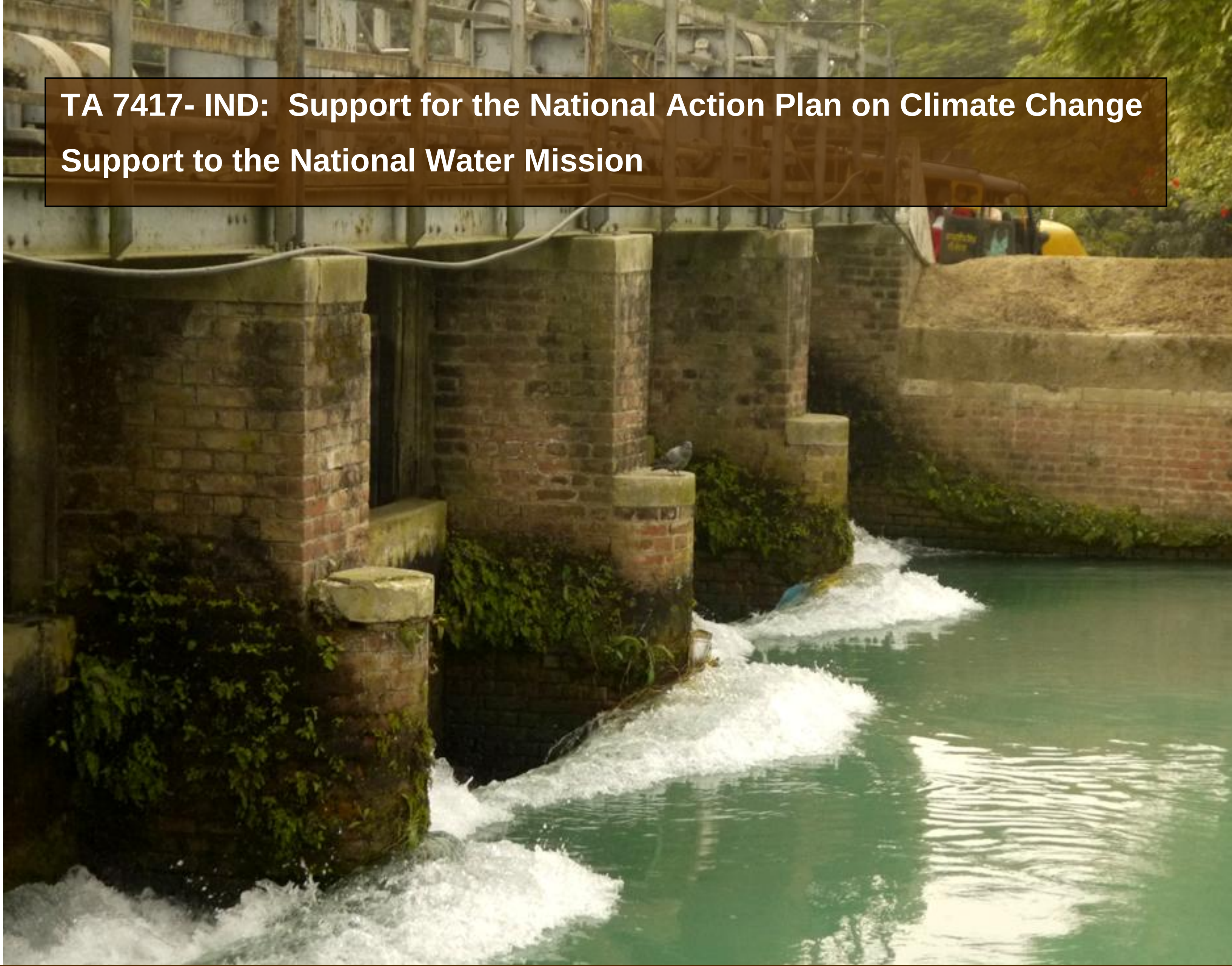

TA 7417- IND: Support for the National Action Plan on Climate Change

Support to the National Water Mission

Final Report September 2011
Appendix 4 Cauvery Delta Sub Basin

PREPARED FOR
Government of India
Governments of Punjab, Madhya Pradesh and Tamil Nadu
Asian Development Bank

Appendix 4

Cauvery Delta Sub Basin Tamil Nadu

SUMMARY OF ABBREVIATIONS

A1B	IPCC Climate Change Scenario A1 assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B).
A2	IPCC climate change Scenario A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.
ADB	Asian Development Bank
AGTC	Agriculture Technocrats Action Committee of Punjab
AOGCM	Atmosphere Ocean Global Circulation Model
APHRODITE	Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources - a observed gridded rainfall dataset developed in Japan
APN	Asian Pacific Network for Global Change Research
AR	Artificial Recharge
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
AWM	Adaptive Water Management
B1	IPCC climate change Scenario B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy.
B2	IPCC climate change Scenario B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability.
BBMB	Bhakra Beas Management Board
BCM	Billion Cubic Metres
BML	Bhakra Main Line Canal
BPL	Below the Poverty Line
BPMO	Basin Planning and Management Organisation of the CWC
CAD	Command Area Development
CADA	Command Area Development Authority
CBO	Community Based Organisation
CCA	Command Control Area
CCIP	Climate Change Implementation Plan
CDM	Clean Development Mechanism
CDMR	Cauvery Delta Modernisation Report
CESER	Centre for Earth Systems Engineering Research, Newcastle University, UK
CGIAR	Consultative Group on International Agricultural Research
CGWA	Central Ground Water Authority
CGWB	Central Ground Water Board
CMIP	Coupled Model Intercomparison Project - an IPCC initiative to compare climate models
CMR	Cauvery Modernization Report
CNES	French Centre National d'Etudes Spatiales
CPCB	Central Pollution Control Board
CSK HPAU	CSK Himachal Pradesh Agricultural University
CUSECS	Cubic feet per second
CWC	Central Water Commission
CWPRS	Central Water and Power Research Station
DEA	Department of Economic Affairs
DEM	Digital Elevation Model
DJF	December-January-February
DMC	Developing Member Country
DMR	Delta Management Report
DSS	Decision Support System
DSSAT	Decision Support System for Agricultural Technology
DTR	Diurnal Temperature Range
EC	Electrical Conductivity
ED&MM	Exploratory Drilling and Materials Management
EIA	Environmental Impact Assessment
EMC	Environmental Monitoring Committee
EMP	Environmental Management Plan
ESSP	Earth System Science Programme
ETo	Evapotranspiration
FAO	Food and Agriculture Organisation of the United Nations
FASS	Farmers Advisory Services Schemes

FPARP	Farmer's Participatory Action Research Programme
FYP	Five Year Plan
GCM	Global Circulation or Climate Model
GIS	Geographic Information Systems
GLOF	Glacial Lake Outburst Flood
GOI	Government of India
GRBMP	Ganga River Basin Management Plan
GSI	Geological Survey of India
GW	Groundwater
HAM	Hectare Metres
HIS	Hydrological Information System
HP	Himachal Pradesh
HP2	Hydrology Project 2
I&D	Irrigation and Drainage
ICIMOD	International Centre for Integrated Mountain Development
ICT	Information and Communication Technologies
IITM	Indian Institute for Tropical Meteorology
IMD	Indian Meteorological Department
IMTI	Irrigation Management Training Institute
INCCA	Indian Network of Climate Change Assessment
IPCC	International Panel on Climate Change
IRBM	Integrated River Basin Management
IS	Institutional Strengthening
ISRO	Indian Space Research Organisation
IWRM	Integrated Water Resources Management
JF	January-February
JJAS	June-July-August-September
KVK	Krishi Vigyan Kendras
LBC	Lateral Boundary Conditions
l/s/ha	litre per second per hectare
LBC	Lateral Boundary Conditions
LIS	Legal Information System
MAM	March-April-May
MCM	Million Cubic Meters
MODFLOW	Three-dimensional finite-difference groundwater flow model developed by the US Geological Survey
MoEF	Ministry of Environment and Forests
MOHC	Met Office Hadley Centre (UK)
MOU	Memorandum of Understanding
MoWR	Ministry of Water Resources
MP	Madhya Pradesh
MSL	Mean Sea Level
MSP	Minimum Support Price
MTM	Megha-Tropiques Mission
NAPCC	National Action Plan for Climate Change
NARBO	Network of Asian River Basin Organisations
NCDS	National Committee on Dam Safety
NCIWRD	National Commission for Water Resources Development
NCMRFF	National Centre for Medium Range Weather Forecasting
NDC	National Data Centre, India
NDMA	National Disaster Management Agency
NGO	Non-Governmental Organisation
NIH	National Institute of Hydrology
NMSKCC	National Mission on Strategic Knowledge for Climate Change
NREGA	National Rural Employment Guarantee Act
NRSA	National Remote Sensing Agency
NSRC	National Remote Sensing Centre
NWH	North-western Himalayan Region
NWM	National Water Mission of the NAPCC
ON	October-November
OND	October-November-December
PAFC	Punjab Agro Foods Corporation
PAO	Project Appraisal Organisation

PATA	Policy Advisory Technical Assistance
PAU	Punjab Agricultural University
PES	Payment for Environmental Services
PIM	Participatory Irrigation Management
PPE	Perturbed Physics Ensemble
PPP	Public Private Partnerships
PRA	Participatory Rural Appraisal
PRECIS	Providing Regional Climates for Impacts Studies
PRI	Panchayati Raj Institutions
PWD	Public Works Department
Q14, Q1 Q0	Identifiers for runs with different perturbations
QUMP	Quantifying Uncertainty in Model Predictions is an approach which aims to provide probabilistic projections of future climate.
RegCM	Regional Climate Model system RegCM
R&R	Rehabilitation and Resettlement
RBO	River Basin Organisation
RCM	Regional Circulation or Climate Model
RCP	Representative Concentration Pathways
RGNGT&RI	Rajiv Gandhi National Ground Water Training and Research Institute
RSC	Residual Sodium Carbonate
RTDSS	Real Time Data Support Systems
SAM	Survey Assessment and Monitoring
SAPCC	State Action Plans for Climate Change
SD&MA	Service Delivery and Management Alternatives
SGWA	State Ground Water Authority
SML	Sustainable Management and Liaison
S-NWM	ADB Support TA to the National Water Mission of the NAPCC
SRES	Special Report on Emission Scenario (IPCC SRES November 2000
SRI	System of Rice Intensification
SRTM90	A DEM with 90m resolution developed by the Shuttle Radar Topography Mission
START	Global change system for analysis, research and training coordinated by IIT Mumbai
SWAP	Soil-Water-Atmosphere-Plant
SWAT	Soil and Water Assessment Tool
T&TT	Training and Technology Transfer
TA	Technical Assistance
TERI	The Energy and Resources Institute
TMC	Thousand million cubic feet equals 28.3 million m^3
TN	Tamil Nadu
TNRRI	Tamil Nadu Rice Research Institute
TNSEB	Tamil Nadu State Electricity Board
UKIERI	UK India Education and Research Initiative
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
UT	Union Territory
WC	Conveyance efficiency
WD	Drainage efficiency
WEAP	Water Evaluation and Planning System- planning tool from Stockholm Environment Institute
WF	On-farm application efficiency
WHS	Water Harvesting Structures
WP	Water use efficiency at the project level
WQAA	Water Quality Assessment Authority
WR	Reservoir or weir efficiency
WRCRC	Water Resources Control and Review Council
WRD	Water Resources Department
WRIS	Water Resources Information System
WRO	Water Resources Organisation
WUA	Water Users Association
WWF	World Wildlife Fund

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Appendix 4A: Cauvery Delta Sub Basin

Sub Basin Profile

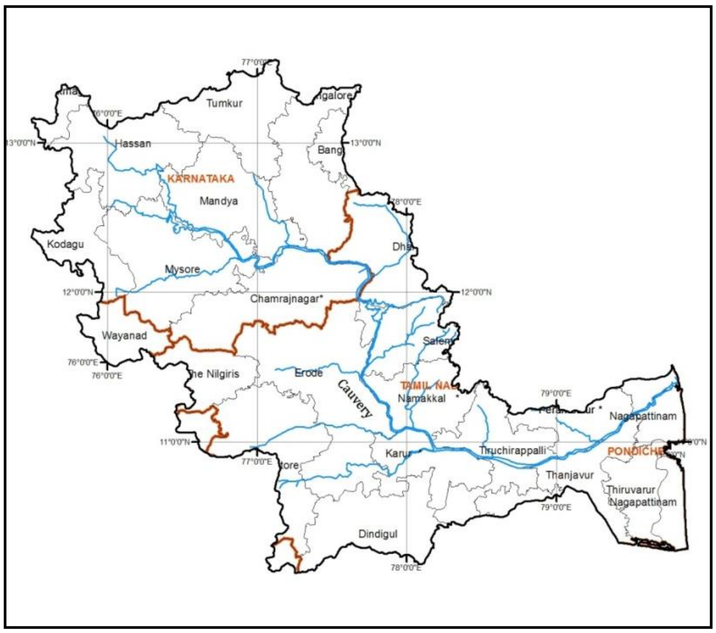
I. INTRODUCTION

1. Tamil Nadu is heavily dependent on monsoon rains, and thereby is prone to droughts when the monsoons fail. The climate of the state ranges from dry sub-humid to semi-arid. The state has three distinct periods of rainfall; (i) South West monsoon from June to September, with strong southwest winds; (ii) North East monsoon from October to December, with dominant northeast winds; and (iii) Dry season from January to May.

2. The Cauvery Delta forms the lower part of the Cauvery River System and has complex water systems with issues of surface and groundwater, coastal instability and salinity intrusion.

3. The normal annual rainfall of the state is about 945 mm of which 48% is through the North East monsoon, and 32% through the South West monsoon. Since the state is entirely dependent on rains for recharging its water resources, monsoon failures lead to acute water scarcity and severe drought [Nathan, 1995].

Figure 1: Cauvery Basin



4. The Cauvery Delta lies at the bottom of the Cauvery river basin. The river Cauvery is the fourth largest river of southern region and flows from north west to south east. Cauvery Delta lies in the eastern point of Tamil Nadu between 10:00 N to 11:30 N Latitude and between 78.15 E to79.45 E Longitude. Cauvery Delta zone consist of four districts of Nagappattinam, Thanjavur and Thrivarur and parts of the district Trichy, Cuddalore and Puddubbottai in Tamil Nadu. Cauvery Delta zone has a total geographical land area of 1.45 million Ha which is equivalent 11% of the area of Tamil Nadu state

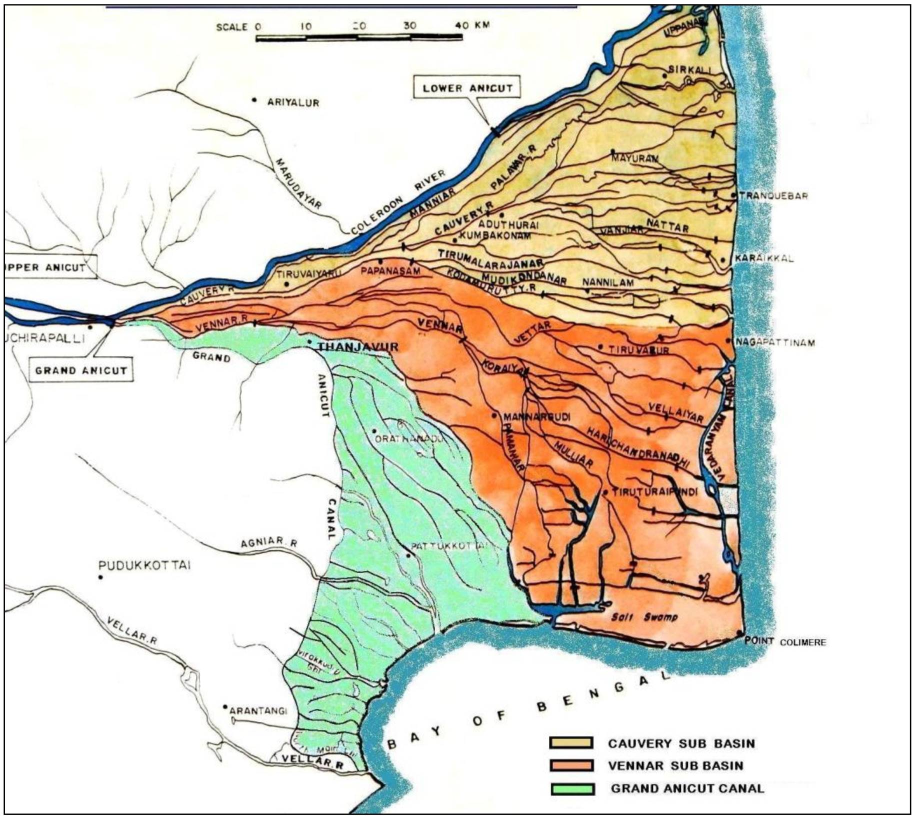
5. On its total course of about 800 km, the Cauvery travels through the states of Karnataka, Tamil Nadu, Kerala and a Union Territory of Pondicherry before falling into the Bay of Bengal. The Cauvery has a total drainage area of 81,155 sq km (2.5% of the total geographical area of the country). Of this 42 % lies in Karnataka, 54 % in Tamil Nadu, 3.5 % in Kerala and the rest in the Karaikkal region of Pondicherry. The overall basin map is shown in Figure 2.

6. Cauvery river originates in the Mercara District of Karnataka in the Brahmagiri range of hills in the Western Ghats at an elevation of 1341 m above mean sea level. River enters the state of Tamil Nadu where Metter dam (1934) impounds 95.6 TMC of water for use in the Cauvery Delta area. At Upper Anicut, about 177 kms from Metter dam the river splits into two branches the northern branch in called the Coleroon, a flood carrier and the southern branch in the main Cauvery which carries water for irrigation.

7. The Grand Anicut (Barrage) is constructed on the main Cauvery river. At Grand Anicut complex, the river Cauvery splits into two branches Cauvery and Vennar . These two rivers act as the main irrigation canals with the help of head regulators provided on the both the rivers separately. These rivers in turn, divide and sub divide into number of branches which form network all over delta and distributes the Cauvery water in the vast irrigation system. These channels also carry the drainage water and act as irrigation cum drainage channels in the lower delta.

8. The northern branch of Cauvery namely the Coleroon bifurcates at the Upper Anicut from the Cauvery is the main flood carrier and it continues to flow in a north-easterly direction to enter the Bay of Bengal south of Porto Novo at the confluence of Vellar in the north. The Lower Coleroon Anicut (LCA), which is the last point of utilisation of Cauvery water, is located about 110km below the Upper Anicut. More than 50% of the area irrigated in Cauvery Basin in Tamil Nadu comes under Cauvery Delta, the total area is 560,000 ha with four systems of canals; (i) Lower Coleroon Anicut system (49,000ha) (ii) Cauvery System (200,000ha); (iii) Vennar System (190,000) and the (iv) Grand Anicut System (121,000) as shown in Figure 2

Figure 2: Cauvery Delta



9. The population of the delta is estimated to be around 4.8 million, composed of about 73% rural population, the delta covers three districts as shown in Table 1

Table 1: Population

District	Rural	Urban	Total
Thanjavur	1,467,577	748,561	2,216,138
Tiruvarur	932,231	237,243	169,474
Nagapattinam	1,158,557	1,488,839	330,282
Total	**3,558,365**	**1,316,085**	**4,874,451**

II. SURFACE WATER RESOURCES

A. Cauvery Basin Characteristics

10. The basin location and key topographic and drainage features are shown in Figure 3. The major tributaries and their characteristics are listed in Table 2.

Figure 3: Cauvery Basin Elevations

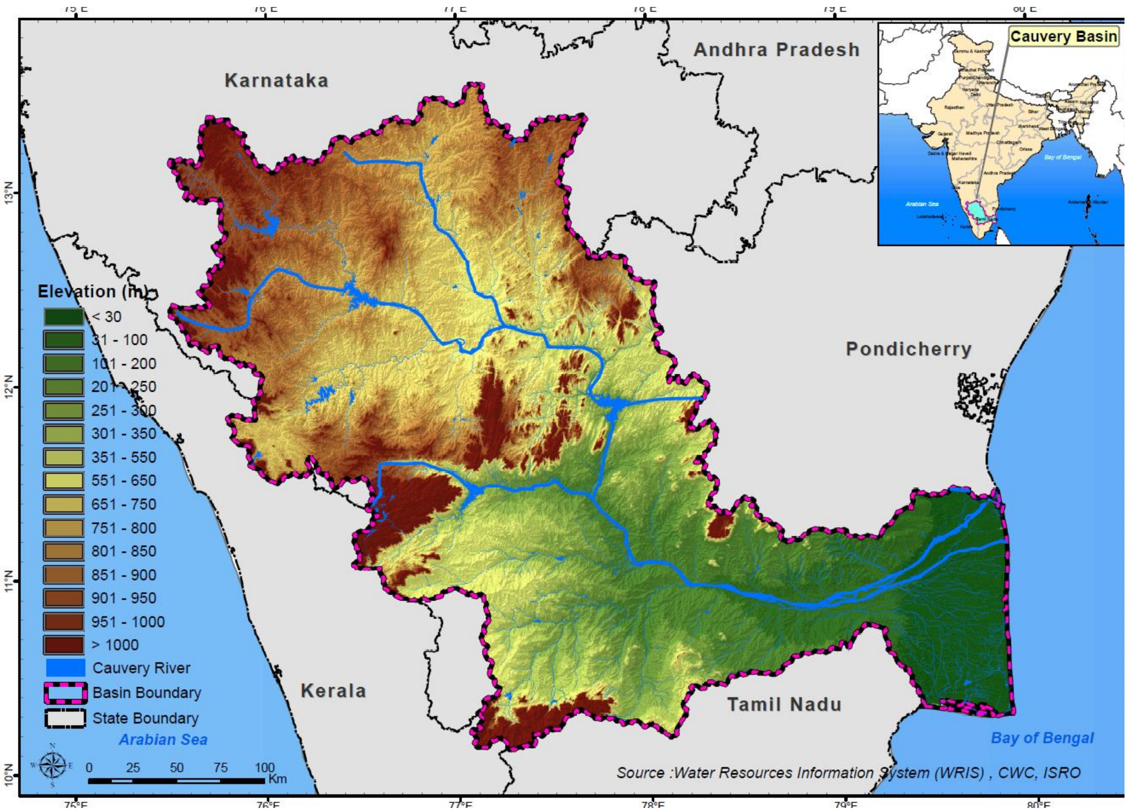


Table 2: Major Tributaries of Cauvery

Tributary Name	Catch ment Area (km2)	Origin	Altitude (m)	Length (km)	Sub-Tributaries	State
Arakavathy	4351	Nandidurga	1480	161	Kumaudavathy, Manihalla, Kuttehole, Vrishabhavathy	Karnataka and Tamil Nadu
Harangi	717	Pushpagiri Hills of Western Ghats.	1067	50		Karnataka
Hemavathy	5410	Ballarayana Durga in Western Ghats	1219	245		Karnataka
Kabini	7040	Western Ghats in Kerala	2140	230	Taraka, Hebballa, Nugu, Gundal	Karnataka, Kerala and Tamil Nadu
Lakshmana Thirtha		Western Ghats	1950	131	Ramathirtha	Karnataka
Shimsha	8469	Tumkur District	914	221	Veeravaishnavi, Kanihalla, Chickkhole, Habbahalla, Mullahalla, Kanva	Karnataka
Suvarnavathy	1787	Nasrur Ghat Range		88		
Source: http://www.indiawaterportal.org/node/91						

11. The average annual surface water potential of the basin has been estimated[1] to be 21.4 km^3. It has been further estimated that 19.0 km^3 is utilizable. Present surface water use in the basin is 18.0 km^3. The principal soil types found in the basin are red soils, black soils, laterite, alluvial soils, forest soils and mixed soils. The major soil type is red soils. Major land uses are the agriculture and forest. The cultivable area in the basin is about 5.8 Million ha, which is 3% of the total cultivable area of the country. The land under cultivation is 48%. with about 24% of the cultivable area is under irrigation. The major crops grown in the basin are paddy, sugarcane, ragi, jowar and cash crops of coffee, pepper, banana, betel vine, gingili, onion, cotton, black gram. The hydropower potential of the basin has been assessed as 1359 MW at 60% load factor.

B. The Hydrometric Network

12. The hydrometric network in the basin includes 159 rain gauges and 24 meteorological stations maintained by IMD (Figure 4) falling in the states of Karnataka, part of Kerala and Tamilnadu. CWC observe stream flow (GD), sediment (GS) and water quality (WQ) at 12 stations in Karnataka, 1 in Kerala and 17 in Tamil Nadu as shown in Figure 5. Six streamflow stations are in the delta area, concentrated around a small area that is a part of Pondicherry.

[1] Cauvery River Basin: An overview: http://www.indiawaterportal.org/node/24

Figure 4: IMD Hydro-meteorological Sites

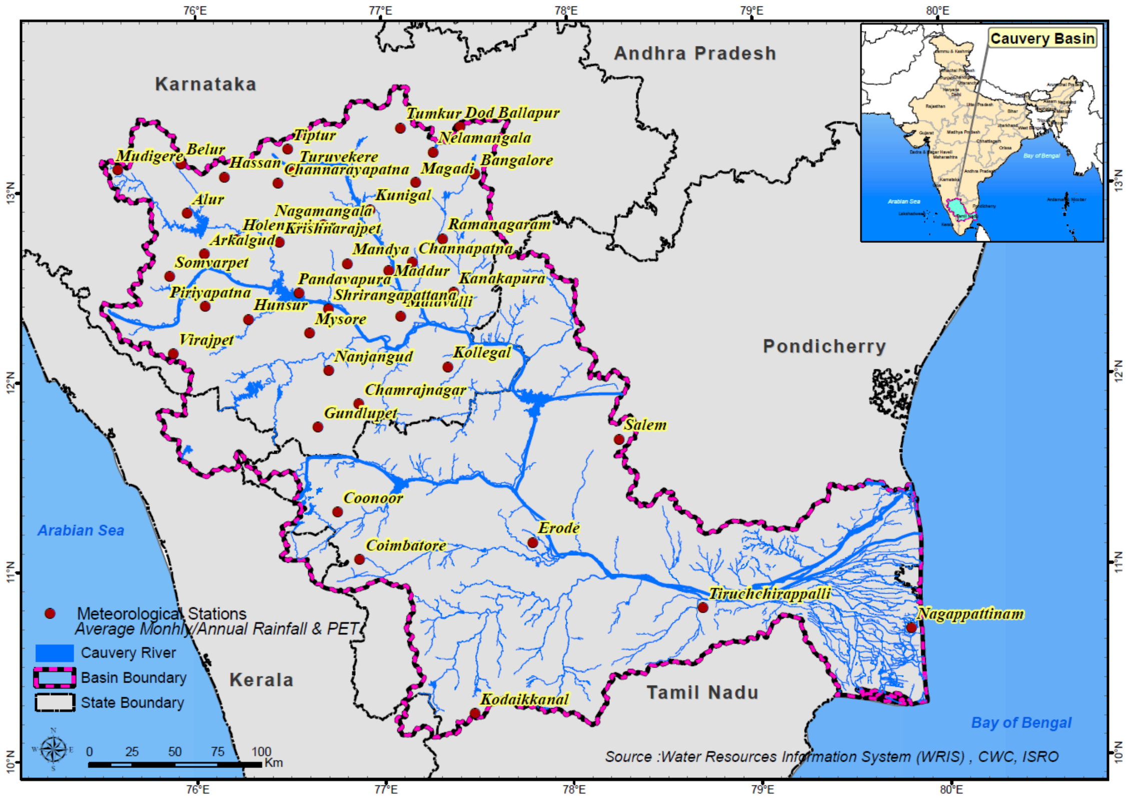
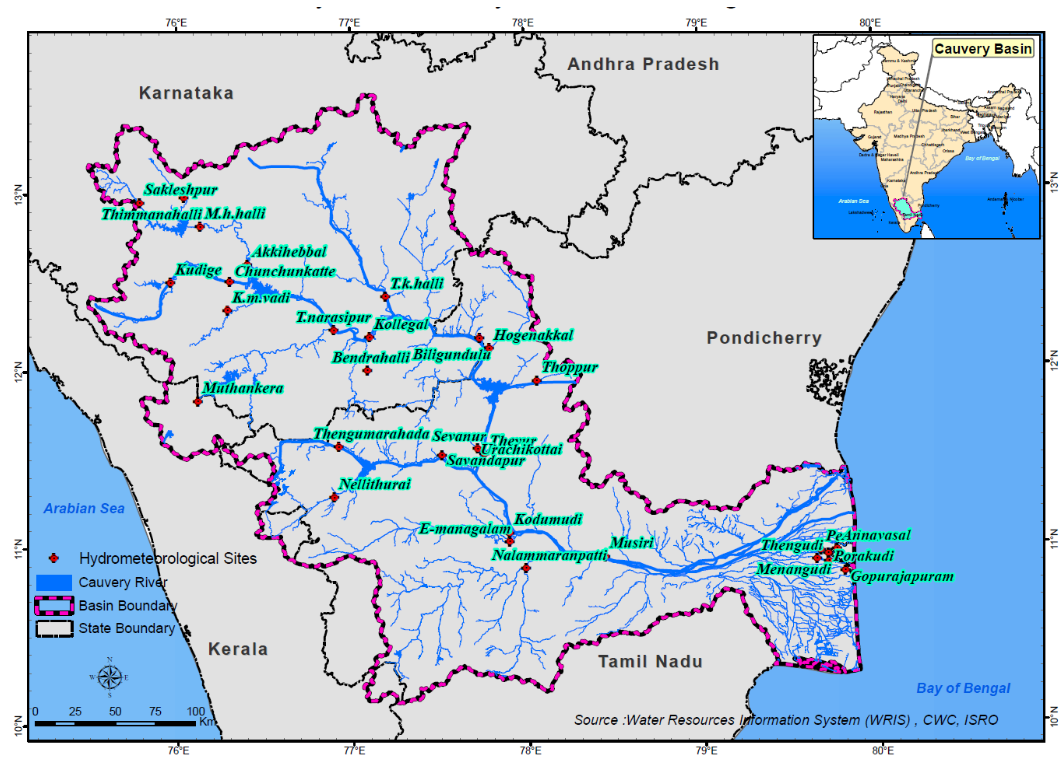


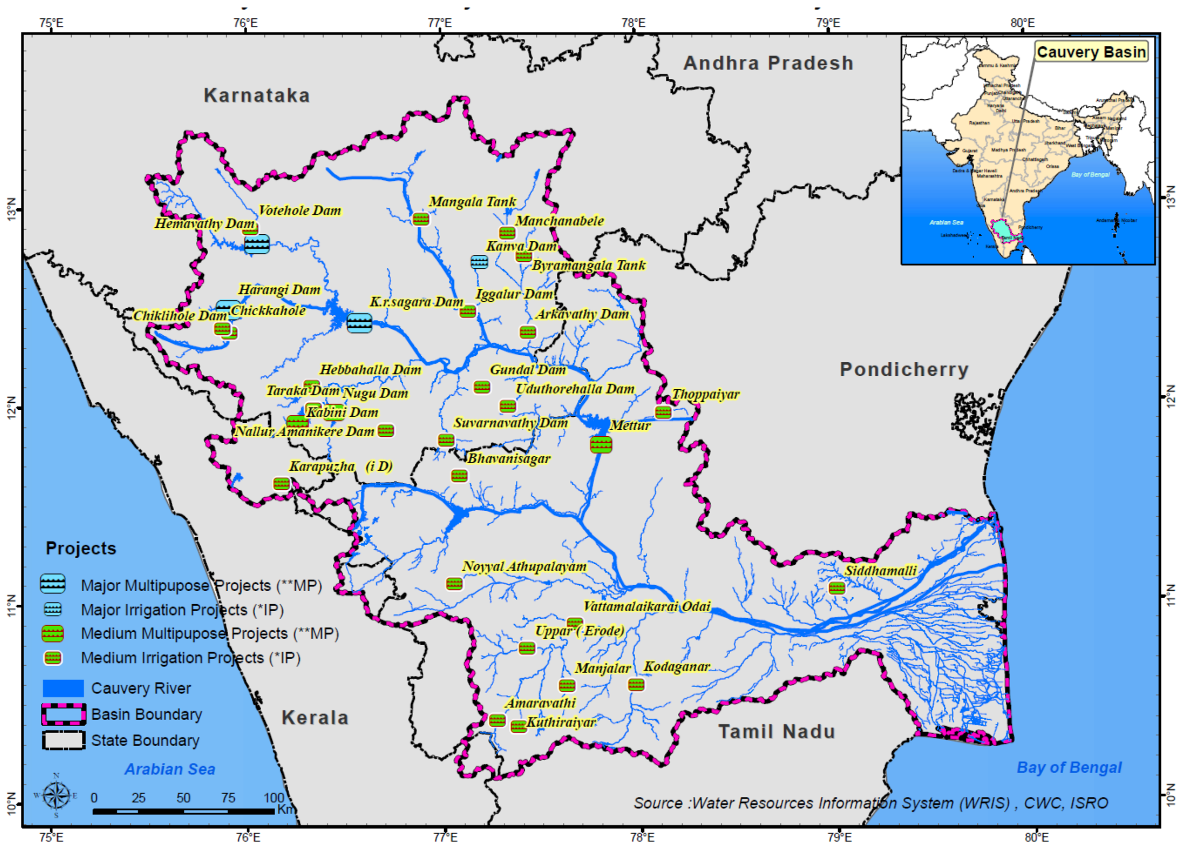
Figure 5: River Gauges



C. Projects

13. There are three major and two medium sized multipurpose projects in the basin, and one major and 26 medium sized irrigation projects (Figure 6).

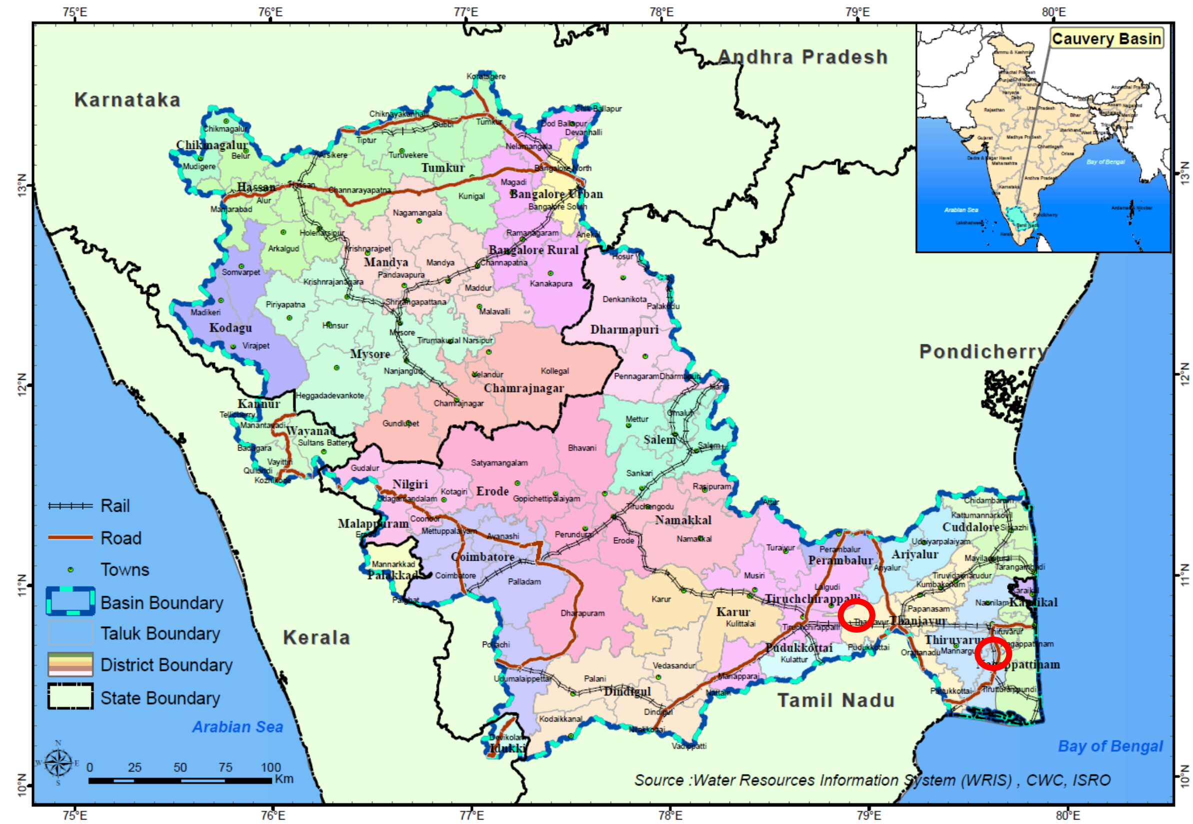
Figure 6: Major and Medium Project Locations



D. Climatic Norms, Cauvery Basin

14. An assessment has been made of climatic norms in the Cauvery Basin for station at Tiruchchirapalli and Nagappattinam. The location of the stations (red circles) is shown in Figure 7.

Figure 7: Stations Used for Assessing Climatic Norms



15. In the absence of meteorological data from the Indian Meteorological Department (IMD) in time for the preparation of this report, use was made of the FAO CLIMWAT database[2] which includes mean monthly meteorological data for over 5000 stations worldwide.

16. Figure 8 and Figure 9 show climatic norms for Tiruchchirapalli and Nagappattinam respectively and includes potential evapotranspiration and effective rainfall calculated using the FAO CROPWAT 8 package[3]. CROPWAT 8 uses the FAO Penman method in the calculation of ETo, and calculates effective rainfall using the USDA S.C. method.

17. **Tiruchchirapalli** *:* Mean daily temperatures range from a low of about 25°C in December to a high of about 32°C in May. April to June are the hottest months with mean daily maximums close to 31°C. The mean daily temperature range is typically about 8°C. The maximum range occurs in May and the minimum in December. Relative humidity is at its lowest in June, averaging 60%, and peaks in November at 73%. Wind speeds are generally in the range of 1.5 to 6.3 m/s, and are highest in June to July. Solar radiation is at its peak in March and low in November. The climatic parameters combine to give an annual potential evapotranspiration at of 2191 mm, with peak evapotranspiration in June, July and August. The peak daily rates of evapotranspiration occur in July with a mean of 8.4 mm/day. It is clear from Figure 8 that the effective precipitation is far short of potential evapotranspiration. Mean annual rainfall is 902 mm, and the computed mean annual effective rainfall is 726 mm.

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[2] http://www.fao.org/nr/water/infores_databases_climwat.html

[3] http://www.fao.org/nr/water/infores_databases_cropwat.html

Figure 8 Tiruchchirapalli Climate Norms

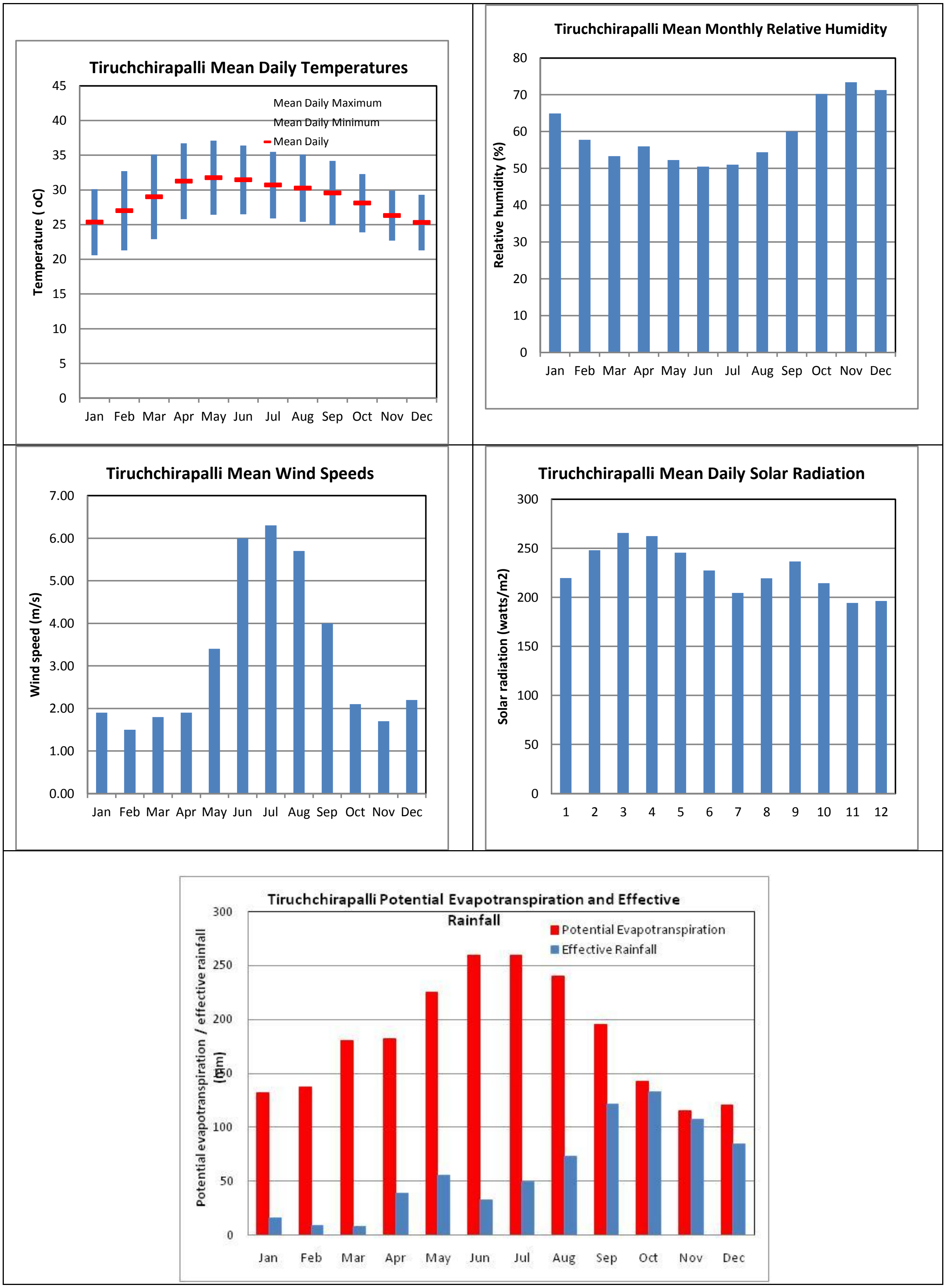
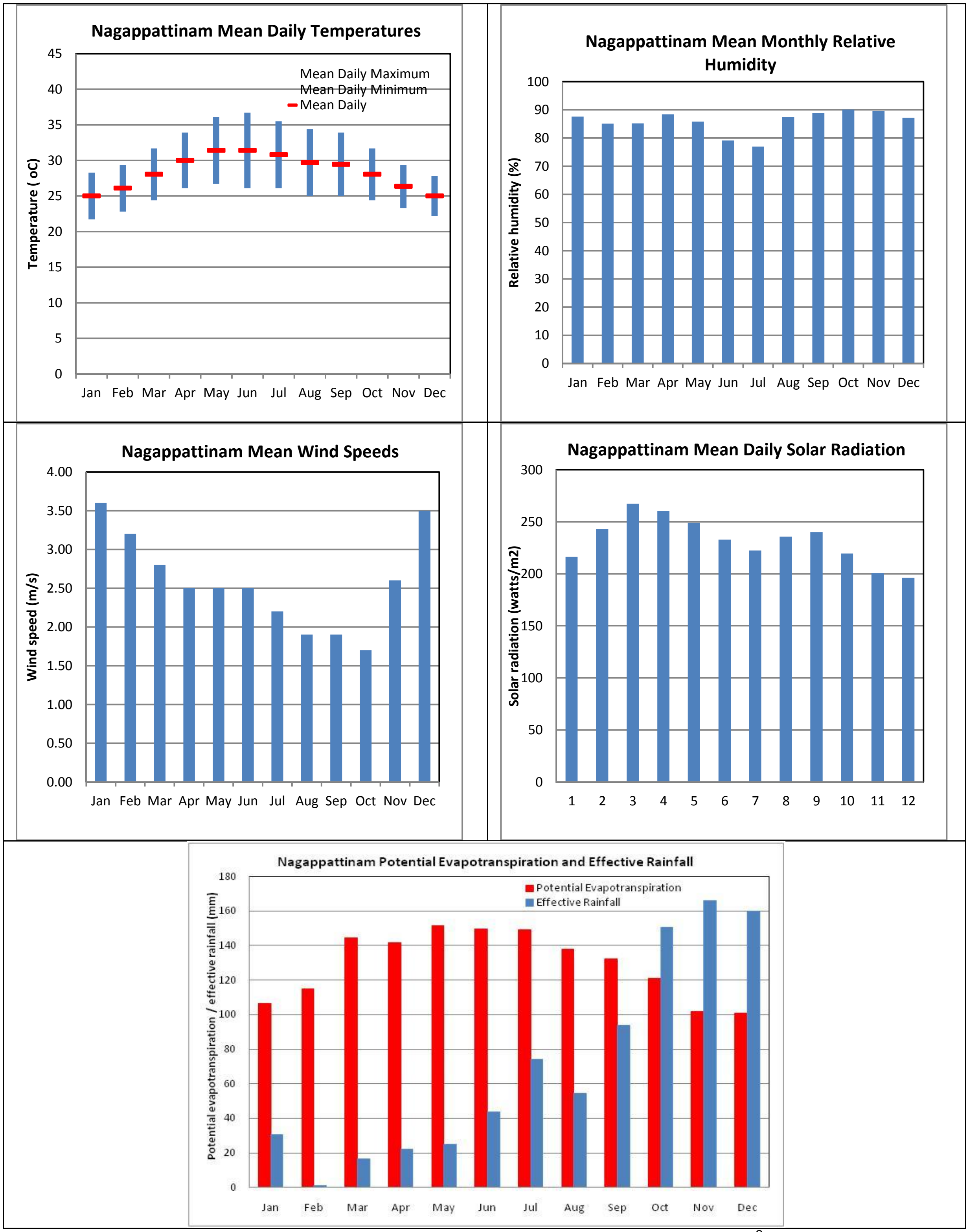


Figure 9 Climatic Norms for Nagappattinam



18. **Nagappattinam*:*** Mean daily temperatures range from a low of about 25°C in December to a high of about 31.4°C in May. May and June are the hottest months with mean daily maximums close to 31°C.

The mean daily temperature range is typically about 8°C. The maximum range occurs in May-June and the minimum range in November-December. Relative humidity is very high throughout the year, being at its lowest in July when it averages 76%, and peaking in October at 90%. Wind speeds are generally in the range of 1.7 to 3.6 m/s, and are highest in March to June. Solar radiation is at its peak in March and lowest in December. The climatic parameters combine to give an annual potential evapotranspiration at of 1552 mm, with peak evapotranspiration in May and June. The peak daily rates of evapotranspiration occur in May with a mean of 4.9 mm/day. It is clear from Figure 9 , that except for the months of October, November and December, the effective precipitation is far short of potential evapotranspiration. Mean annual rainfall is 1421 mm, and the computed mean annual effective rainfall is 837 mm.

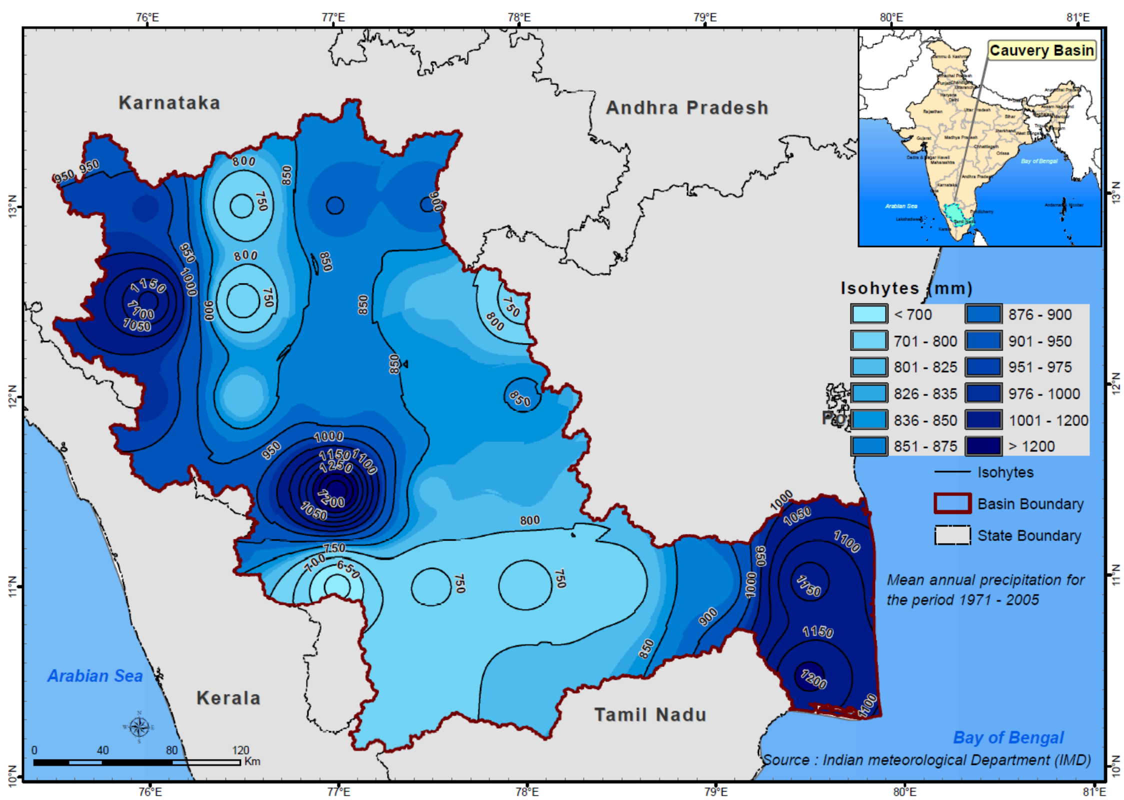
E. Precipitation in the Cauvery Basin

19. The analysis presented here is based on the IMD gridded 0.5°×0.5° data that covers the 35 year period 1971 to 2005.

1. Annual Precipitation

20. Figure 10 presents isohyets of mean annual precipitation over the Cauvery Basin. Precipitation varies considerably across the basin. The western side of the catchment mainly experiences the south-west monsoon from June to September and the eastern side experiences north-east monsoon from October to December. The rainfall during the rest of the year is insignificant. The total rainfall in the basin across the year can be segregated into parts; about 50% is received during the south-west monsoon, about 33% in the northeast monsoon, roughly 10% in the pre monsoons and the rest in the winter months. Annual precipitation varies from about 700-900 mm in the interior to 1200 and above in the eastern and western edges of the basin.

Figure 10: Mean Annual Precipitation



21. Coefficients of variation in annual rainfall are shown in Figure 11. Inter annual variability is more or less spatially uniform in the delta region. Variability is greater in the higher elevation ranges in the south

western part. Figure 12 shows deviations from the mean of annual precipitation in the Cauvery basin in the period 1971 to 2005. It is clear that there is significant spatial variability. Interestingly there was consistent drought across the basin the early 2000s, followed by an extremely wet year at a number of locations in 2005.

Figure 11: Coefficient of Variation of Annual Rainfall

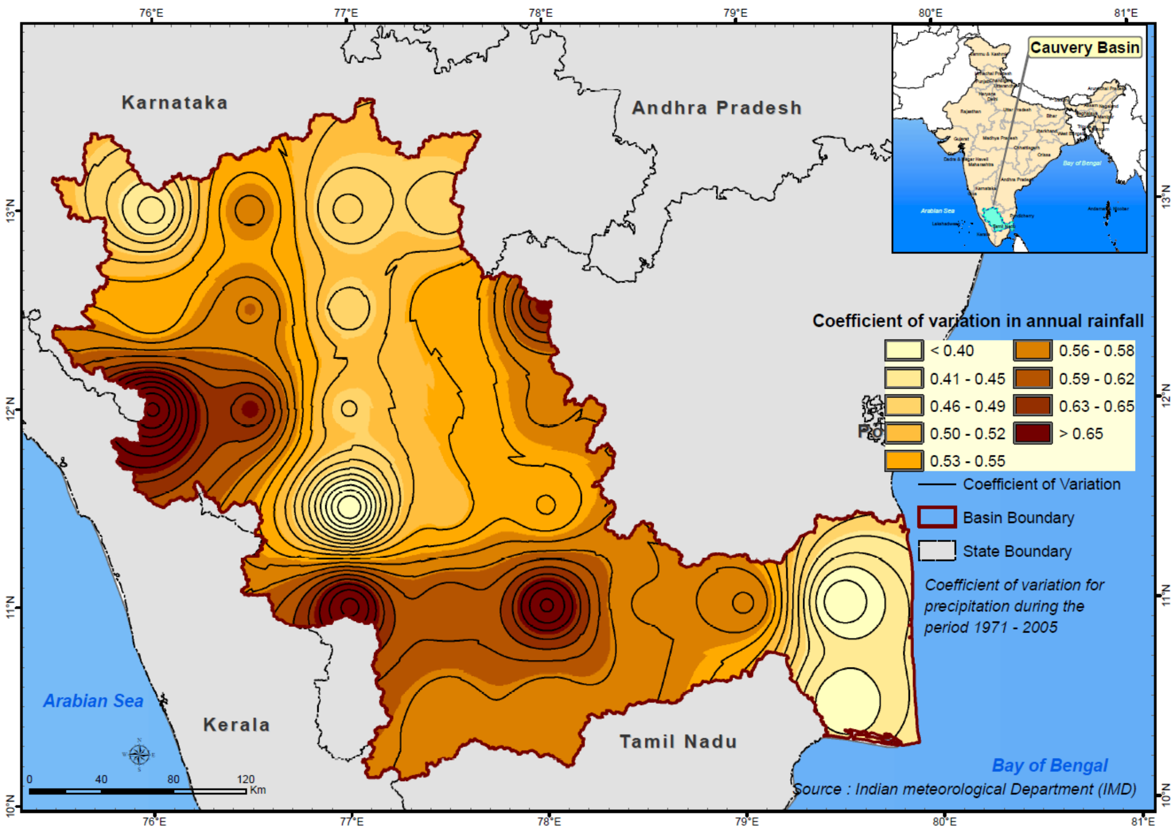
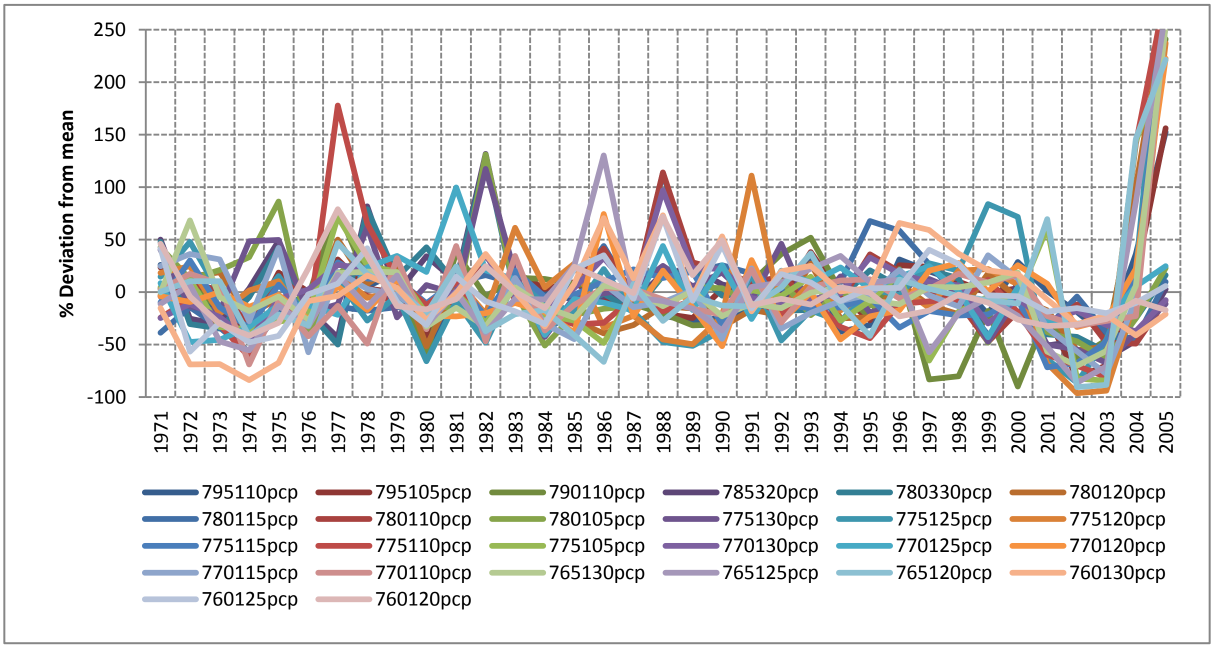


Figure 12: Deviations from the Mean of Annual Rainfall at all IMD grids



F. Seasonal Precipitation

22. Seasonal precipitation has been analysed in a similar way to that of annual precipitation. For the purposes of analysis, seasons were defined as March, April, May (MAM); June, July, August, September (JJAS); October, November (ON); December, January, February (DJF). The seasonal precipitation is shown in Figure 13. Under the influence of the southwest monsoon, precipitation in the northwest of the basin is double that of the delta area. Approximately 50 % of the annual rainfall in the Cauvery basin occurs in the JJAS period. During OND the delta experiences wetter conditions under the influence of the northeast monsoon. About 33 % of the basin's rainfall is experienced during this period, and over 50% of the delta rainfall. JF is the driest season for the Cauvery basin.

23. The coefficient of variations for the seasons are shown in Figure 14. Precipitation is highly variable in JF, particularly in the northwest and coefficients of variation increases from northwest to southeast. The coefficients of variation in JJAS precipitation are significantly lower than in MAM.

Figure 13: Mean Seasonal Precipitation

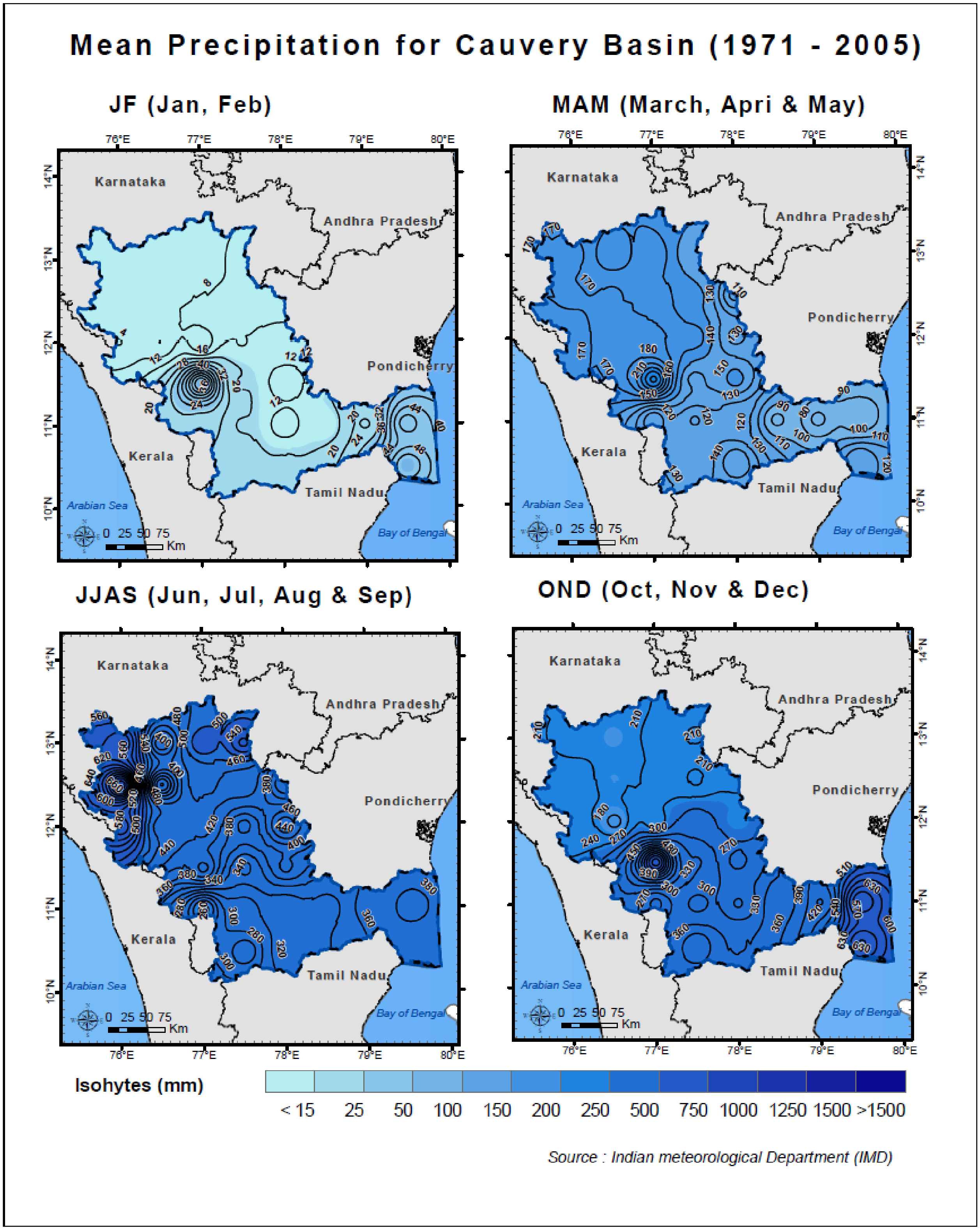
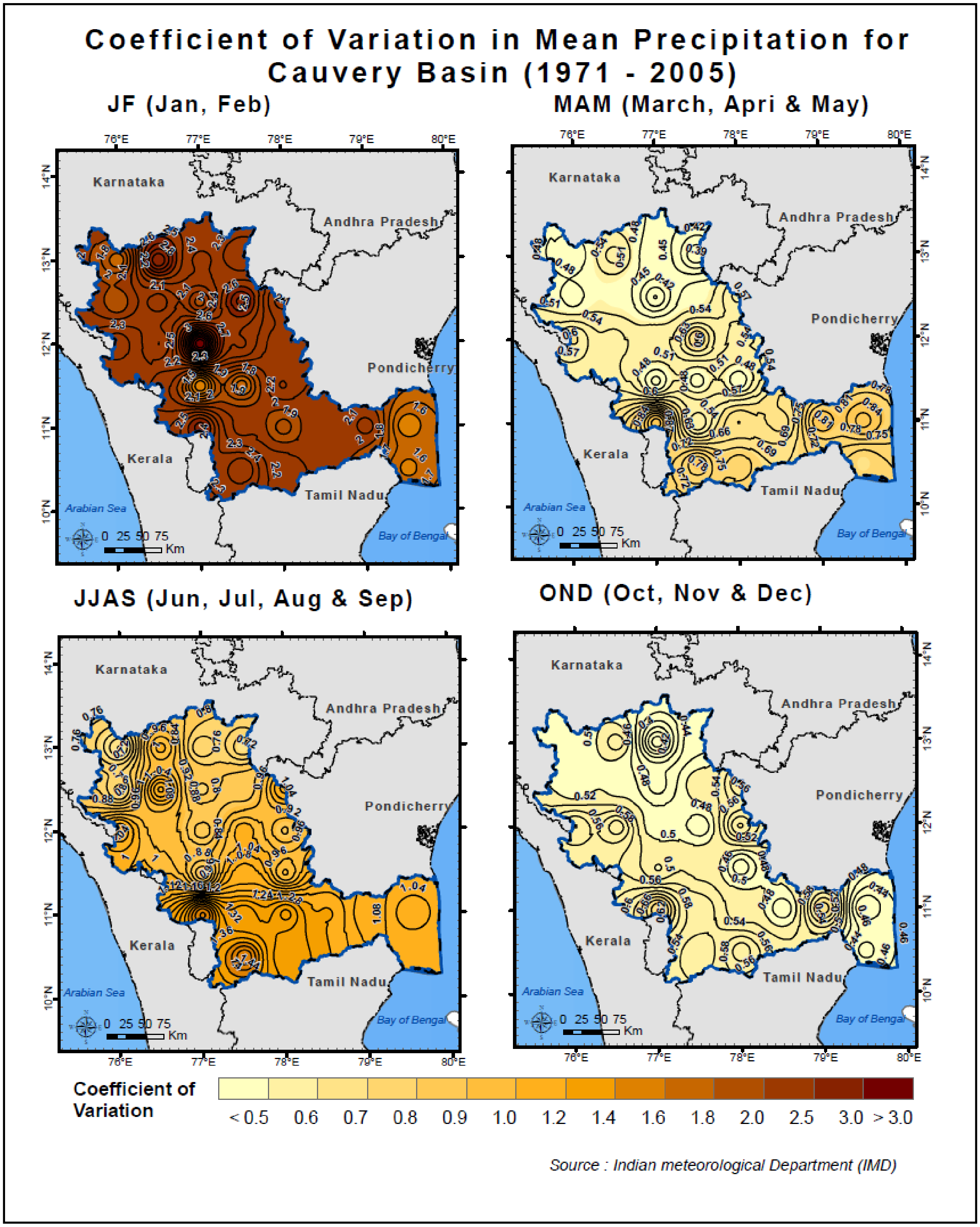


Figure 14: Seasonal Coefficients of Variation in Rainfall



G. Drought Characteristics

24. An analysis has been made of drought durations with a 10 mm precipitation threshold in the Kharif (JJAS) and Rabi (ONDJF) season. The mean annual drought durations are shown in Figure 15 and Figure 16 for the two seasons. This analysis is of most interest in the basin, since it is indicative of agricultural risk and irrigation needs. In the Kharif season, mean annual drought durations vary significantly across the basin. On the 10 mm threshold drought durations of 60 days occur in the south. In the north, the range is more typically 20 to 30 days. The time series of annual drought durations during the Kharif season shown in Figure 17 clearly indicates the high variability in rainfall that exists in many parts of the basin.

25. Drought duration on the 10 mm threshold for the Rabi season are shown in Figure 16. The northwest of the basin clearly experiences extended droughts during this period, while the south and east, under the influence of the northeast monsoon have much shorter drought periods.

Figure 15: Mean Annual Drought Durations During Kharif Season

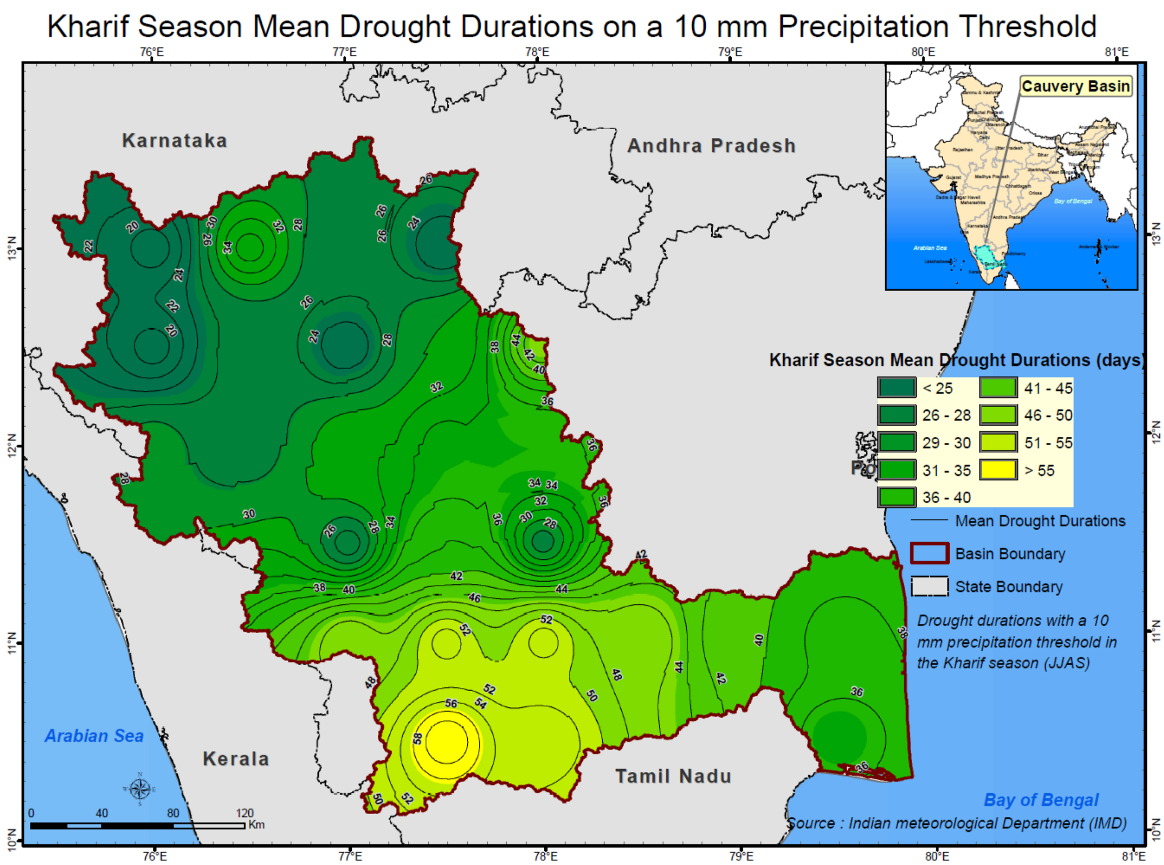


Figure 16: Mean Annual Drought Durations during Rabi Season

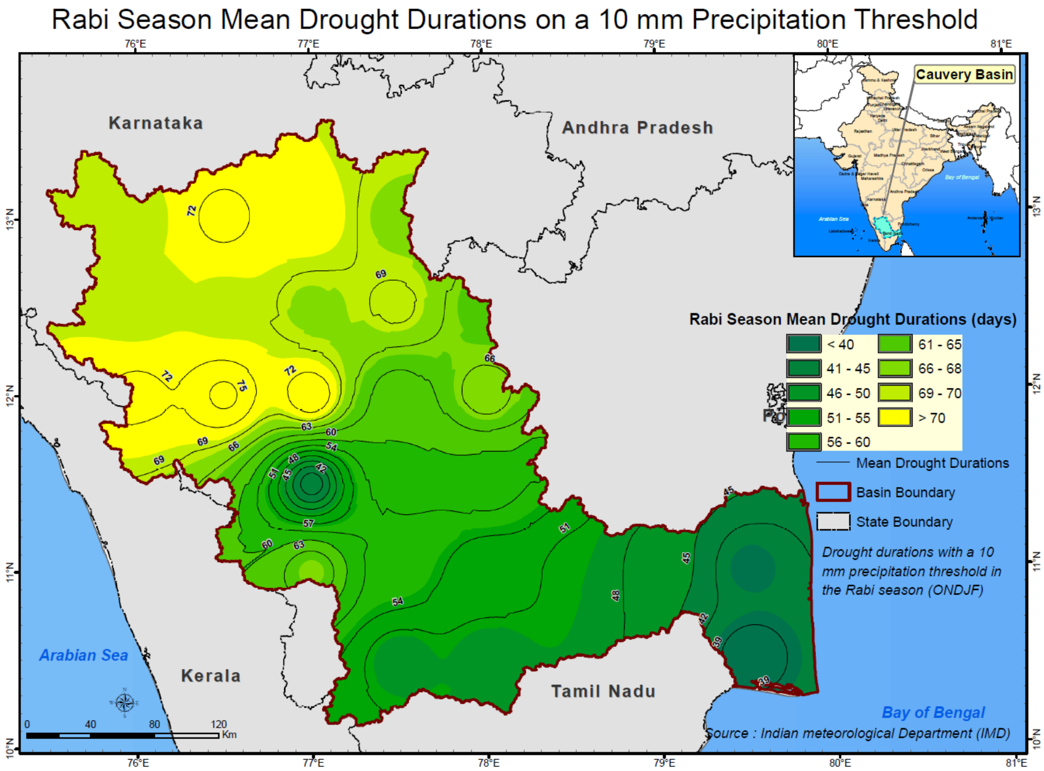
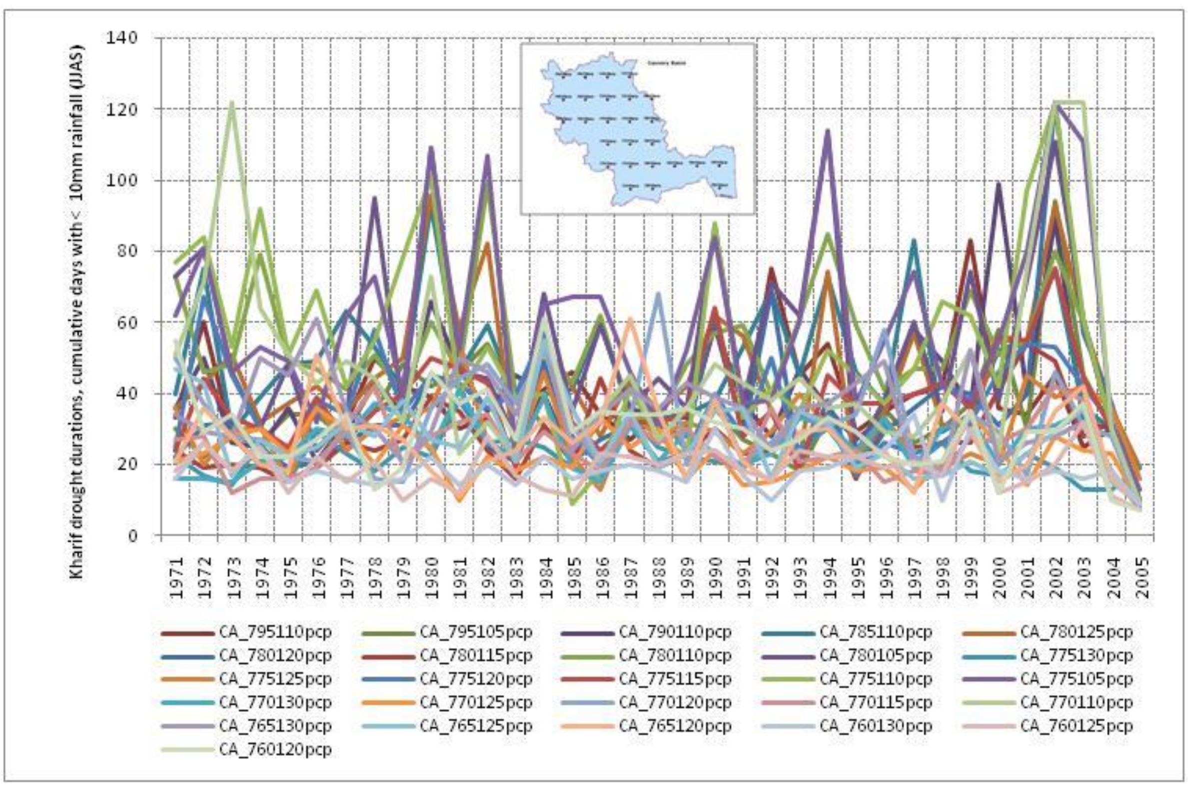


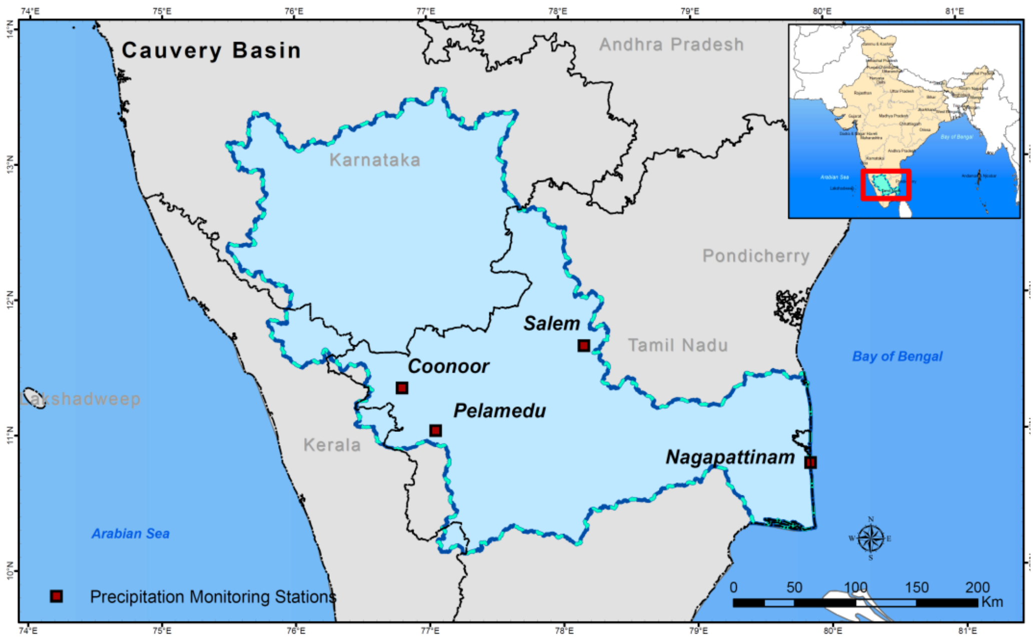
Figure 17: Time Series of Annual Droughts with a 10 mm Threshold in the Kharif Season



H. Trends in Annual and Seasonal Rainfall

26. Tests for trend have been made with data for four IMD raingauges in the Cauvery basin. IMD made data available for the period from 1971 to 2005. The stations used were at Coonoor, Nagapatinam, Peelamedu and Salem. Their locations are shown in Figure 18. The time series was extended using the GHCN[4] data for the same stations from 1901 – 1971.

Figure 18 Locations of IMD observed rain gauge stations in the Cauvery basin



1. Mann-Kendall Analysis

27. The Mann-Kendall test has been used in trend analysis. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987[5]). One benefit of this test is that the data need not conform to any particular distribution.

28. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

Mann-Kendall statistic (S) is given by

[4] http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/
[5] Gilbert, R.O., 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York. Kendall, M.G., 1975. Rank correlation methods, 4th ed. Charles Griffin, London

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

where: $x_1, x_2, \ldots x_n$ represent n data points, where x_j represents the data point at time j.
$sign(k_j\text{-}x_k) = 1$ if $k_j - X_k > 0$
$= 0$ if if $k_j - X_k = 0$
$= -1$ if if $k_j - X_k < 0$

29. A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend.

2. Data Quality

30. There were significant periods of missing data at all four stations, particularly in the IMD data. At Coonoor there were no data for the period 1997-2002, and very sparse data between 1987 and 1994. Pelemadu had missing data in similar periods. There were significantly fewer missing records in the GHCN data, and the indication is that data quality has deteriorated in recent decades.

3. Test Results

31. The results of the Mann-Kendall trend analyses using the composite records at all four stations are summarised in Table 3 to Table 5. Generally in the evaluation of these tests, a significance level of less than 0.05 would indicate the existence of trend, or there would be 95% confidence in the existence of trend.

32. In terms of annual rainfall there is no statistically significant evidence of trend at any station. Figure 19 to Figure 22 show the time series of annual rainfalls. At Coornoor regression picks up a mild declining trend, but the significance level is 0.15 and this is not therefore significant. Similarly in the southwest and northeast monsoons there are no statistically significant trends

Table 3: Annual rainfall trends

Stations	Basin	Linear equations	Mann-Kendall test statistics (Calculated z)	Significance level
Peelamedu	Cauvery	y = 0.9469x + 551.39	0.25	> 0.50
Coornoor	Cauvery	y = -2.1381x + 1564.5	-1.42	> 0.10
Salem	Cauvery	Y = -0.2524x + 969.26	0.06	> 0.50
Nagpatinam	Cauvery	y = 0.2192x + 1350.1	-0.01	> 0.50

Table 4: Seasonal rainfall trends, southwest monsoon (June-September)

Stations	Basin	Linear equations	Mann-Kendall test statistics (Calculated z)	Significance level
Peelamedu	Cauvery	y = -0.571x + 184.02	-1.26	> 0.20
Coornoor	Cauvery	y = -0.2931x + 338.69	-0.62	> 0.50
Salem	Cauvery	y = -0.2197x + 489.06	0.16	> 0.50
Nagpatinam	Cauvery	y = 0.3015x + 221.67	1.39	> 0.10

Table 5: Seasonal rainfall trends, northeast monsoon (October-December)

Rainfall Stations	Basin	Linear equations	Mann-Kendall test statistics (Calculated z)	Significance level
Peelamedu	Cauvery	y = 1.8137x + 237.14	0.25	> 0.50
Coornoor	Cauvery	y = 0.2153x + 754.48	-1.42	> 0.10
Salem	Cauvery	y = 0.3289x + 283.77	0.06	> 0.50
Nagpatinam	Cauvery	y = -0.3588x + 944.92	-0.01	> 0.50

Figure 19: Time series of annual rainfall record at Peelamedu

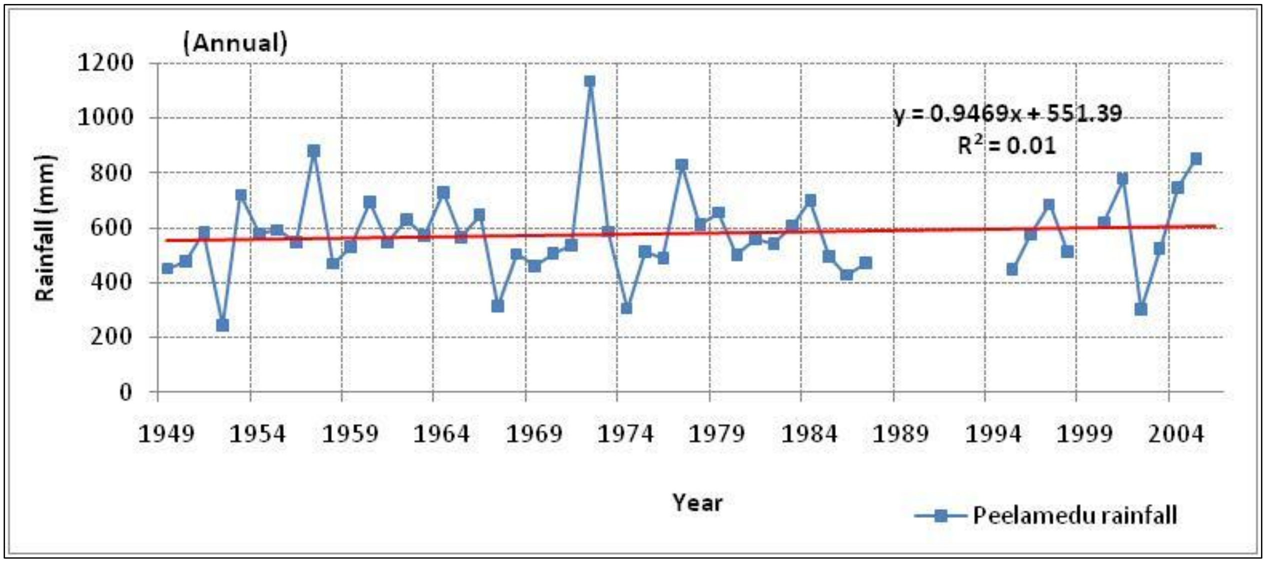


Figure 20: Time series of annual rainfall record at Coornoor

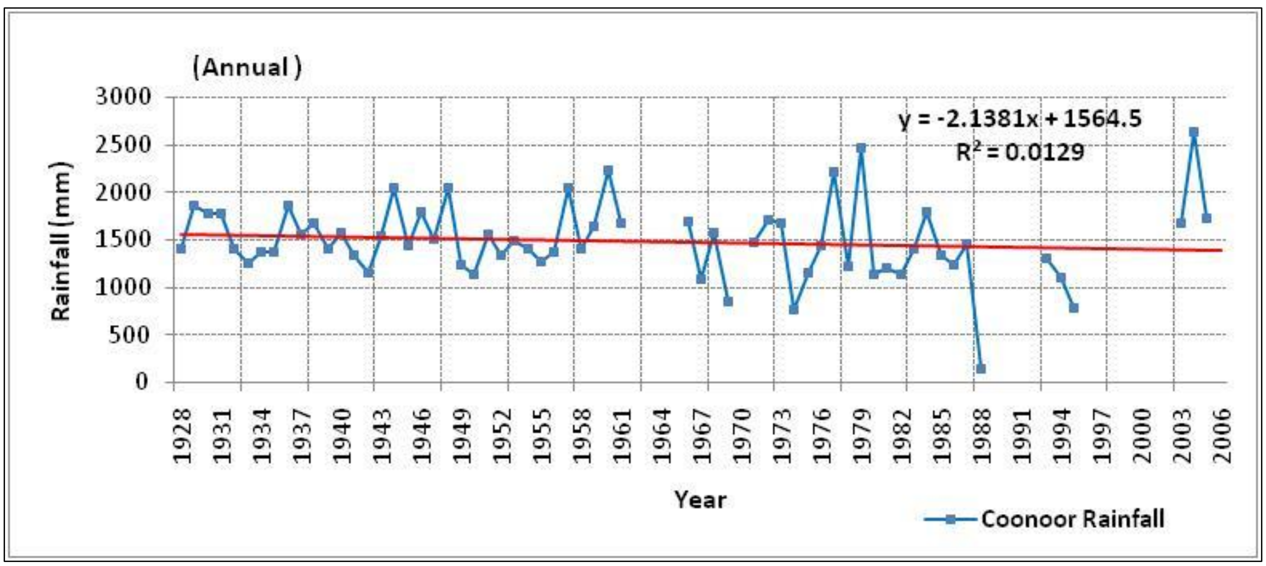


Figure 21: Time series of annual rainfall record at Salem

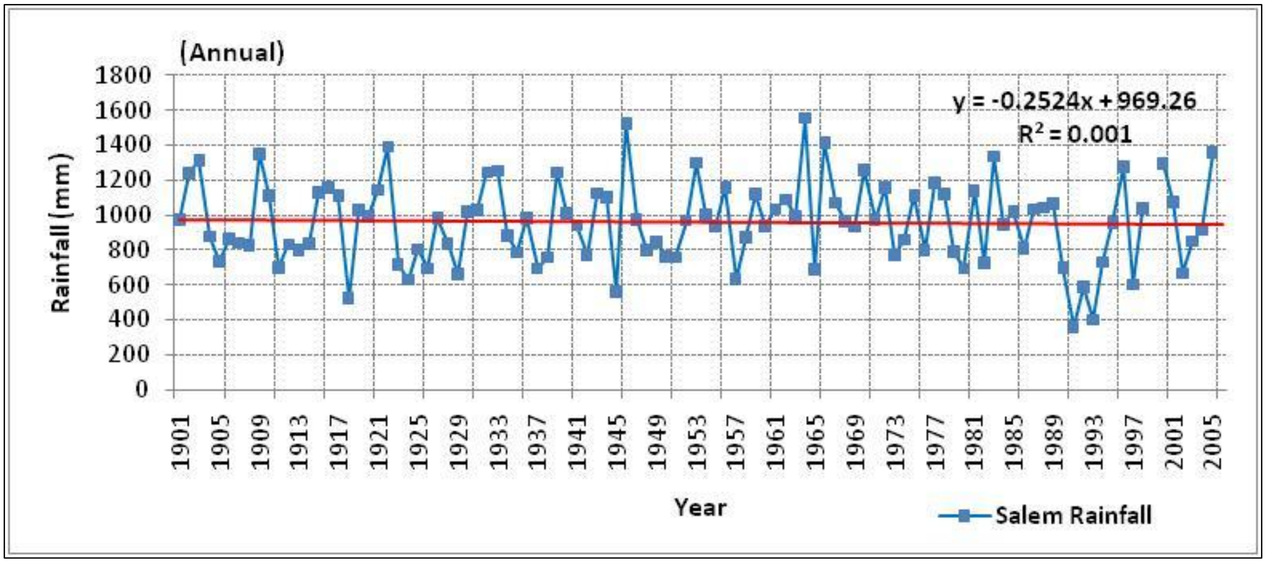
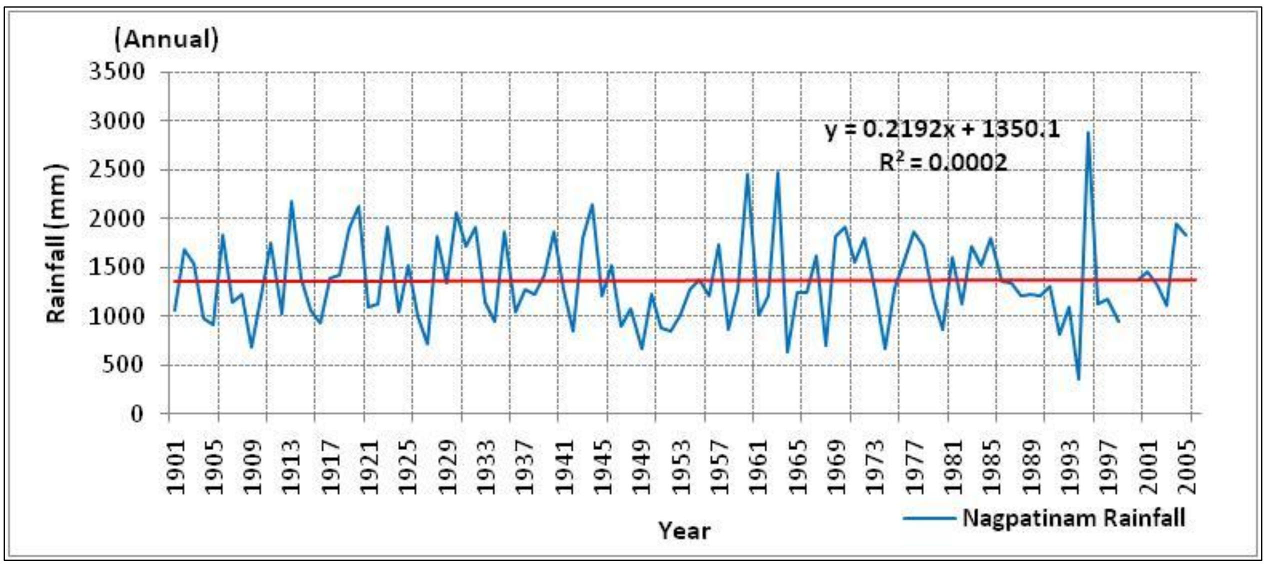


Figure 22: Time series of annual rainfall record at Nagpatinam



III. GROUNDWATER

A. Introduction

33. The total area of Cauvery basin is 81,155 sq.km. Out of this an area of 34,273 sq.km falls in Karnataka, 43,856 sq.km in Tamil Nadu, 2878 sq.km in Kerala and 148 sq.km in UT of Pondicherry. The Cauvery basin runs from west to east for some 800km and its north-south dimensions ranges from 65 to 280km. The mean annual rainfall in the basin ranges from 575 mm at Singallur, Tamil Nadu to 3350 mm in Markara area, Karnataka . The Cauvery River is dammed by the Mettur Dam and the Grand Anicut barrage. The mean annual flow is 20.5 billion cubic meter per year.

34. Geologically a major part of Cauvery basin is covered with hard crystalline rocks comprising granites, conglomerate and meta-sediments. The semi-consolidated formations comprising sandstones, shale of Gondwanas and Quaternary alluvium occur in delta part of the basin. Geological map of the Basin is given in Figure 23. In the Cauvery delta, rock formations of Precambrian crystalline to Quaternary sediments exist. In the Quaternary alluvial sediments there are both shallow (unconfined) and deep aquifers (semi-confined). A UNDP project in 1972 estimated the presence of 500 million cubic metres of ground water in delta including the part to the north of the Coleroon River .

35. The western and central part of the basin is occupied with hard rock aquifer whose yield potential through tube wells of 100 m depth ranges from 1 to 5 lps. The coastal delta area is underlain with Tertiary sandstones and an alluvial aquifer system. The yield potential of Miocene sandstone aquifers extending to a depth of 80 to 150 m range from 25 to 40 l/s.

36. In general ground water levels in major part of the basin falls between 10 to 20 m bgl, however, in Cauvery delta the water level is less than 10 m bgl during pre monsoon 2009 period. A map of pre and post monsoon depth to ground water level of the basin is given at Figure 24 and Figure 25. The ground water of basin is fresh to mineralized, with EC values range from 750 to 3000 in various parts of the basin as shown in Figure 26 A ground water salinity map of the basin is given in Figure 27 including a map showing the freshwater/saline boundary (Cauvery Modernisation Report 2008)**.**

B. GROUNDWATER

1. Aquifers in the Cauvery Delta

37. The Cauvery Delta region incorporates the districts of Thanjavur, Thiruvarur and Nagapattinam. These districts are underlain by different aquifers namely Archean, cretaceous and Eocene, Miocene and Quaternary alluvial aquifers. The depth of weathered zone in Archean aquifer is 10 to 12m. Dug wells yield in the zone range from 0.1 to 2.5 lps, where as bore well with 100 m depth the yield range from 1 to 5 lps. The Cretaceous sandstone aquifer has maximum thickness of 50 m and yields 5 to 7 lps. The thickness of Eocene sandstone aquifer is 80 m. Eocene sandstone aquifer in the depth range of 120 to 300 m yields 5 to 10 lps. Miocene aquifer comprises sandstones & limestone. The lower Miocene is the Orthanadu deep aquifer and the upper is an artesian aquifer. The thickness of Orthanadu aquifer to a depth of 150m is 30 to 70 m. Tube wells is this aquifer yields between 10 and 18 lps. The flowing zone aquifer is 35 m thick in delta area. The tube wells within 100 m depth is this zone yield 1 to 5 lps. Quaternary alluvial aquifer has thickness of 3 to 25 m and yield water by open wells and shallow tubewells. The shallow tube wells of 20 to 40 m depth yield 8 to 12.5 lps. The CGWB report on Cauvery Basin (2002) indicates that the Miocene aquifers recharges shallow aquifers (Pliocene and Quaternary sediments) in the Cauvery Delta. Broadly the aquifer system of Cauvery delta can be divided into two categories; (i) Miocene aquifer (sandstone); a deep zone–Orthanadu aquifer overlain with auto-flow aquifer; and (ii) quaternary aquifer with shallow quaternary alluvial aquifer underlain by Pliocene aquifer represented by sand & gravels. The aquifer characteristics are given in Table 6.

38.

Table 6: Aquifer Characteristics

Aquifer	Depth range(m)	Thickness(m)
Quaternary alluvial (approximately)	0-45m	5-25m
Pliocene aquifer	30-100 m	10-35m
Flowing zone aquifer	100-200 m	10-35 m
Miocene aquifer orthonadu aquifer	150-300 m	30-70 m

39. Thiruvarur district is drained by the Venner and Vellar tributaries of Cauvery River. The district is underlain by shallow quaternary and deeper sandstones aquifer. The Miocene deposits comprise a deep aquifer. The Orthanadu deep aquifer of 30 to 70 m thickness occur within depth range of 150 to 300 m. The auto-flow zone in which head has reduced is 30m thickness & occurs in the depth level of 10 to 250 m. These two aquifers are hydraulically connected. Quaternary alluvial aquifer of 5 to 25 m thickness occurs within 45 m depth and is source of water through dug wells and filter point wells.

40. Nagapattinam district is also underlain by deeper lower Miocene aquifer and upper quaternary alluvial shallow aquifer system. Deeper aquifer is subdivided into lower Orthanadu aquifer and upper auto-flowing zone aquifer. The thickness of Orthanadu aquifer is 30 to 70 m and flowing zone above is 35 m thick. The deeper quaternary aquifer (Pliocene sand and gravel) is of 10 to 30 m thickness and occur in the depth range of 30 to 100 m. The shallow quaternary aquifer of 5 to 25 m thickness occurs within 45m depth. Hydrogeological map of Cauvery basin is given in Figure 28. The aquifer distribution in the districts is given in Figure 29, Figure 30 and Figure 31 these are based on the studies carried out by UNDP.

41. The Karikal region of Pondicherry is a part of Cauvery basin and is situated at tail end of Cauvery delta. Groundwater in the Karikal region occurs under unconfined /confined conditions in alluvial and sandstone aquifers. The Cuddalore sandstone is a potential confined aquifer. The yield of tube wells ending in various depths of 150 to 400 m yields 8 to 40 lps for drawdown of 6.10 to 21.92 m. The free flow discharge of 19 lps also natural for this aquifer of 9 to 40 m thickness occurs at depth levels of 24 and 43 m. The CGWB report on Cauvery Basin (2002) provide the following summary aquifer characteristics from exploratory wells in the main Tamil Nadu and Pondicherry districts are given in Table 7 below.

Table 7 Aquifer Characteristics from Exploratory Wells

District	No. of Exploratory wells	Specific Capacity (lps per metre of drawdown	Transmissivity (m^2/day)	Storage Coefficient
Thanjavur	16	0.332-11.7	59-3002	4.7×10^{-4} to 6.09×10^{-2}
Nagappattinam	11	0.283-14.5	32-1672	9.91×10^{-3}
Thiruvarur	16	0.217-7.367	8-1202	4.8×10^{-4}
U.T. of Pondicherry	5	0.422-4.9	39-2640	1.2×10^{-4} to 1.02×10^{-3}

2. Groundwater levels

42. A hydrological cross section is given in Figure 32. A long term time series data of ground water levels of representative well hydrographs of Nagapattinam and Tahanjuvur district are given in Figure 33 and representative hydrographs of Piezometer well in Nagapattinam district is given in Figure 34 and Thanjavur District in Figure 35 and Tiruvarur district in Figure 36 The range of pre-monsoon and post monsoon depth to ground water level and annual fall and rise in Cauvery delta is given in Table 8 below.

Table 8 Pre and Post monsoon (2008) Ground Water Levels

Depth	DTW - pre-monsoon (m bgl)	DTW - post monsoon (m bgl)	Fall (annual) (m)	Rise (Annual) (m)
1.Nagapattinam	2-9.45	GL-2.64	0.022 -0.290	0.31
2.Thanjavur	1.55-18.32	0.22-19.20	0.0097-0.735	0.0027-0.3276
3.Thiruvarur	3.07-7.01	0.37-4.71	0.037-0.430	-

43. Mean Ground water level in the districts of Cauvery delta is given in Table 9 below. Between 1980 and 2009 ground water levels have dropped between 0.57 and 2.79 metres, with greatest fall occurring during pre-monsoon. Nagapattinam exhibited greatest lowering of water table during this period.

Table 9: Mean Ground Water levels in districts

Sl No	**District**	**Mean GW Depth (m bgl)**			
		May-80	**Nov-80**	**May-09**	**Nov-09**
1	Nagapattinam	1.96	1.10	4.75	3.49
2	Thanjavur	3.47	2.78	6.09	3.39
3	Tiruvarur	2.04	1.00	4.52	1.57

C. Water Quality

44. Groundwater quality of shallow aquifer in Thanjavur district is alkaline in nature. The EC of groundwater ranges from 279 to 12250 micro-mhos/cm and in major part of district it is below 1500 micro-mhos/cm. Groundwater of area has medium to high salinity and alkaline hazard potentials Thiruvarur district is also alkaline in nature with EC values of shallow groundwater is in range of 620 to 4400 micro-mhos/cm. In major part of the district it ranges from 750 to 2250 micro-mhos/cm. EC exceeding 2250 micro-mhos/cm is found to occur is Muthupetae block of the district.

45. Groundwater of the Nagapattinam district of Cauvery delta is predominantly alkaline. The EC of the shallow groundwater ranges from 714 to 3640 micro-mhos/cm. Saline groundwater with EC more then10000 micro-mhos/cm is observed is southern part of the district. Most part of the district has pH value of shallow groundwater in excess of 8. Freshwater lenses exist in the sand dune areas which is exploited by shallow wells. The ground water quality of districts of Cauvery delta is given in Table 16.

46. The saline-freshwater boundary map indicates a steady migration inland. In geological history, the low-lying coastal sedimentary aquifers the Cauvery Delta have been flooded during marine transgressions[6]. More recently over-abstraction of groundwater, land use, surface water ingress of sea-water and changes to upstream surface water discharges and have resulted in land-ward saltwater intrusion. Water logging and salinity is also prevalent around the Grand Anicut and other parts of Delta. A map showing the main areas of water logging is presented in Figure 37.

D. Groundwater Resources

47. District wise position of groundwater resource availability, draft and overall status of the district in terms of overexploitation in Cauvery delta is given in Table 10 below:

Table 10 Dynamic Ground Water Resources by District (2004)

S,No.	District	Net Annual groundwater availability (MCM)	Annual groundwater Draft (MCM)	Extend of groundwater use (in %)	Number of ground water overexploited blocks
1	Thanjavur	776	527	72	3
2	Thiruvarur	324	268	83	1
3	Nagapattinam	181	232	128	4

48. A more detailed overview of groundwater resources in the three main districts by block is shown in Table 11 below.

[6] Frank van Weert, Jac van der Gun and Josef Reckman (2009) Global Overview of Saline Groundwater Occurrence and Genesis. Utrecht, Report nr. GP 2009-1

Table 11: Dynamic Ground Water Resources by District and Block

Nr	BLOCK DISTRICT	Net Annual Ground water Availability (MCM)	Present 2010 (MCM)				Future 2035 (MCM)		
			Gross Draft for irrigation	Gross Draft for Domestic & Industry	Total gross draft	Stage of GW devpment	Estimated draft for WS and Industry to 2035	Future gross draft	Stage of GW devpment
	NAGAPATTINAM								
1	Keelaiyur								
2	Kilvelur								
3	Kollidam	32	37	4	41	128	5	42	128
4	Kuttalam	42	67	9	76	181	9	76	182
5	Myladuthurai	39	31	3	34	87	3	35	88
6	Nagapattinam								
7	Sembanarkoil	37	43	2	45	121	2	45	121
8	Sirkazhi	31	34	2	36	114	2	36	115
9	Thalainayar								
10	Thirumarugal								
11	VEDARANYAM								
TOTAL NAGAPATTINAM		182	212	20	232	128	21	233	128
	THANJAVUR								
1	Ammapet	64	58	2	60	95	2	60	95
2	Budalur	71	11	2	13	18	2	13	18
3	Kumbakonam	59	56	4	59	100	4	59	101
4	Madukkur	38	30	2	32	84	2	32	84
5	Orathanadu	61	32	3	35	58	3	35	58
6	Papanasam	46	14	6	20	43	6	20	44
7	Pattukottai	71	36	7	43	60	7	43	60
8	Peravoorani	27	16	0	17	63	0	17	63
9	Sethubhavachattiram	32	19	4	22	70	4	22	70
10	Thanjavur	105	41	3	44	42	3	44	42
11	Thiruppanandal	38	41	2	43	111	2	43	112
12	Thiruvaiyaru	43	34	2	36	84	2	36	84
13	Thiruvidaimaruthur	50	75	5	80	160	5	80	160
14	Thiruvonam	32	24	1	25	78	1	25	78
TOTAL THANJAVUR		736	486	42	528	72	43	529	72
	TIRUVARUR								
1	Kodavasal	37	34	2	36	98	2	36	98
2	Koradachery	38	21	2	23	61	2	23	61
3	Kottur	39	14	2	17	42	2	17	43
4	Mannargudi	56	28	3	31	55	3	31	56
5	Muthupet								
6	Nannilam	32	25	1	27	85	1	27	85
7	Needamangalam	61	39	5	45	73	6	45	73
8	Thiruthuraipoondi								
9	Thiruvarur	16	7	0	8	50	0	8	51
10	Valangaiman	46	80	2	82	180	2	82	180
TOTAL TIRUVARUR		324	250	18	268		19	269	

E. Ground Water Irrigation

49. The block wise area of groundwater irrigation by tube wells in the districts covering Cauvery Delta is given in Table 12 below:

Table 12 Ground Water Irrigation in Thanjavur District

Block	Net area irrigated by tube well (ha)	Area irrigated by Dug wells
Thanjavur	2540	268
Budalur	1404	12
Thiruvaiyaru	1928	-
Orathanadu	11833	-
Thiruvonam	4151	-
Pattukottai	2259	196
Madukkur	2272	24
Peravoorani	5058	1
Sethubhavachattiram	1474	12
Kumbakonam	1616	-
Thiruvidaimaruthur	1122	-
Thiruppanandal	210	-
Papanasam	482	-
Ammapet	930	-
Total	37279	513

50. The status of irrigation development from groundwater in state can be understood from the statistics such as the total utilizable ground water for irrigation is 2.08192 m ha m /year and with weighted average ranging from 0.37 to 0.93 m the utilizable irrigation potential is 2.83205 m ha m. The irrigation potential created is to the tune of 1.31450 m ha m and potential utilized for irrigation is 1.31190 m ha m. There is further scope of creating irrigation potential to the tune of 1.52 m ha m.

1. Government and Private Tubewells:

51. The status of area irrigated with use of govt. and privately owned tubewells and with supplementary wells for Cauvery delta region is given in Table 13, Table 14 and Table 15 below. The vast majority of groundwater usage occurs through private abstraction. Therefore, management or control of groundwater abstraction will need to address private ownership, subsidies and usage.

Table 13: Area irrigated by groundwater (in ha) through Tube wells

District	Tube well					
	Gross area			Net Area		
	Govt.	Pvt.	Total	Govt.	Pvt.	Total
Thanjavur	0	513	513	0	513	513
Thiruvarur	0	0	0	0	0	0
Nagapattinam	0	0	0	0	0	0
Pudukottai	286	19165	19451	252	18650	18902
Cuddalore	164	113847	114011	164	92287	92451

Table 14: Area irrigated by groundwater (in ha) through open wells

District	Open Wells					
	Gross area			Net Area		
	Govt.	Pvt.	Total	Govt.	Pvt.	Total
Thanjavur	0	513	513	0	513	513
Thiruvarur	0	0	0	0	0	0
Nagapattinam	0	0	0	0	0	0
Pudukottai	151	8569	8720	147	8335	8482

Table 15: Area Irrigated by Groundwater (in ha) through Supplementary wells

District	Supplementary Wells					
	Gross area			Net Area		
	Govt.	Pvt.	Total	Govt.	Pvt.	Total
Thanjavur	44	30292	30336	14	25009	25023
Thiruvarur	55	15348	15403	55	15143	15198
Nagapattinam	52	32282	32334	52	30433	30485

F. Regulatory Framework for Groundwater

52. The State Government of Tamil Nadu passed an Act "Tamil Nadu groundwater (Development & Management) Act,2003 on 4.3.2003 to include process for setting up Tamil Nadu groundwater Authority to regulate and control ground water development in the state. The act is being implemented.Vide ordinance no. 4 of 2003 laws relating to Municipal Corporation and Municipalities in State have been amended making it mandatory for all the existing and new buildings to provide rain water harvesting facilities. The State has launched implementation of rain water harvesting scheme on massive scale in Govt. buildings, private house /institutions and commercial buildings in urban & rural area. The state Govt. has achieved sizeable coverage in roof top rainwater harvesting. The CGWA has notified Gangabialli, Thalaivasal and Veerapani blocks of Salem district, Thuraijur block of Trichinapally district, Chengar block of Vallore and Pernampet block of Vellore districts for regulation of groundwater abstraction structures. The Pondicherry groundwater (Control & Regulation) Act 2002 is invoked to regulate and control development of groundwater in whole of UT. of Pondicherry.

G. Problems and Issues

53. The main issues include (i) flooding and inundation due to back water and flood; water logging of soils around Grand Anicut and other areas of Delta; (ii) increased in salinisation of land; (iii) saline groundwater intrusion in coastal aquifer due to sea water ingress and over-exploitation of groundwater; (iv) a steady increase in groundwater over-exploited blocks in delta area districts of Nagapattinam, Thiruvarur, and Thanjavur; (v) reduction of in potentiometric head of the Orthoanadu Aquifer (Miocene) around Grand Anicut;(vi) aquaculture farms adding contamination to water sources; (vii potential rise in sea level; (viii).problems of salinity, sodicity and water logging in Nagapattinam and Thanjavur district; (ix) H2So2-toxicity, sodicity, salinity and deficiency of nutrients are constraints for rice production; (x) reduced surface water inflows in delta area, ground water use is intensified resulting in saline water intrusion close to coastal area; and (xi) uncertainly in availability of Mattur Dam water in delta area.

Figure 23: Cauvery Geology

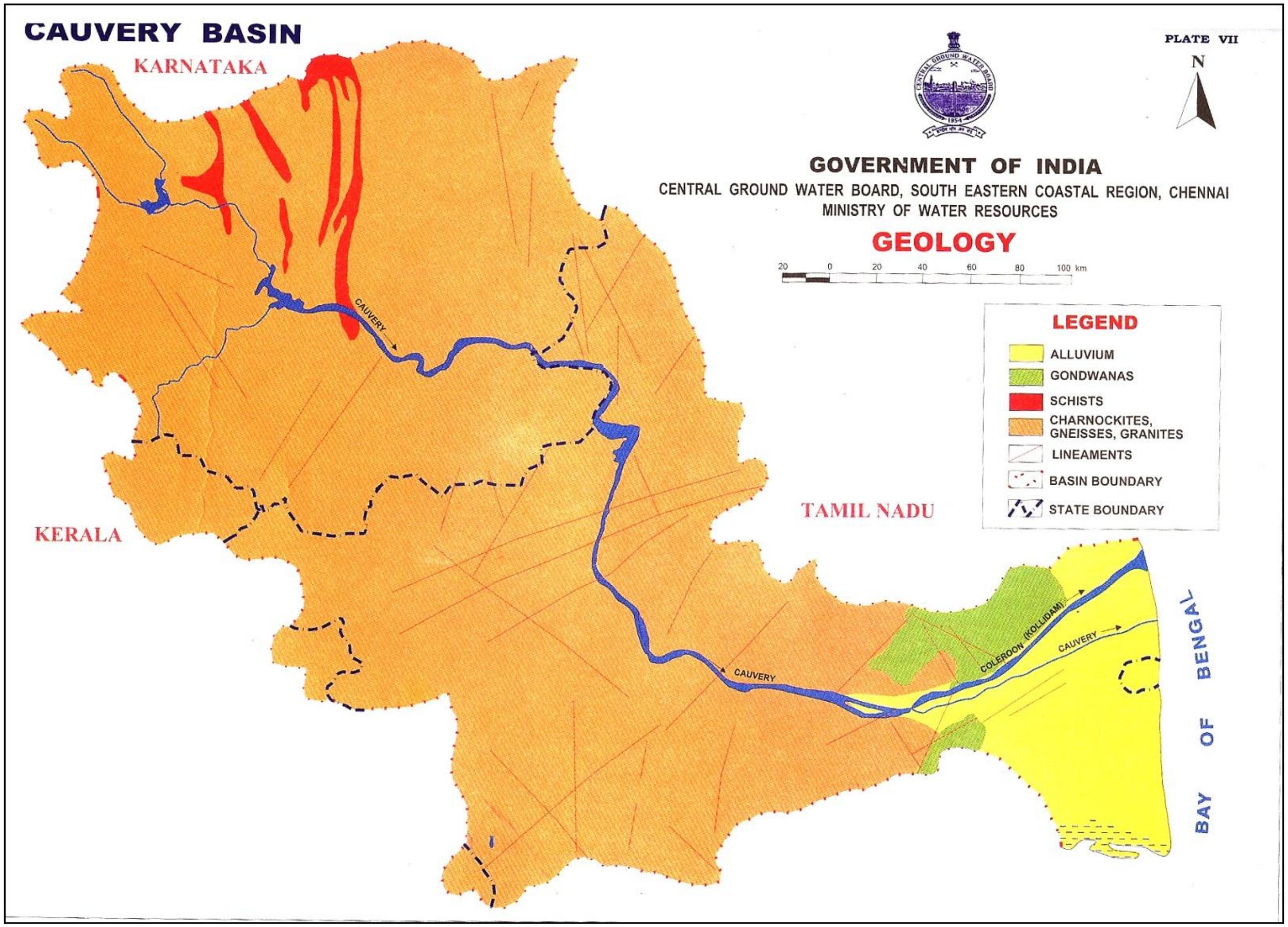


Figure 24: Pre Monsoon Depth to Water

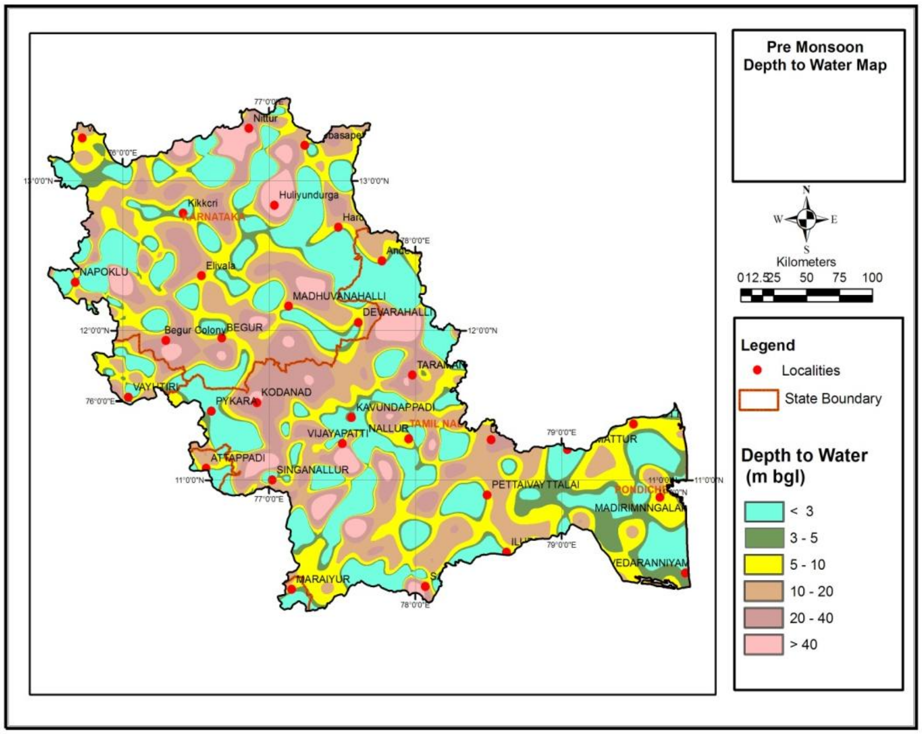


Figure 25: Post Monsoon Depth to Water

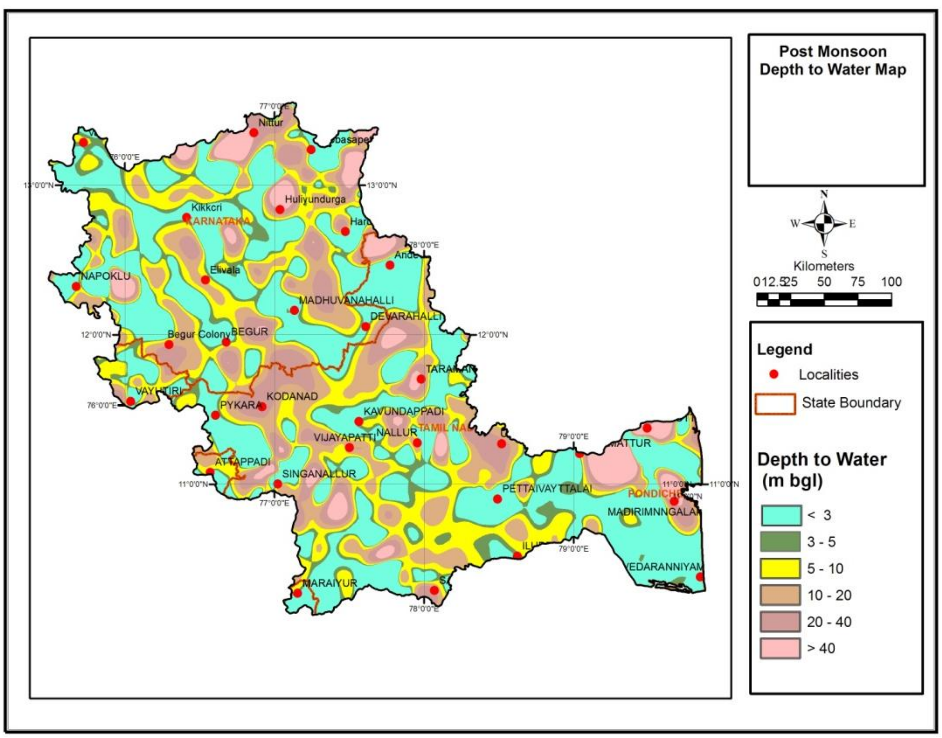


Figure 26: Electrical Conductivity

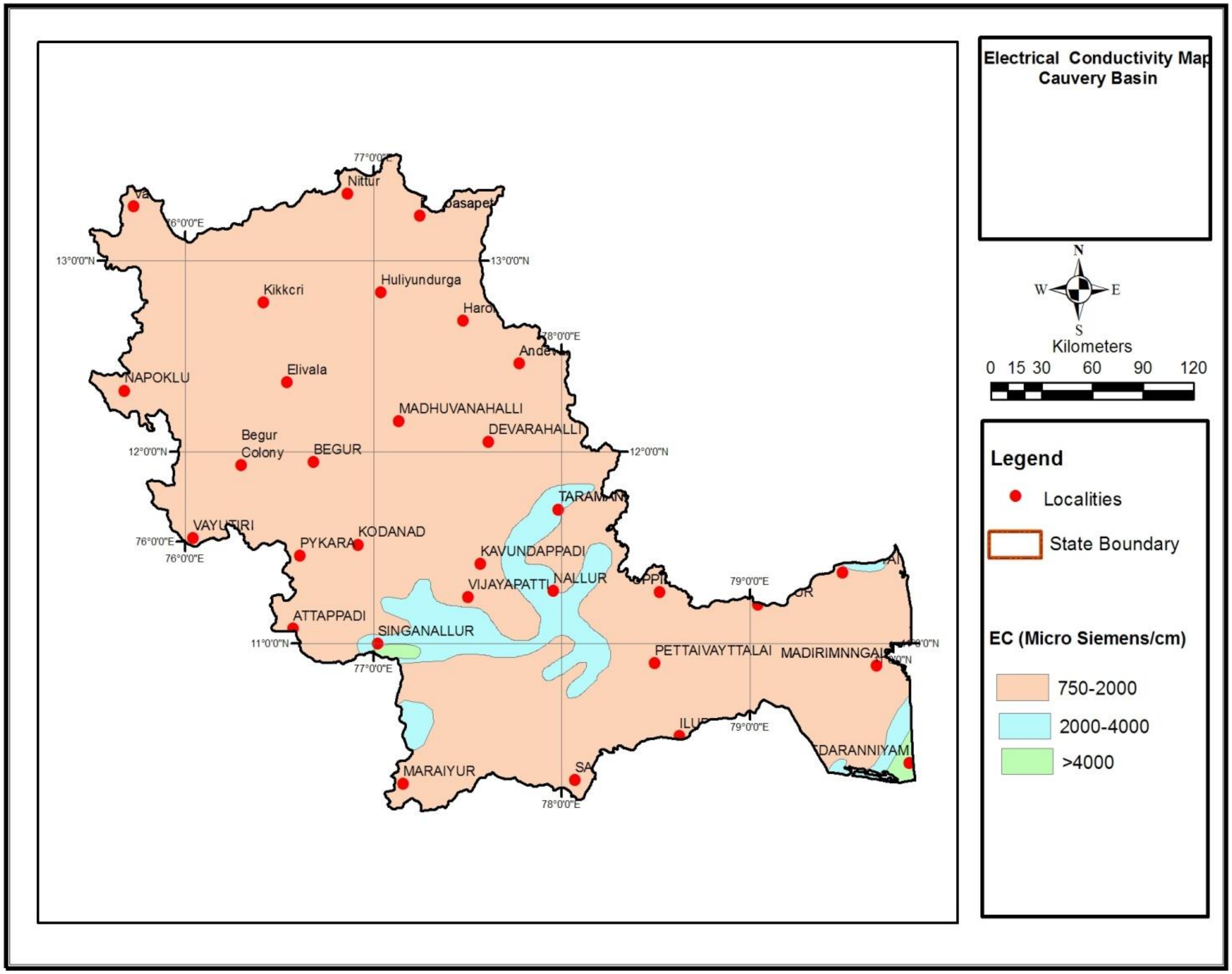


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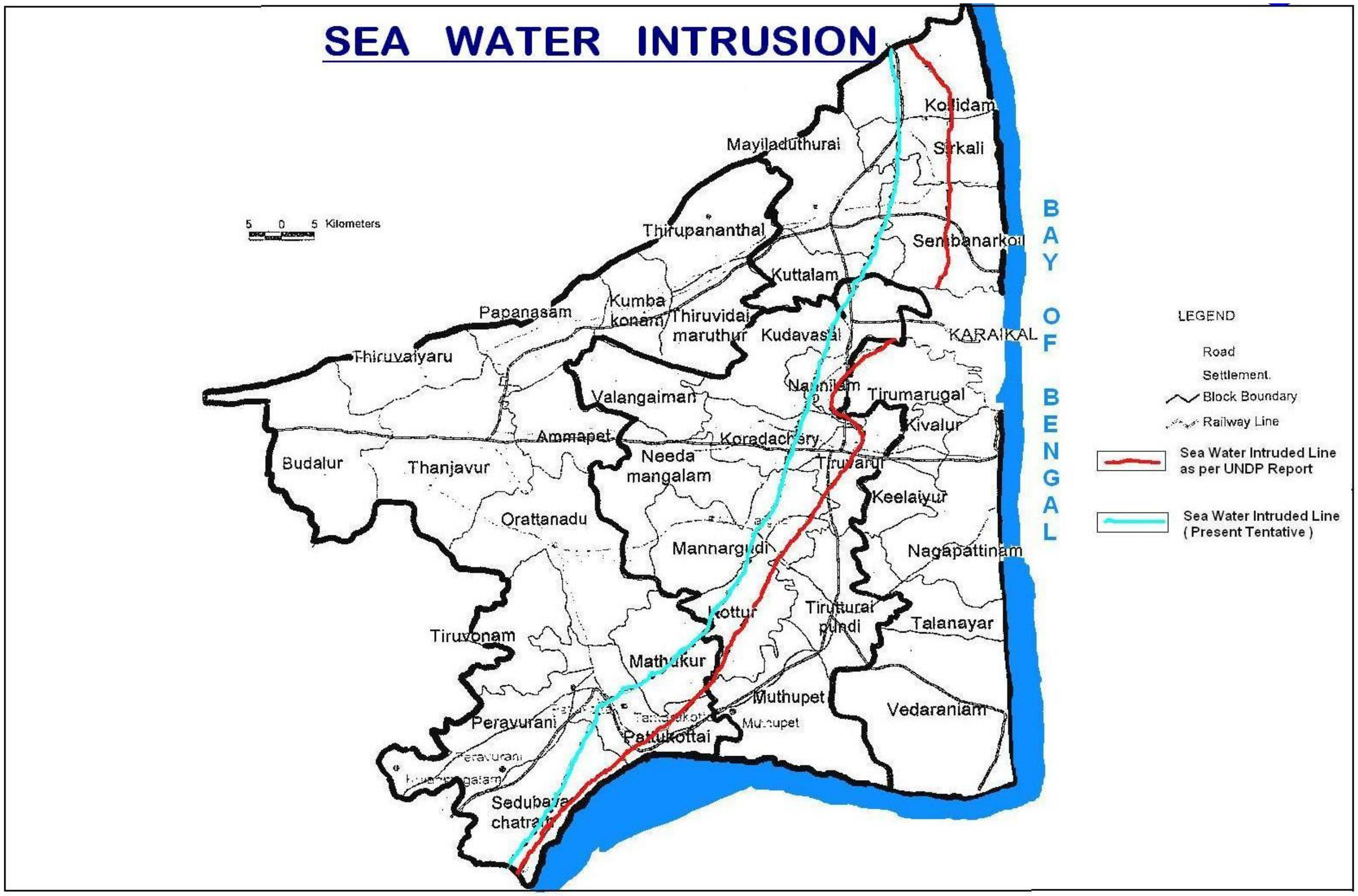
Figure 27: Sea Water Intrusion



Source: Cauvery Delta Modernisation Plan 2008

Figure 28: Hydrogeological Map

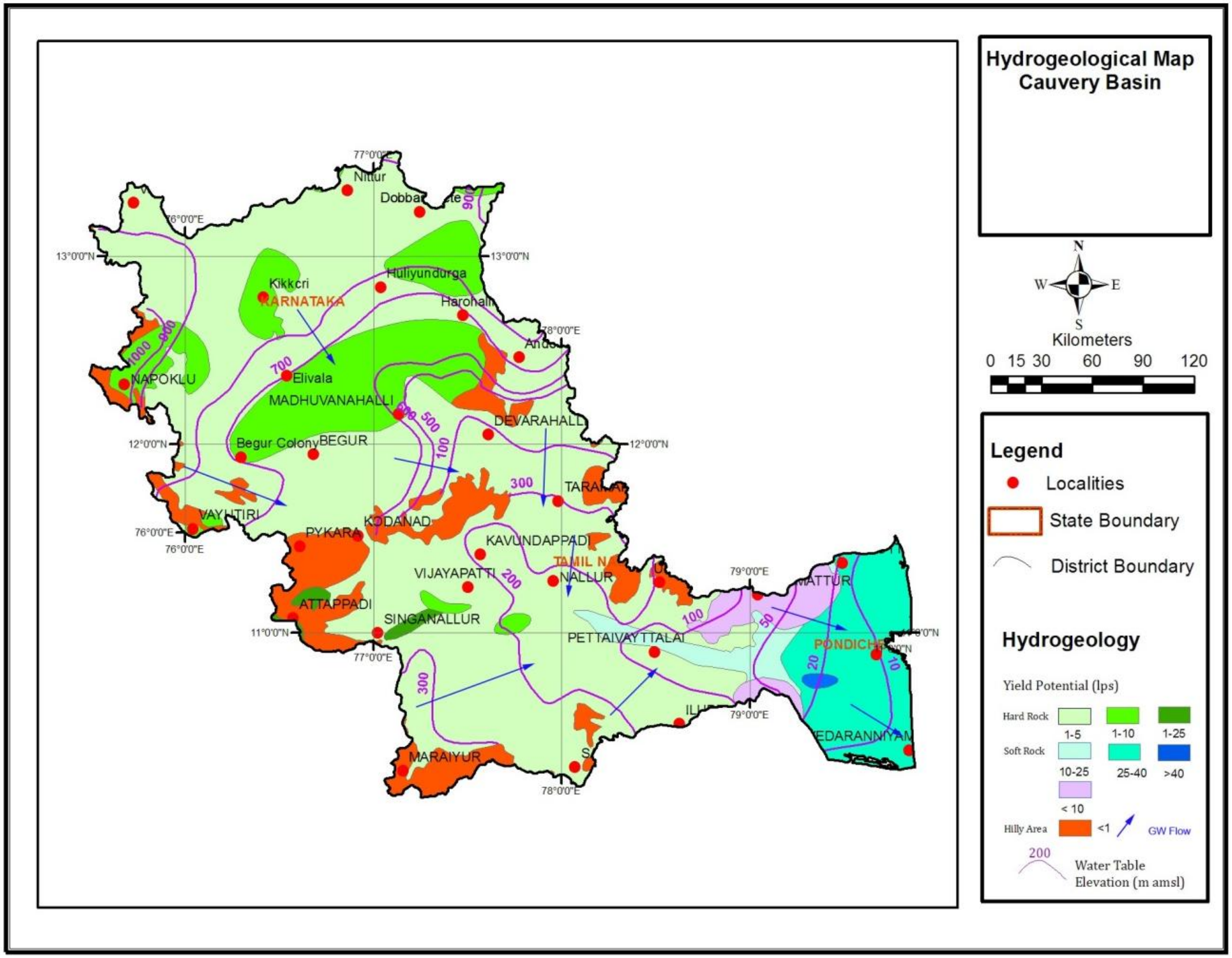


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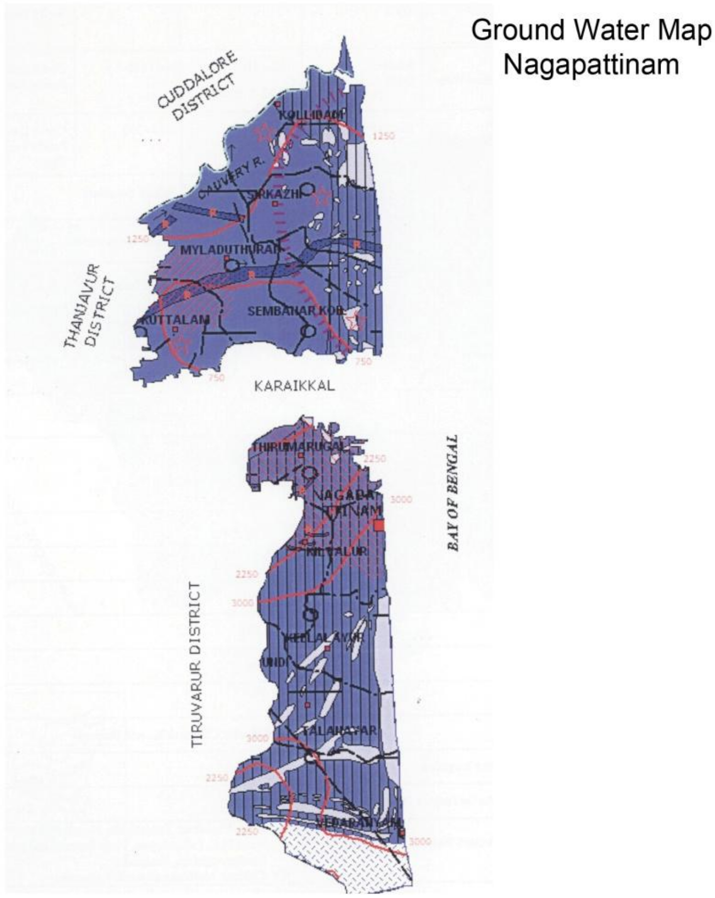
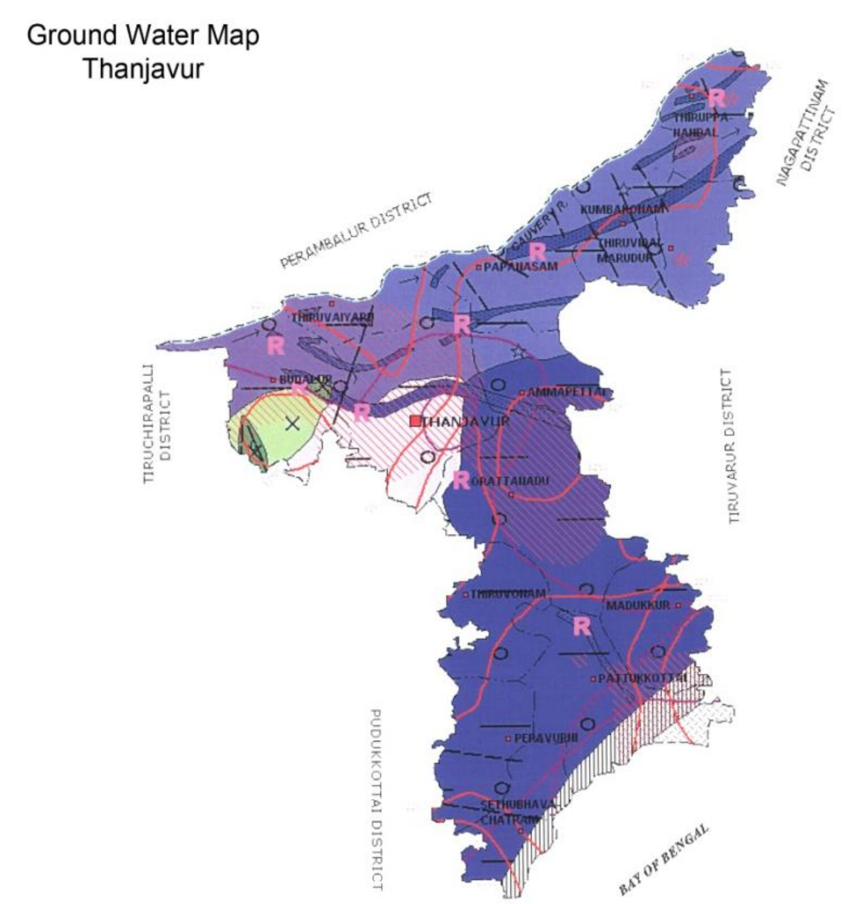
Figure 29: Groundwater Nagapattinam



	Wells Feasible	Rigs Suitable	Depth Of Well (M)	Discharge (LPM)	Suitable Artificial Recharge Structures
Soft Roc Aquifer	Dug Well Filter Point	Manual Hand Bore	5 – 10	Less Than 300	Rain Water Harvesting/ Surface & Subsurface Storage Tanks
Soft Rock Aquifer	Dug Well Filter Point Tube Well	Manual Hand Bore Direct Rotary	8 – 12 10 – 15 100 – 450	400 – 1700	Rain Water Harvesting /Check Dams /Percolation Pond/ Gabion Structures
Soft Rock Aquifer	Filter Point Tube Well	Hand Bore Direct Rotary	10 – 20 40 – 450	300 – 1000 1000 – 3000	Rain Water Harvesting /Check Dams /Percolation Pond/ Gabion Structures

	State Boundary		District Boundary
	Block Boundary		Swamp
	District Headquarters		Block Headquarters
	River	1250	EC In Microsiemens / Cm At 25°C
	Lineament		Auto Flow Zone
	Fluoride Greater Than Maximum Permissible Limit (1.5mg/L)		Nitrate Greater Than Maximum Permissible Limit (45mg/L)
	Palaeo Channal		Saline Zone
R	Recommended Site For Artificial Recharge Structure		

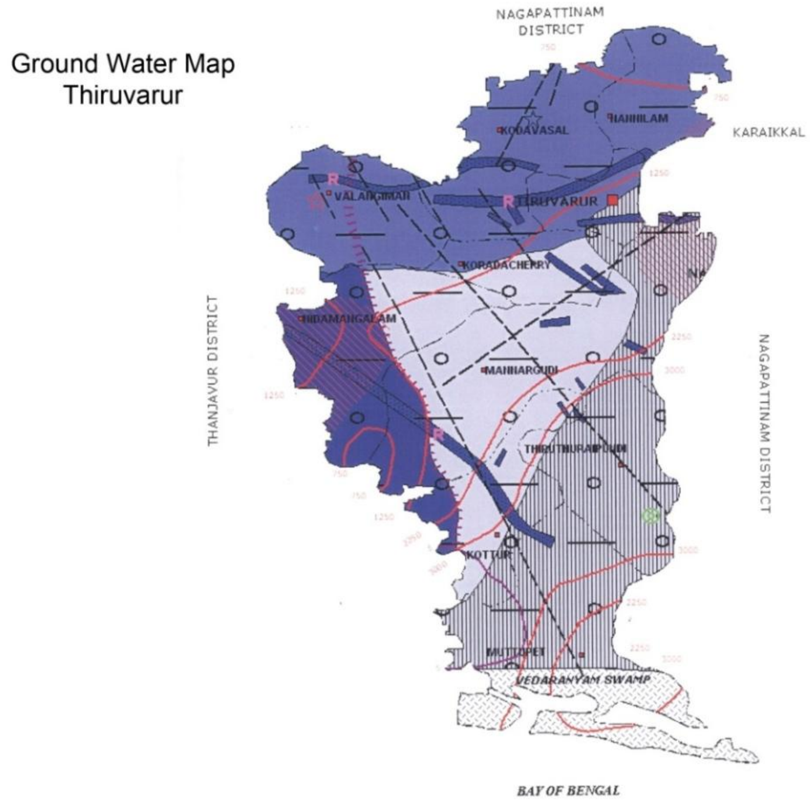
Figure 30: Groundwater Thanjavur



	Wells feasible	Rigs Suitable	Depth of well (m)	Discharge (LPM)	Suitable Artificial Recharge Structures
Soft rock Aquifer	Dug cum bore well Tube well	Manual Direct Rotary	10 + 50 75 – 100	150 - 450	Recharge tube wells Recharge Shaft
Soft rock Aquifer	Dug well Filter point-well Tube well	Manual Hand bore Direct Rotary	8 – 12 10 – 15 100 – 150	500 – 750	Rain water harvesting /Check dams /Percolation Pond/ Gabion Structures/ Recharge tube wells Recharge Shaft
Soft rock Aquifer	Dug well Dug cum bore well Tube well	Manual Manual + Rotary Direct Rotary	5 - 10 10 + 3 100 - 250	150 – 450 1100 – 1700	Check dams /Percolation Pond/ Recharge wells/ Injection wells
Hard rock Aquifer	Dug Well Bore Well	Manual DTH	8 - 12 Less than 100	20 - 100	Check dams/ Percolation ponds/ farm ponds
Hard rock Aquifer	Dug Well Bore Well	Manual DTH	8 - 12 Less than 100	More than 100	Check dams/ Percolation ponds/ farm ponds /Gully plugs

	District boundary		Block boundary
	District headquarters		Block headquarters
	Swamp		Palaeo channel
5	Water Level-Pre-monsoon (decadal mean 1993-2002) mbgl	1250	EC in microsiemens / cm at 25°C
	River		Lineament
	Nitrate Greater Than Maximum Permissible Limit (45mg/l)		Saline Zone
R	Recommended Site For Artificial Recharge Structure		Auto flow zone

Figure 31: Groundwater Thiruvarur



	Wells Feasible	Rigs Suitable	Depth Of Well (M)	Discharge (LPM)	Suitable Artificial Recharge Structures
Soft Rock Aquifer	Dug Well Filter Point-Well Tube Well	Manual Hand Bore Direct Rotary	8 – 12 10 + 40 200 – 450	Less Than 300	Rain Water Harvesting /Check Dams /Percolation Pond/ Recharge Wells /Gabion Structures
Soft Rock Aquifer	Dug Well Filter Point-Well Tube Well	Manual Hand Bore Direct Rotary	8 – 12 10 – 15 100 – 450	300 – 500	Rain Water Harvesting /Check Dams /Percolation Pond/ Gabion Structures
Soft Rock Aquifer	Dug Well Dug Cum Bore Well Tube Well	Manual Manual + Rotary Direct Rotary	5 - 10 10 + 30 100 250	500 – 1700	Check Dams /Percolation Pond/ Recharge Wells/ Injection Wells

	State Boundary		District Boundary
	Block Boundary		Palaeo Channel
	District Headquarters		Block Headquarters
	River	1250	EC In Microsiemens / Cm At 25°C
	Saline Zone		Nitrate Greater Than Maximum Permissible Limit (45mg/L)
	Thermal Water		Auto Flow Zone
	Lineament	R	Recommended Site For Artificial Recharge Structure

Figure 32: Hydrologic Cross Section

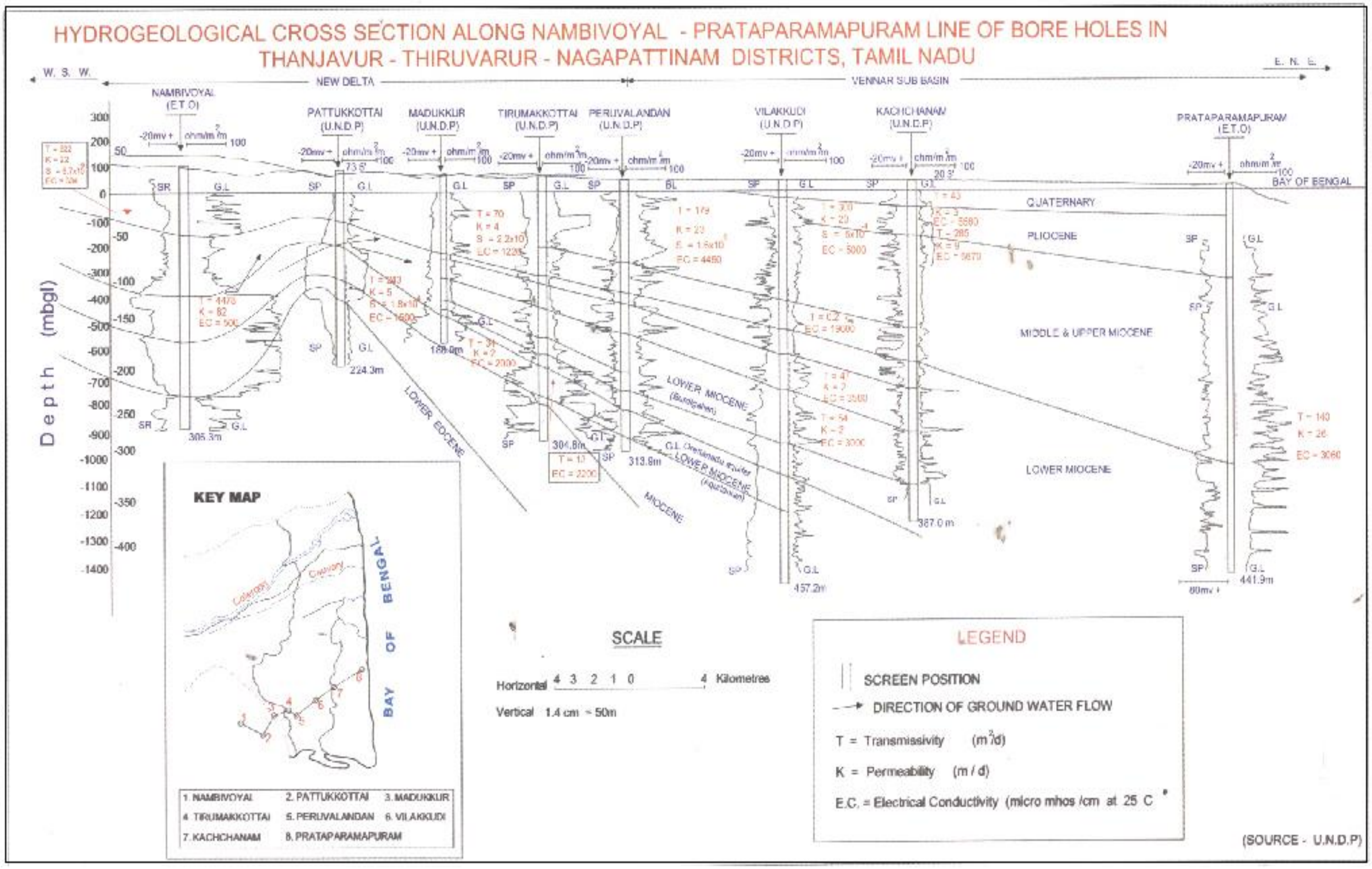
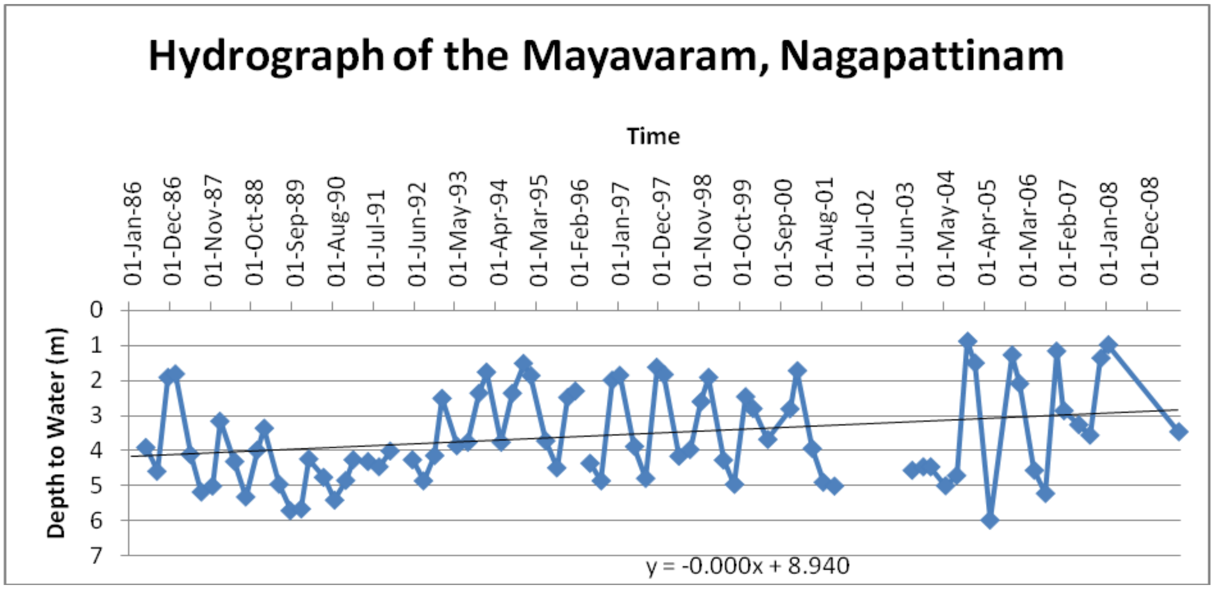


Figure 33: Hydrographs of Observation Dug Wells in Cauvery Delta



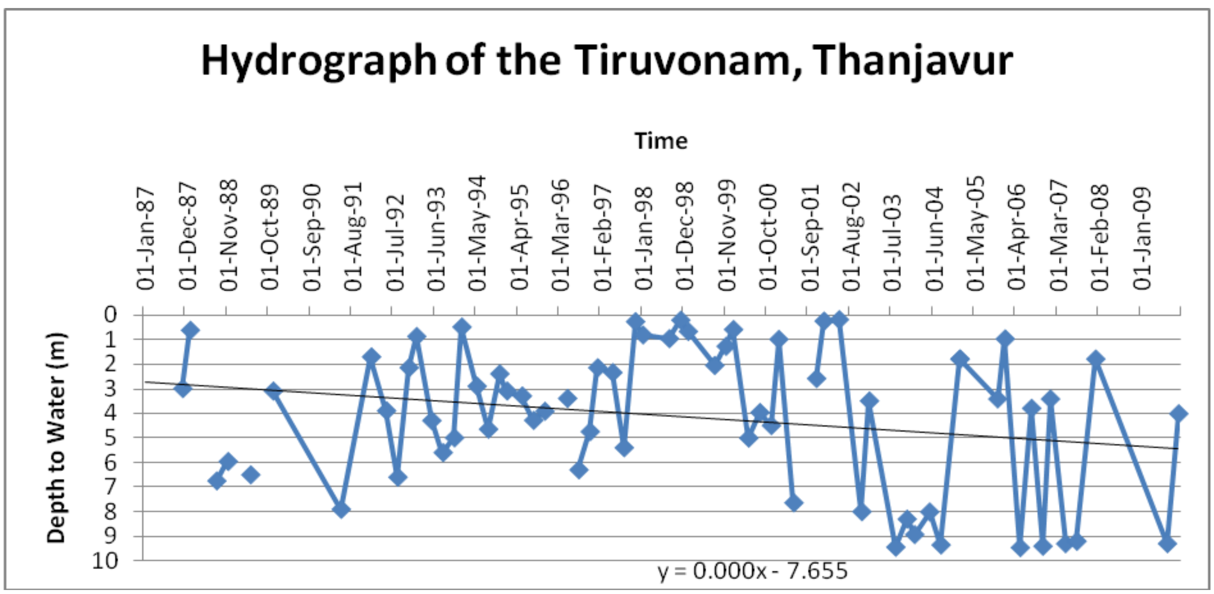
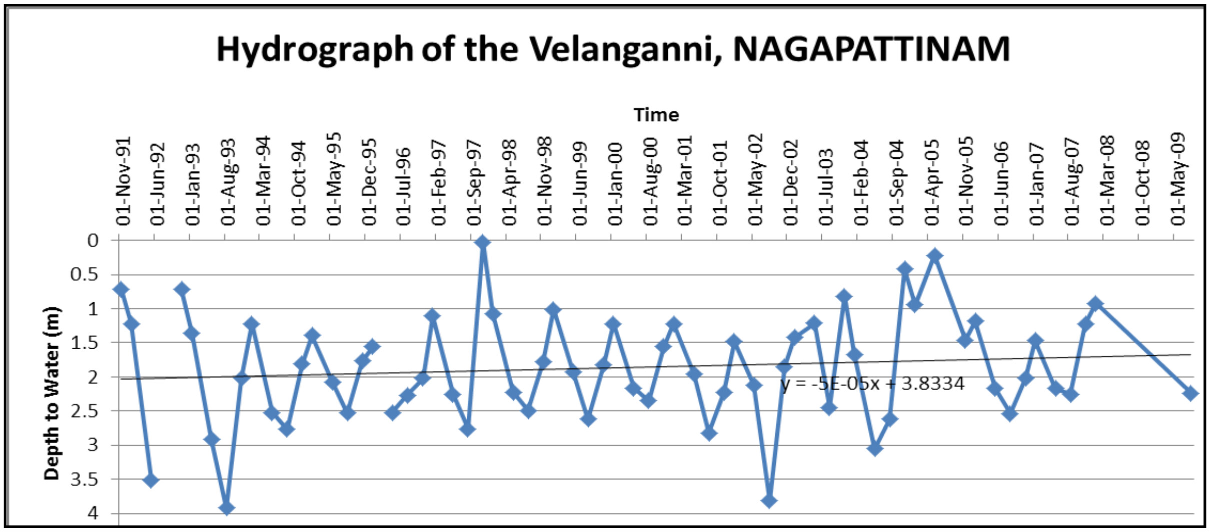
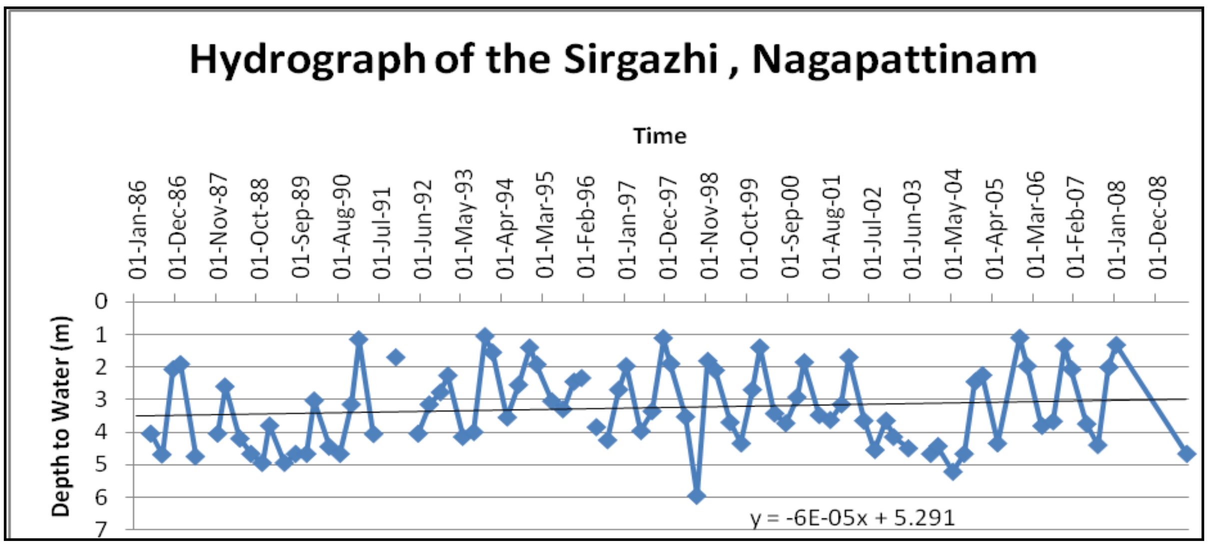


Figure 34: Hydrograph of Piezometer in Velanganni, Nagapattinam District





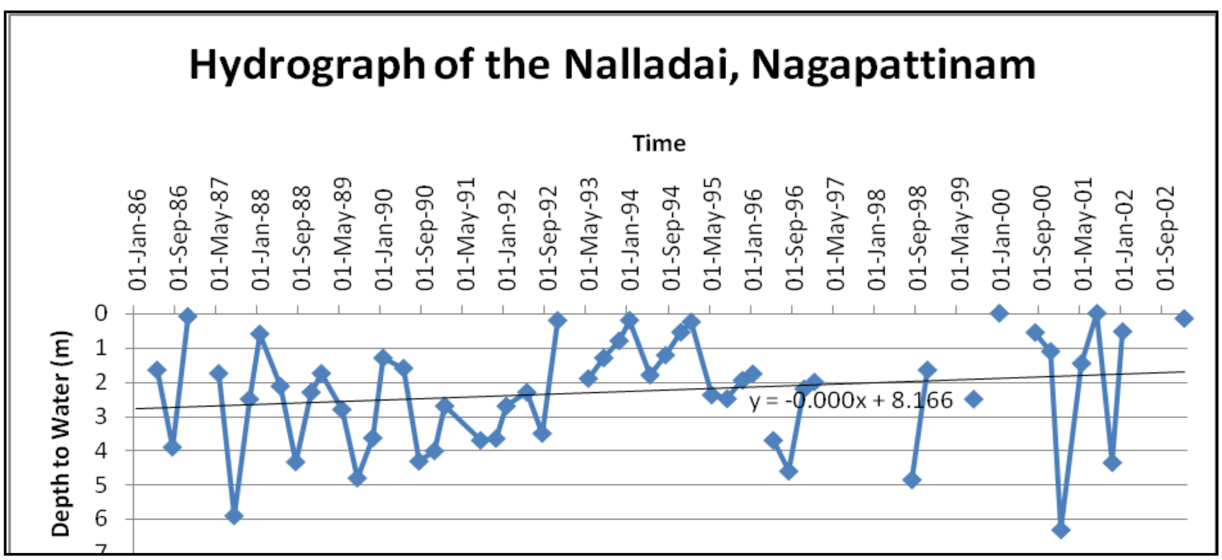
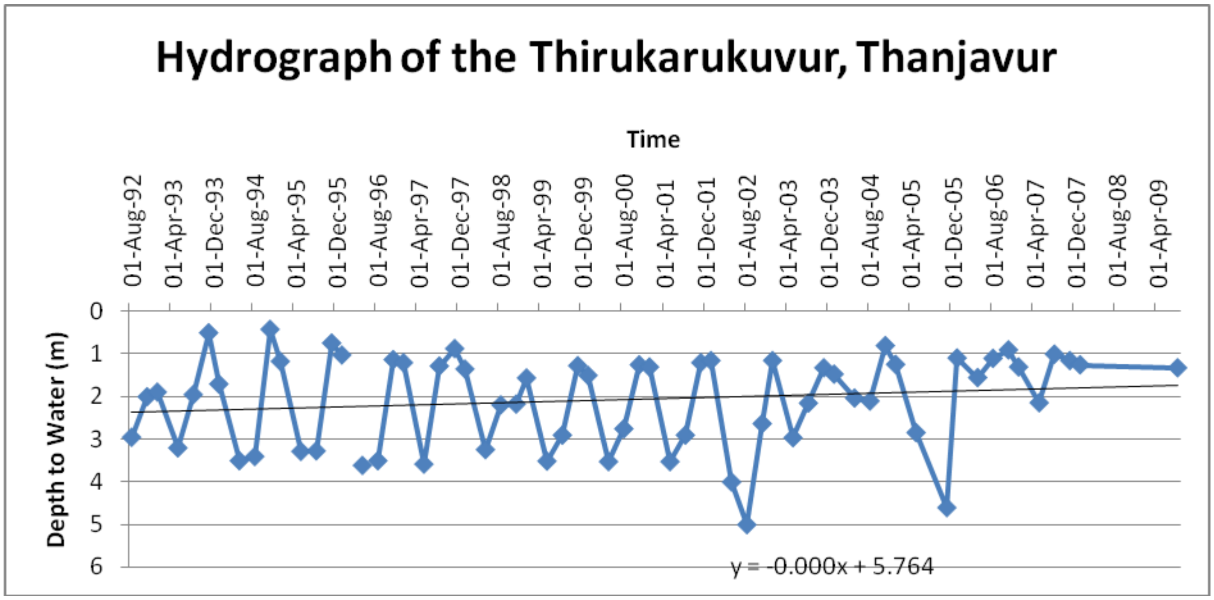


Figure 35: Hydrograph of Piezometers in Thanjavur Disrtrict



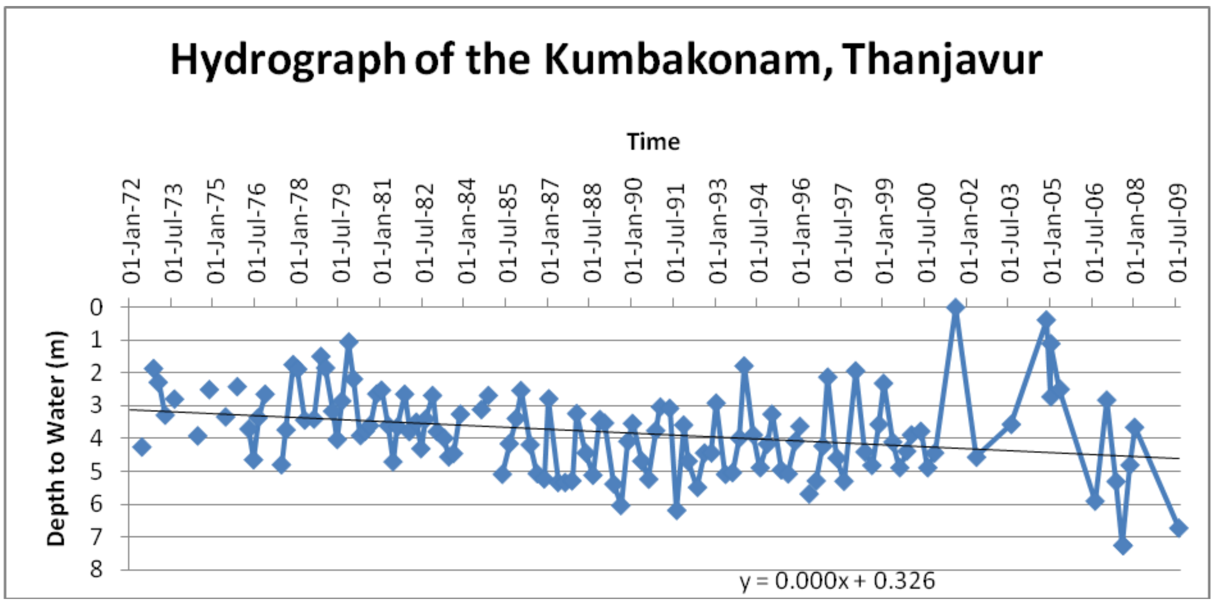
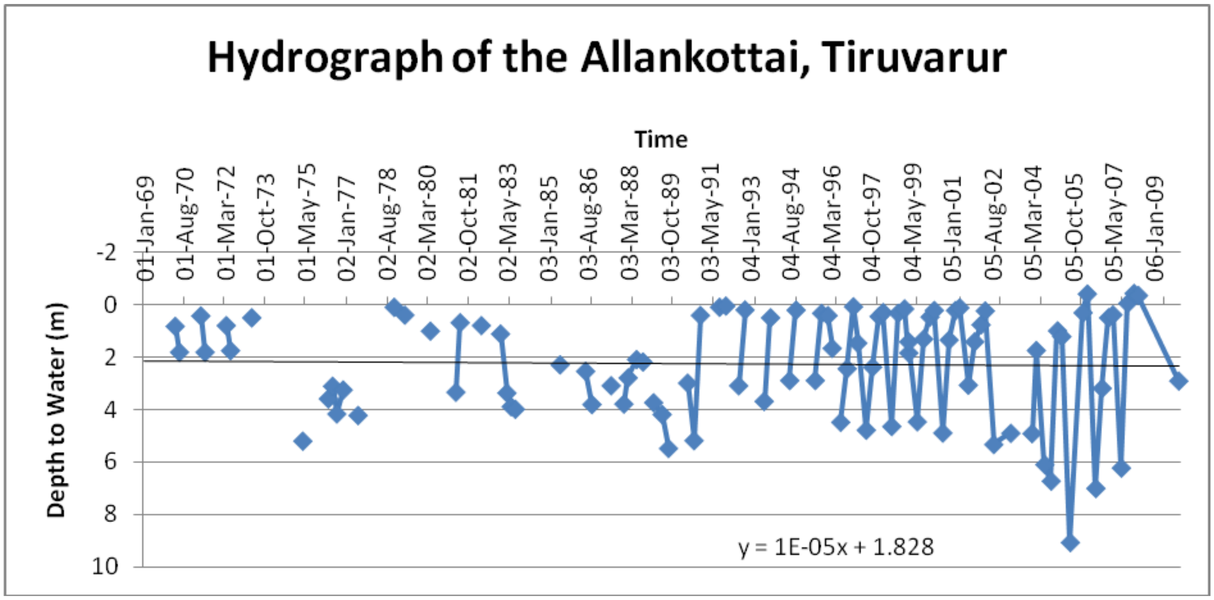


Figure 36: Hydrographs of Piezometers in Tiruvarur



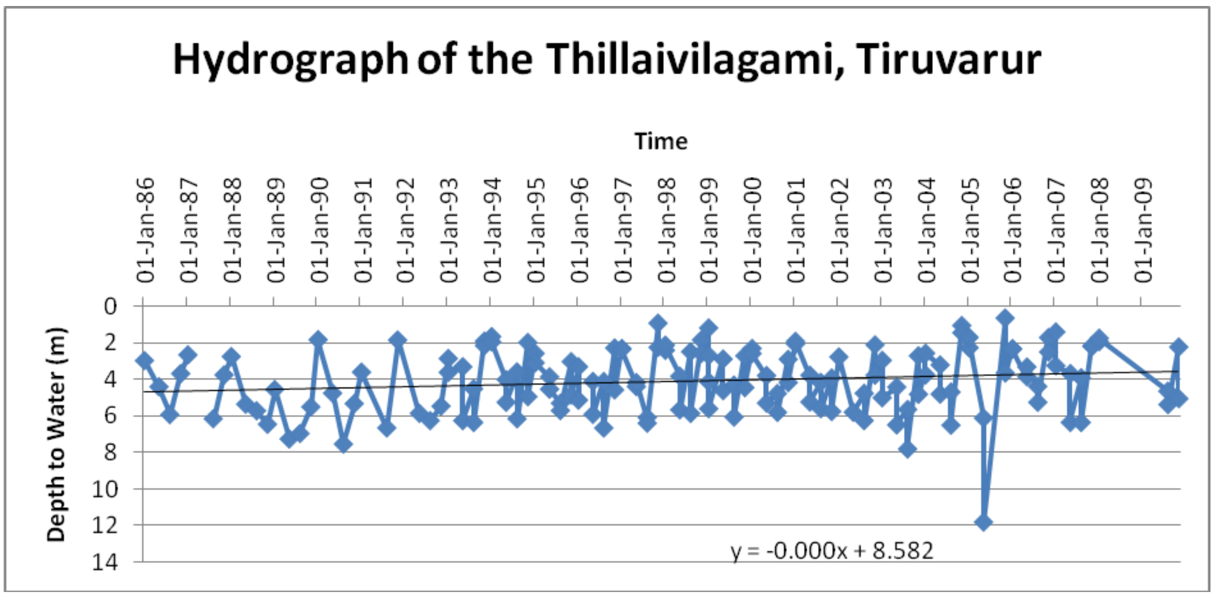


Table 16: Nagapattinam Water Quality

SITE NAME	Mg	pH	NITRATE	K	SULPHATE	EC	Ca	Na	CARBONATE	BICARBONATE	CHLORIDE	FLUORIDE	SAR	RSC
Vedaranyam	12.21	7.3	7	8	14	463	40	35	0	177	50	0.63	1.24	-0.10
Thagattur	34.13	7.3	5	8	120	2040	72	343	0	500	369	0.64	8.34	1.79
Velanganni	104.72	7.4	19	20	163	3540	144	453	0	421	893	0.52	7.01	-8.90
Keelvalur	48.69	7.2	92	16	58	1208	50	120	0	268	174	0.50	2.90	-2.11
Nagapattinam	47.52	7.3	35	8	86	1736	86	207	0	427	277	0.68	4.45	-1.20
Nagore	76.63	7.2	2	8	38	1966	38	267	0	494	386	0.70	5.74	-0.10
Tranquebar	54.78	7.5	9	8	24	1980	66	276	0	427	440	0.60	6.08	-0.80
Mayavaram	155.72	7.2	99	20	1152	3890	92	497	0	342	284	0.65	7.33	11.79

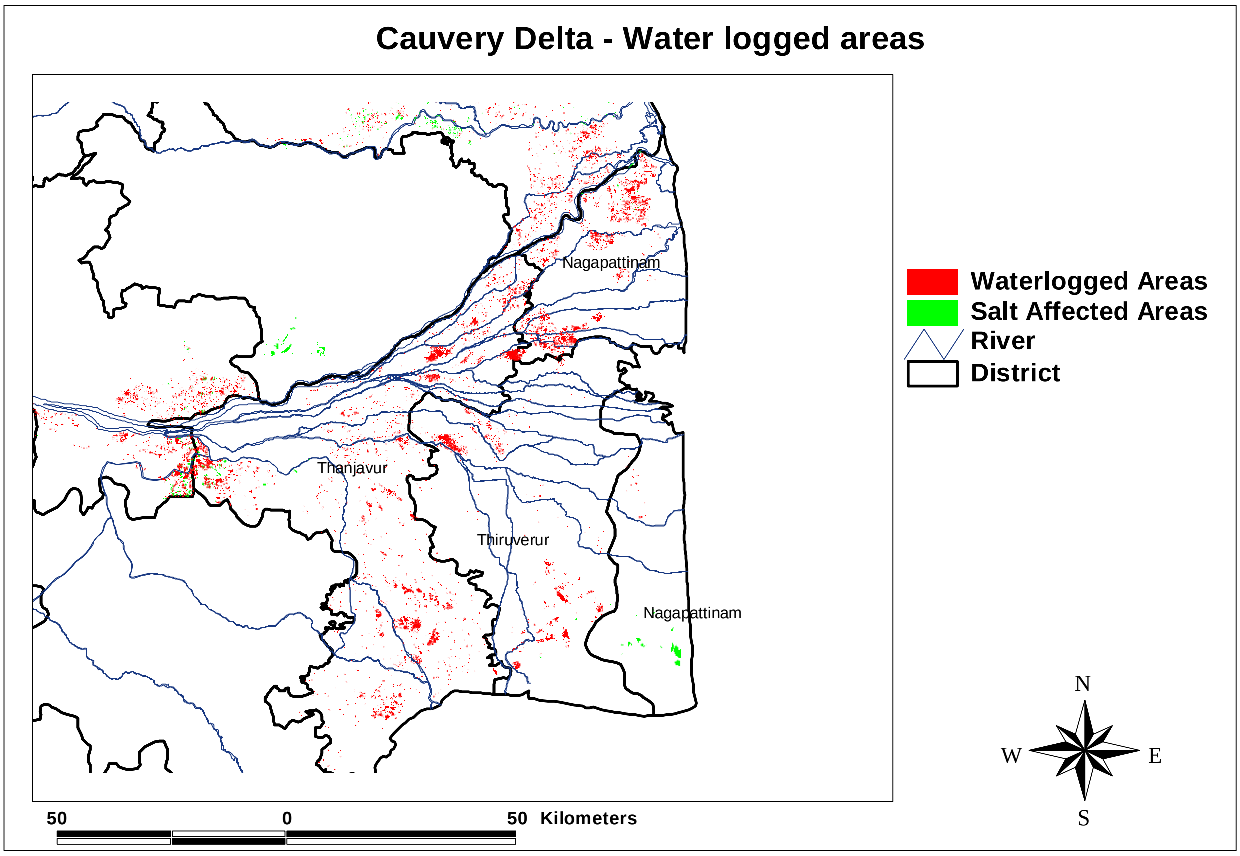
Thivarur

SITE NAME	Mg	pH	NITRATE	K	SULPHATE	EC	Ca	Na	CARBONATE	BICARBONATE	CHLORIDE	FLUORIDE	SAR	RSC
Tirumazhisai	65.69	8.0	35	25	60	1900	40	260	0	500	337	0.78	5.88	0.80
Mettukandigai	97.32	7.2	22	5	300	2870	58	425	0	372	589	0.74	7.92	-4.80
Tiruvalangadu	36.56	8.0	6	0	40	1305	76	156	0	317	259	0.57	3.68	-1.60
Tiruvallur	127.70	7.6	41	50	150	2730	44	354	0	512	606	0.91	6.11	-4.31
Pulal	25.56	7.6	23	25	33	415	28	10	0	55	78	0.44	0.33	-2.60
Tiruttani	80.26	7.8	68	10	50	1100	22	72	0	305	135	1.20	1.60	-2.70
Kanakammachatrm	63.26	8.0	6	0	120	3120	40	615	0	787	652	1.37	14.10	5.70
Samiyarmadam	115.50	7.7	24	10	360	1970	10	254	0	384	273	0.81	4.94	-3.71
Attipattu	92.48	7.7	1	18	100	2410	74	285	0	323	621	1.17	5.22	-6.01
Nandiambakkam	104.59	8.0	116	10	70	1590	38	126	0	354	248	1.08	2.39	-4.70
Palavakkam	40.19	8.2	23	5	40	1035	62	82	0	366	113	0.52	1.99	-0.40
Uthukottai	55.95	8.2	5	20	45	1085	22	116	0	366	145	0.59	2.99	0.30
Gummidipoondi	30.49	8.2	10	15	50	1115	80	110	0	262	209	0.60	2.65	-2.21

Thanjavur

SITENAME	Mg	pH	NITRATE	K	SULPHATE	EC	Ca	Na	CARBONATE	BICARBONATE	CHLORIDE	FLUORIDE	SAR	RSC
Sanarpatti1	24.39	7.1	25	4	48	879	66	81	0	244	121	0.80	2.16	-1.3
T Budalur	68.43	7.2	130	4	86	2590	288	198	0	305	702	0.60	2.72	-15.0
Thanjavur	47.51	7.5	87	8	67	1653	80	196	0	488	206	0.54	4.29	0.1
Thirukarukuvur	92.48	7.5	12	20	134	2120	76	230	0	604	312	0.72	4.19	-1.5
Thiruvaiyaru	247.99	7.2				3020								
Papanasam	43.89	7.6	7	8	53	1123	100	55	0	366	142	0.53	1.15	-2.6
Kumbakonam1	165.63	7.3	446	297	389	6340	248	731	0	793	1305	0.61	8.82	-13.0
Aduthurai	42.59	7.5	1	8	24	991	34	104	0	397	103	0.51	2.81	1.3
Narsinganpettai	80.28	7.2	32	20	10	1230	36	81	0	427	160	0.56	1.72	-1.4
Lower Anicut	66.89	7.3	3	8	38	1545	24	198	0	586	174	0.62	4.71	2.9

Figure 37: Water Logged Areas



IV. AGRICULTURE

54. In the Cauvery Delta rice is the principle crop; it is either single or double cropped. A third crop rise is also grown during summer in some parts. Because of plentiful rainfall during North-East monsoon and good irrigation facilities rice is the most suitable from September to December. Pulses are the next important crop after the rice harvest and is grown through, out the delta regions from January onwards. Black gram and gingelly is sown in April with summer irrigation and some summer showers. Vegetables are also grown during summer months in some areas depending upon the availability of water. In different scattered places coconut trees and bamboos are also grown. Many places fruits like mangoes, guava, citrus fruits, jack fruits, banana and cashew are grown as longer duration crops occupying the land for more than one year for successive returns. Similarly sugar came, rose, crusade and arali are also grown at many places.

55. State Agricultural Policy is to achieve the goal of “Doubling Food production” in the immediate future. To achieve this goal, the State Government has formulated an agricultural policy, which aims at; (i) developing a scientific approach to support the development of the rural economy and preservation of ecological balance based on the requirements of agro climatic zones; (ii) to increase productivity, production and profitability; and (iii) implement of farmers welfare schemes such as integrated watershed development, land management, development of water resources, organic farming especially use of green manure, bio-fertilizers, bioconversion of agricultural wastes, bio pesticides and parasites, integrated pest management, remunerative price to agricultural produce, processing, value addition to agricultural produce, promotion of crops with export potential, with a view to ensure economic improvement, besides rural prosperity.

56. The short duration (105-110 Days) rice varieties Kuruvai is most popular among the formers. This is first crop of paddy cultivated in June –July, followed by Thaladi (135 days) as the second crop of paddy in the double crop lands, while in the single crop lands long duration Samba paddy (150 days) grown. Samba is being grown under dry and semi dry conditions also. The ground water tapped with filter points tube wells is mainly used for raising advance paddy nurseries and for meeting crop water requirements during the late maturity of the crop.

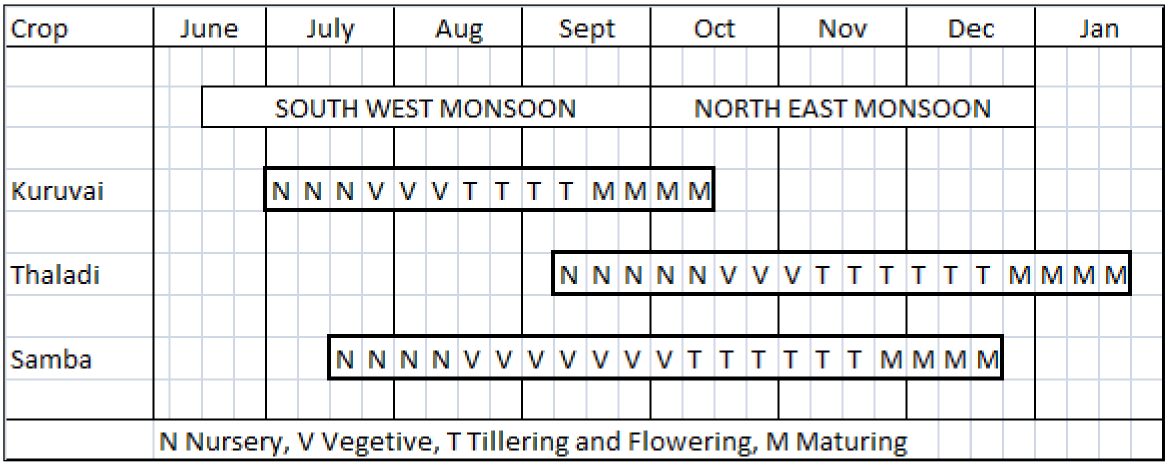
57. The problems faced by the delta formers can be summarized as below.

- Because of overall water shortage in the basin and lack of assurance about the Mettur Dam releases, planning of the cultivation is not systematic.
- Torrential rainfalls during North-East Monsoon hinder both Kuruvai harvesting as well as Thaladi transplanting.
- Lack of storage facilities of rain water. the number of ponds, check dams, small reservoirs and diverts etc are very limited to control water at times of heavy inundation.
- Lack of drainage facilities in the Delta region. Groundwater recharge is very poor and soil reclamation is not feasible making water unfit for agriculture purposes.
- There is labour shortage during peak season of harvesting or planting. Because of insufficient yield in crop production remuneration to the farmers for rice cultivation are low in many case, timely field operation are not carried out. Lack of co-ordination between owners and tenants, as well as between farmers and fisherman create social problems.
- Many times unfavorable weather conditions lead to heavy incidence of pests /diseases to the crops.
- Clear cut policies and planning of contingency cropping sequence in the events of mishaps in the routine cultivation has not been developed. There is a lack of co-ordination between agriculture and PWD officials on water and crop management.
- There are efforts for development of new crops suitable to the prevailing delta conditions but farmers are not much aware of the same. Non rice crops, vegetables, horticulture are getting more popular but because of complexity of water soil regime in delta, extensive research and planning is needed to guide the cultivators.
- Poor cash flow have to be managed among the cultivators by providing micro-credit facilities and insurance services.

58. The irrigation season is from June to end February, the practice is to have either; (i) a double crop system with a short duration rice Kuravai (105 days) followed by a medium duration rice Thaladi

(135 days) or; (ii) a long duration Samba crop (150 days).The cropping calendar is shown in Figure 38.

Figure 38 Cropping Calendar



59. The cropping systems are rice-rice-rice followed by crops like pulses/cotton/sesame. The area of different crops is given in Table 17.

Table 17 Delta Cropping Systems

Crop	**Area (ha)**
Rice	Kuruvai – 168,000 ha
	Thaladi – 144,000 ha
	Samba – 299,000 ha
Pulses	
Blackgram	142944 ha
Greengram	45909 ha
Gingelly	10358 ha
Cotton	2711 ha

60. The land holdings in the delta are quite small with more than 75% are one ha or less. Population growth has progressively diminished the size of land holdings. Labour intensive practices in agriculture is preferred to mechanization since mechanization in small holdings is not economical. Being engaged in agriculture for most part of the year he does not seek any other avocation and the community is essentially agrarian with a few possessing the land and the others working as agricultural labourers on the land. This is different from the scene in similar irrigated areas in the uplands where the irrigated expanse will not be this large but confined to a defined command and the people would be engaged in diversified avocations.

V. IRRIGATION AND WATER SUPPLY

A. Cauvery Tribunal.

61. Surface water allocations to the delta are defined by the Cauvery Tribunal which assessed the mean annual water availability of the Cauvery river basin as 740 TMC. Overall Cauvery water allocation by the Tribunal to the State of Tamil Nadu has been fixed as 419 TMC. The water allocation is summarised Table 18 below.

Table 18 Cauvery Tribunal Summary of the Award

Aspect	Water Allocation (MCM)	Water Allocation (TMC)
Irrigation requirement 999,684ha	11,061	390.85
Domestic water	62	2.2
Industrial water and Thermal Power	1,500	53
Share in balance water		
Share in balance of water additional allocation -	728	25.71
Total	**11,858**	**419**
Out of 390.85 TMC for the entire Cauvery basin (999 964 ha) in Tamil Nadu, the allocation for Cauvery delta zone is 215.98 TMC		
Cauvery delta system (415,612 ha)	4,247	150.06
Lower Coleroon Anicut (56,615 ha)	551	19.47
Cauvery Mettur Project (Grand Anicut Canal System) (111,693ha)	1,315	46.45
Total	**6,225**	**219.98**

62. The tribunal reserved 14 TMC (396MCM) of water as environmental flow and seepage to the sea. The distress due to short fall in the water in the basin during any year has to be shared by the basin state in the proportionate basin. The tribunal has also fixed monthly inflow at Mettur reservoir as water flows from Karnataka to Tamil Nadu breaking the annual allocation of 419 TMC into monthly allocations. The final Tribunal award has not been notified therefore the monthly sharing of water is currently governed by an interim award of the Cauvery Tribunal (1991). The annual and monthly water allocation has been fixed by the Tribunal considering the overall annual availability to be 740 TMC is on dependability of 50% only. Therefore there are chances of less water availability during the 50% of the years.

63. The tribunal has also considered overall efficiency of irrigations system to be 60% to 65%, which is quite difficult to achieve considering the unlined canal systems. Tribunal has also considered the mean annual rainfall to be available to the farmers while calculating the irrigation water demands. However due the frequent high intensity rain fall and lack of storage facilities the Northern-Eastern monsoon water cannot be properly utilized. On the contrary high intensity rainfall and consequent flooding causes damages the agriculture fields and water goes waste as surface run off to the sea, and in most part of the lower delta regions drainage congestion occurs.

B. Irrigation Efficiency:

64. The overall project efficiency is taken as product of (i) on form field application efficiency, (ii) field channels efficiency and (iii) canal conveyance efficiency. Field application efficiency can be enhanced by good water management, and adequate on form development in the form of land shaping and grading and construction of field water courses and drains. Field canal efficiency can be enhanced by lining the field channels (from block outlet or canal outlet to the field inlets) or by piped supply. Canal conveyance efficiency can be improved by canal lining, weed eradication, reduction of wastages from escape and improved gate control.

65. Conjunctive efficiency should be applied when considering overall basin efficiency and efficient conjunctive use planning. Under such situations lining of canal systems is not considered to be beneficial way of saving water. The lining of system is preferred only if there is water logging and salinity in the command area caused by seepage of water or lining is preferred where seepage losses are very heavy and need to be avoided to save the water. Moreover, canal lining is also considered to be very costly and disturb the canal irrigation by closing of canals during construction.

66. The Cauvery Delta system is different from most other irrigation schemes. The Delta irrigation system is served by numerous distributaries of Cauvery River as natural river course which serve as combined irrigation and drainage canals. As the canals are in the regime condition, redesigning of the system with lining is not feasible. The water use efficiency has to be mostly obtained by on farm water management practices and more methodical water distribution. Water allocations are not measured due to the lack of measuring structures; the very flat terrain poses technical problems of water measurement.

67. There are reported to be around 39,000 tanks in the Cauvery delta with a total capacity of 540MCM and 23 reservoirs with a capacity of 4,379 MCM

C. Cauvery Delta Modernization Project

68. The Government of Tamil Nadu constituted a task force in September 2007 for preparation of a comprehensive report on modernization of Cauvery delta irrigation and flood control and drainage works. The report of task force[7] along with estimate of proposed works was brought out in November 2008. The Cauvery delta modernization project had also been prepared earlier two times, but the funding required for the project could not be approval by the Central Government because of the dispute on Cauvery water under adjudication in the Cauvery Water Dispute Tribunal. In the current proposal prepared by the task force the overall cost of the project has been estimated to be Rs, 5100 crore, out of which Rs, 4500 crore has been estimated for structural works. The major components of work are (i) strengthening of river banks; (ii) strengthening and lining of distributor network; (iii) repairs and replacement of structure and additional structures; (iv) tail end regulators; (v) improvement in the drainage system; (vi) improvement in the drainage system and Vedaranyam Canal system.

69. Some works related to be improvement of structure and distribution network have been taken up by PWD with the NABARD funding. GoTN has also prepared a funding request to GOI for funding under Accelerated Irrigation Benefit Programmes.

70. The modernisation report includes the following components:-

(i) Strengthening of banks
(ii) Improvements to the irrigation channels and their network; it is proposed to improve the channel by provision of relocation and introduction of outlets for well defined compact block under each out let, construction of notches and other masonry works to ensure equitable water supply. Selective lining of canal, including lining for all larger irrigation channels which off take from the rivers, with clubbing of the channels where ever possible.
(iii) Repairs and replacement to the structures; it is proposed to repair and modify canal structures to the extent required.
(iv) Reconstruction of tail end regulators and some additional tail end regulators; regulator are proposed to be redesigned with large vent ways and easy operating gear to serve as salinity barriers at location where tidal flux ends.

71. **Flood Control**; these include remediation measures against flooding, drainage congestion and salinity ingress. Floods and drainage are a complex problem in the delta. The Northern-East monsoon starting in last week of November gives about 700 mm of rainfall. The south-west monsoon giving about 300 mm of rainfall in the delta is easily absorbed in the system this rainfall is fully utilized for agricultural activities.

[7] Report of the Task Force On The Modernisation of the Cauvery Delta Zone in the Cauvery Basin Of Tamil Nadu November 2008 Tamil Nadu Water Resources Organisation

72. The North-East monsoon is generally associated with cyclones. Because of flow from the upper position of delta and heavy showers in lower region the delta becomes fully congested to drain any water into sea. If the inundation is prolonged for more than 5 to 7 days, there is damage to the standing paddy crops. Some of the lower delta area is below sea level which makes it impossible to drain. The speedy drainage of the area becomes important for protection against excessive and long duration flooding to save the paddy crop which can survive inundation for 3-4 days. The tidal variation of the sea is about four feet which also causes a significant ingress of sea water into lower delta during high tide. Another problem being faced is closing of mouth of drainage outlets by the sand bars formed by strong littoral currents and deposition of river sediment. Of about 1600 km of river network in Cauvery Delta about 530 km serve as standalone irrigation. The remaining channels function as irrigation cum drainage.

73. The Cauvery Delta Modernization project PWD, Government of Tamil Nadu has proposed following measure for flood and drainage control:-

- (i) Aquatic weeds in the bed and sides of channels to be removed and further growth and proliferation are to be controlled with proper weed management.
- (ii) Reshaping of exiting drains wherever necessary bringing the section to required standard and strengthening the banks.
- (iii) Strengthening the meandering courses and opening of more straight cutting drains.
- (iv) Improvement to the cross-masonry structures and providing suitable inlets and outlets with regulating arrangements.
- (v) Excavation of additional drains.
- (vi) Provision of additional escapes, inlets and outlets structure are to be provided. Place where roads are blocking the drainage water to be identified and culverts be provided or the existing vent way of the culverts to be enlarged.
- (vii) Restructuring and improvements in Vedaranyam Canal and strengthening the canal bunds. (the Vedaranyam Canal runs parallel to the sea originally a navigation canal, and acts as drainage water body with complex hydrology)

74. The major and important works proposed is dismantling and reconstruction of all the tail end regulators at the tail ends of each distributor which in fall into sea. The regulators have various functions including (i) lifting the elevation of the water for irrigation(with the gates closed); (ii) allowing free discharging the flood generated inland to flow down the river to in fall into sea with all gates opened; (ii) to prevent the ingress of sea water inland and support the reduction of salinity in the area. There are eighteen tail end regulators requiring to be redesigned with adequate vent capacities and easy operating systems.

VI. WATER SECTOR COMMUNITIES AND STAKEHOLDERS

75. Effective long term water planning requires makes it almost mandatory to have stakeholders' participation in the design, implementation of public policy and decisions about the delivery of services (Martin, 2005) and also as peer monitoring group. Stakeholders are those who have an interest in a particular decision, either as individuals or representatives of a group. People who influence or can influence a decision as well as those affected by it can be considered as stakeholders. Community of stakeholders can become active with some specific goal. Without going into the definitional debate on 'community' across disciplines we can use it here to describe a group who shares identity on some specific respect and shares (any one or all) belief, resources, concerns, needs etc. The size of a community can vary.

76. A commonly shared vision by all stakeholders can help support a successful intervention, be it policy, technology or systemic. For the current assignment, specific goal around which we are trying to identify a community is "to examine intervention requirements, scope and strategies to improve the efficiency of water systems and how improved efficiency may be applied to climate change adaptation".

77. To identify water sector stakeholders from climate change point of view within the scope of this assignment we consider the community associated with the issue at hand. It covers part of the human society whose employment/livelihood/income/productivity stream will be directly impacted in future - become riskier/decline- with change in stock and/or flow of water. The stakeholders who are active with this goal are both national and state government across various departments, knowledge generators engaged in technological and social innovation, farmers, NGOs. In the context of this study stakeholders/community are broadly: water source owners, water flow service providers and water stock and flow users.

78. Water source ownership in the state is represented by multiple categories of stakeholders not fully coordinated and rules on human interventions on the natural water system if not governed by fully defined rules.

79. Primary sources of water flow are natural[8] (rainfall, ocean) defining the overall constraint on primary water supply. In climate change context adaptation challenge is if the community has knowledge and preparedness to take actions now so that the individuals, households and community becomes resilient to uncertain water supply condition in future without affecting wellbeing (in micro sense we consider current and future income stream of farmers and in macro sense productivity in agriculture to make state domestic product resilient).

80. Secondary sources are various institutional sources based on surface water flow: Interstate high level body (e.g Mettur dam) in control of surface water, WRD department owned canal system, Agriculture department owned micro and medium irrigation systems and famers withdrawing water from open access ground water aquifers with variety of pumping technology and farm pond based water harvesting systems.

81. In this sense stakeholders for this study can divided into water providers and water users. as shown in Figure 39

[8] nature do not play an active role as stakeholder for our decision making purpose

Figure 39 Profile of Stakeholders

STAKEHOLDER	
WATER USERS	**WATER PROVIDER**
Water for final use: Household demand for drinking purpose **Water for intermediate use/input in production process:** Household demand for cooking, hygine and sanitation, bathing, gardening etc. Agricultural water demand for irrigation Industrial water demand for process.	**Water suppliers/managers** **Formal:** Government managed water supply department for distribution of canal waterf or irrigation and drinking water Water users association **Informal**: Farmers with pump to lift ground water and sells at a cost either monetized (cash) or non monetized (in kind)

1. Understanding stakeholder perceptions

82. In the Cauvery Delta major water users with changing demand are engaged in fishery and agriculture sector. Residential water users are also important but they have a more or less fixed demand for drinking, cooking and sanitation. The focus has been on farmers, rural households of various income strata (defined by landholding size/inland/open sea fishing community) and water managers from irrigation, panchayats. Source of information is primary first hand data collected through rapid rural appraisal through face to face participatory and focus group discussions and household surveys.

83. The goal is to identify key issues regarding surface water, groundwater, water related sectors and the environment to help in preparation of strategic framework planning. Also, to examine intervention requirements, scope, and strategies to improve the efficiency of water systems and study how climate change dimensions may effectively be incorporated in IWRM climate change adaptation roadmaps.

84. The specific goal of PRA and household survey[9] has been to understand community perception at various levels and to get first hand information on :

- stakeholder assessment of current issues related to surface and ground water
- the problems and causes of issues
- perception of change in climate induced parameters and impact on water resource
- to test the response to potential initiatives to address water issues
- identify possible initiatives that could be further investigated

2. Adopted Approach for PRA and Household Survey

85. The PRA is designed to support the stakeholders through the process of analysis of the problems and help them identify appropriate response to the difficulties and opportunities. We have used preset questionnaire as checklist to get structured response. Qualitative response during focused group discussions has also been recorded, compiled, assessed and presented in the report. The approach has followed the conceptual framework of (livelihood, Institutions, Food security and Empowerment) LIFE approach and Nine square mandal. in preparation of questionnaire in cooperation with other team members involved in the TA. In the sub basin three locations have been identified through prior visits, consultative processes with stakeholders. Locations selected are characterized by primarily diversity in conjunctive water use practices and related challenges. ADB-PRA team held stakeholder meetings at the villages with stakeholders assembled in focused group discussion (FGD) in each of the three locations. Primary data has been collected not only from FGD but also through household survey of 74 households covered. These interview methods has been followed to get community, household and individual perceptions.

[9] PRA instrument/questionnaires prepared in full consultation with team members and piloted and tested.

86. The choice for community groups in Cauvery delta has been governed by the diversity in distance from the coast line: less than 3 km, 3-10 km and more than 10 km distance. Study locations were chosen with one in the north and one in the south of delta. The goal has been to understand if the stakeholders' challenges are diversified by occupation category wise and location wise. Secondary criteria have been the fishing community and agricultural farming community followed by water quality and source diversification. The site selections have been preceded by investigative field visits and consultation with different broad categories of stakeholders. The site selections have been preceded by investigative field visits and consultation with different categories of stakeholders.

3. Community Perceptions

87. The stakeholders of various interest groups shared more or less a common vision on current water availability, access, distribution and quality in the region. Diverging views are reflected in quantification of the issues. This is presented below through ranges of values for various variables and parameters. PRAs were organised in Thirmullaivasal for exclusively fishing communities, Voimedu for agricultural communities and in Thondiagadu communities have both agricultural and fishing operations as livelihood options.

88. During the household survey we focused on fishing community and agriculture farming communities to understand current and future challenges for both the communities. So we present below the observations separately for two communities. The occupation categories of surveyed households in two different villages are shown in Table 19.

Table 19: Occupation Distribution across villages

Occupation by village	Agriculture	Fishing
Ananthathandapuram (19)	100%	
Munangadu(11)	82%	18%
Pazhayapalayam (14)	100%	
Thirumullaivasal (20)		100%
Voimedu (10)	100%	

89. Out of total households surveyed, 30% were fisherman and 70% agricultural farmers. 75% farmers have landholding size of five hectares or less and 25% have landholding size of above 5 hectares.

4. Challenges in Drinking Water

90. From the consultations a wide range of drinking water challenges were identified including:

- Drinking Water access and challenges vary depending on distance from coast line.
- Fishing communities surveyed in Thirumullaivasal village in Nagapattanam district of Sirgali block are from the Tsunami affected area. They all live in houses built by Tsunami aid. There was 15m column height of tsunami water standing in the village. The major issue after tsunami is drinking water access. Tsunami has changed ecosystem by affecting the ground water quality. The ground water which is available at a depth of 6-8ft has become saline after Tsunami and is not usable. Drinking water is distributed through piped network managed by panchayat. The source is treated river water under central water supply scheme. The demand for this water has gone up with deteriorating ground water quality. A total of 500 households in the village get piped surface water supply through 60 public standposts managed by Panchayat from an overhead storage tank 200m3 . The demand from community is to double the water storage capacity. Social conflicts are very common around water access.
- The handpumps to extract ground water for household consumption was primary drinking water source before Tsunami. Now that serves only non drinking and cooking purpose as piped water supply is less than demand.
- 5-8% of households use handpumps to get drinking water, Around 31% of agricultural community and 9% of fishing community get water from piped house connection and 44-86% get from piped public stand posts depending on if they are from agricultural community or fisherman.

5. Drinking Water Quality

- 100% respondents in focus group discussion mention salinity related water quality problem.
- Water supply infrastructure; pipe lines are on the roads and Pachayats feel that they get damaged by heavy vehicles and leads to leakage in pipe lines very quickly.
- Females and children spend almost an hour daily to get drinking and cooking water. Water flow is very slow leading to more time spent in collection and leading to disputes often. Sometimes public standposts are stopped from use by disputing families until the dispute gets resolved by Panchayat's intervention.
- There has been an NGO (PCI) engaged in drinking water purifying and bottling for 20litres and selling at Rs 3 per 20 litres. Two years back they handed over the facility to Panchyat but it is now not functioning as Panchyat has no technical knowledge in maintaining the centre. Panchyat feels it can be revived with some technical training. People used to pay to take water from there.
- Participatory management of drinking water can be possible if adequate supply is provided with a business model and technical training. NGO/Panchayat can play an important role on a longer term contract.
- Assessment is, in the longer run desalinization will become an imperative in these areas or building of another dam on river for enhancing reservoir capacity might be a solution as envisaged by the community.

6. Challenges to Fishing Community

- Thirmullaivasal[10] village surveyed is located within 3 km distance from coast line. This was tsunami affected coast. Fishermen live in houses built with tsunami aided .
- After tsunami, fish catch reduced drastically. Certain types of fishes are not available for catch after tsunami.
- The closure of the river barmouth closure during fishing season is a major issue. Drainage course river water meets at the sea. But the increasing problem is of less flow of water into the sea during dry season through river channel . Water flows in both directions: from the river and from the sea are needed for water quality to be conducive to fishing boats to move and for spawning of mudcrab as well. Boats can get stuck in the sand. With reduced fish landing the women need to buy fish at higher cost for marketing. Problem is higher for single women as they anyway have to depend on market for fish they take to market. Common practice is male member goes to sea to catch fish and females sort and sell in the market.
- During rainy season barmouth problems are less as there is adequate flow of water to maintain the river mouth open. The rainy season however (November-December) is not the fishing season as sea remains rough, cyclone etc. makes it risky.
- There is ban from government on fishing for 48 days during April 15-May 31 during fish breeding period.
- Idle time for men increases social and domestic violence. Community have no own solution for additional employment opportunity but demand for training during this period is high.
- All fish vendors are females. They report shortages of transportation and marketing facilities. A few years back, fishing boats from other villages used to come to the village to market their catch and fish vendors had a very good deal. But due to the problem of sea mouth closure, the incoming of no of boats from other fishing villages are reduced. So, Fish vendors are suppose to rely on fewer boats, which forced them to compete more for less fish at higher prices leaving lower profit margin for them.
- This village is situated about 20 kilometres far from the main road and markets so, the marketing of fish is very difficult to the village women. They make a group to bring fish to market for selling purpose. If they make the group then their transport cost will be less, sometimes critical size do not get formed depending in catch and marketable surplus of fish. This village has two or more Self-Help Groups (SHGs). There is need for loan among female vendors.
- Coastal Flood and inundation is major issue. This year they had two times flooding . The area is below sea level. Water enters almost 400 mtrs inland on an average.

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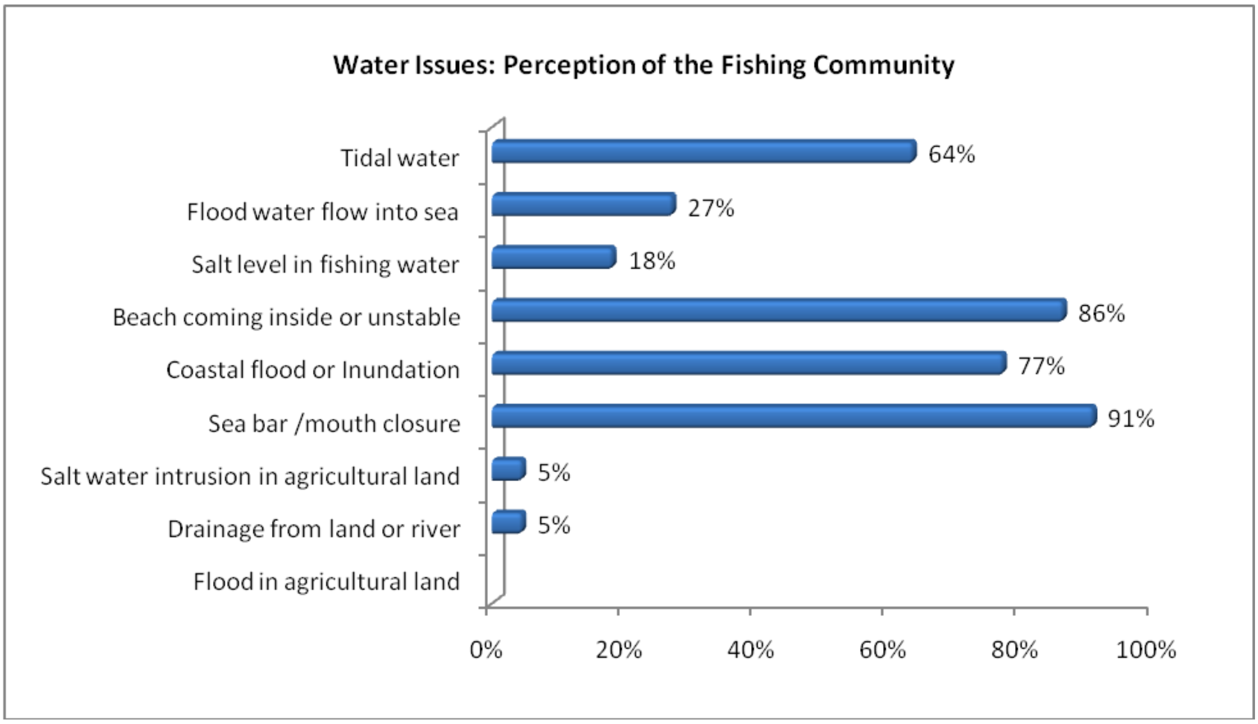
[10] PRA (8.2.2011)was attended by 42 individuals and of whom 10 were women in a thatched roof space on the coast.

- World bank funded project has been taken up after scientific enquiry on barmouth opening through dredging to avoid sand accumulation., but did not work in the delta area. The project is expected to end by 2011 December.
- There is a bridge proposed across the river to reduce transportation time between northern and southern part of delta which will make it difficult for boats to moor so there is need for a jetty on other side of the upcoming bridge.
- Indebtedness to village money lenders are high . They do not go to bank as it takes time and needs collateral. On an average for men they take collectively 50-60 lakhs of loan for boat, gear etc. 50-60mpeople together and women take on an average 10000/-for 100 days per person. They have joined self help group but loans are taken as they need to be rated first by NGOs which has high transaction cost. 10000/- per group/each time.
- Younger generation with college education also stay back in the village as fishing is highly remunerative. They look for more technical knowledge to improve their fishing effort and are ready for training.
- Some have migrated for higher studies and professional education. There is some migration from village to Singapore, Middle East and Malaysia where there their fishing skills are in demand.

91. A summary of water related issues mentioned by fishing households are shown in Figure 40

Figure 40: Perceptions of the Fishing Community Relating to Water

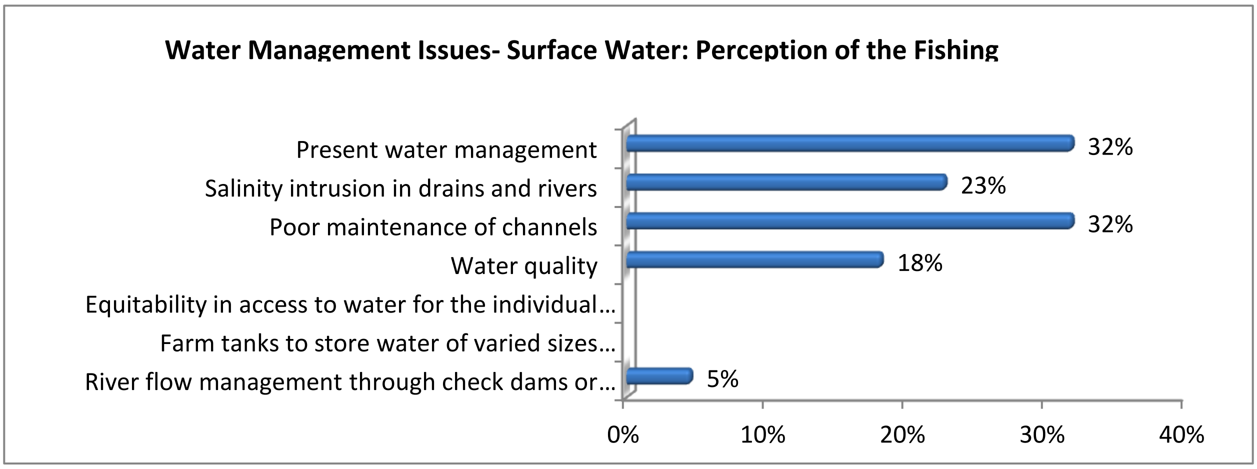


92. The sand bar at the river mouth is a problem is identified by 91% of households as a current major issue while sea shore coming inland is reported by 86% households followed by 77% households responding coastal inundation as major issue followed by tidal water intrusion (64%). Increasing salinity in fishing water is reported by 18% households only.

7. Water Management

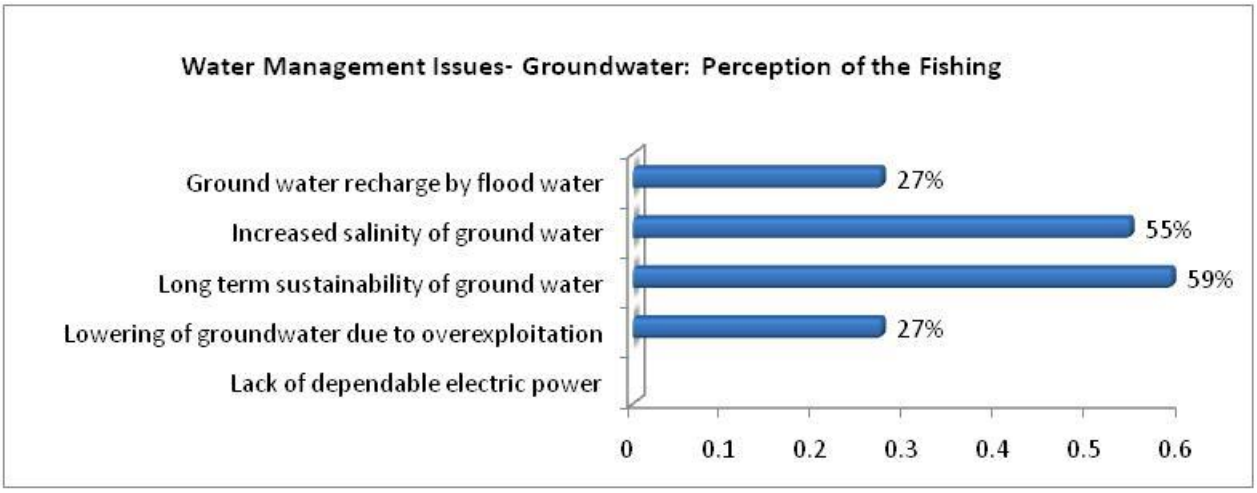
93. The fishing communities' responses are different than agricultural community. For surface water 32% are happy with present water distribution system but also complain about poor channel maintenance, 23% give priority to salinity intrusion management in drainage channels, 18% feel water quality issue be attended and 5% feel through check dams river flow can be managed. Water management issues are summarised in Figure 41.

Figure 41:Water Management Perceptions



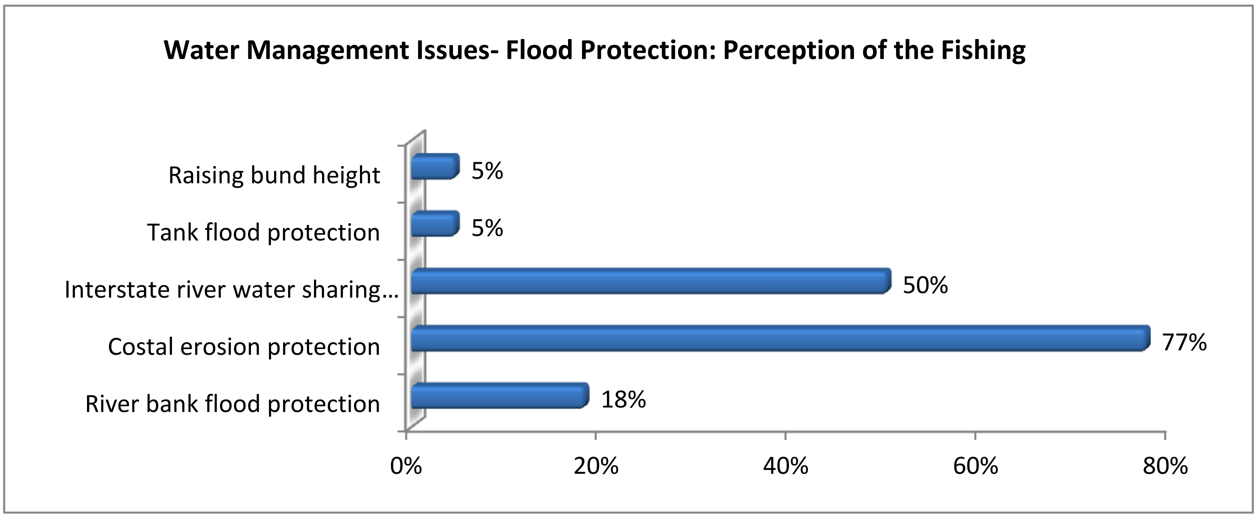
94. For ground water resources are concerned within fishing community 59% feel long term sustainability in ground water resource management be the chosen strategy, 55% feel increased salinity management be the strategy, with 27% feel ground water recharge by flood water and over exploitation of ground water be the strategy. Groundwater perceptions are shown in Figure 42

Figure 42: Groundwater Perceptions



95. About flood protection for fishing community coastal erosion protection is major intervention demand (77%), 50% want interstate water sharing be corrected, 18% prioritise river bank protection and 5% want tanks and raising of river bunds. Flood perceptions are shown in Figure 43.

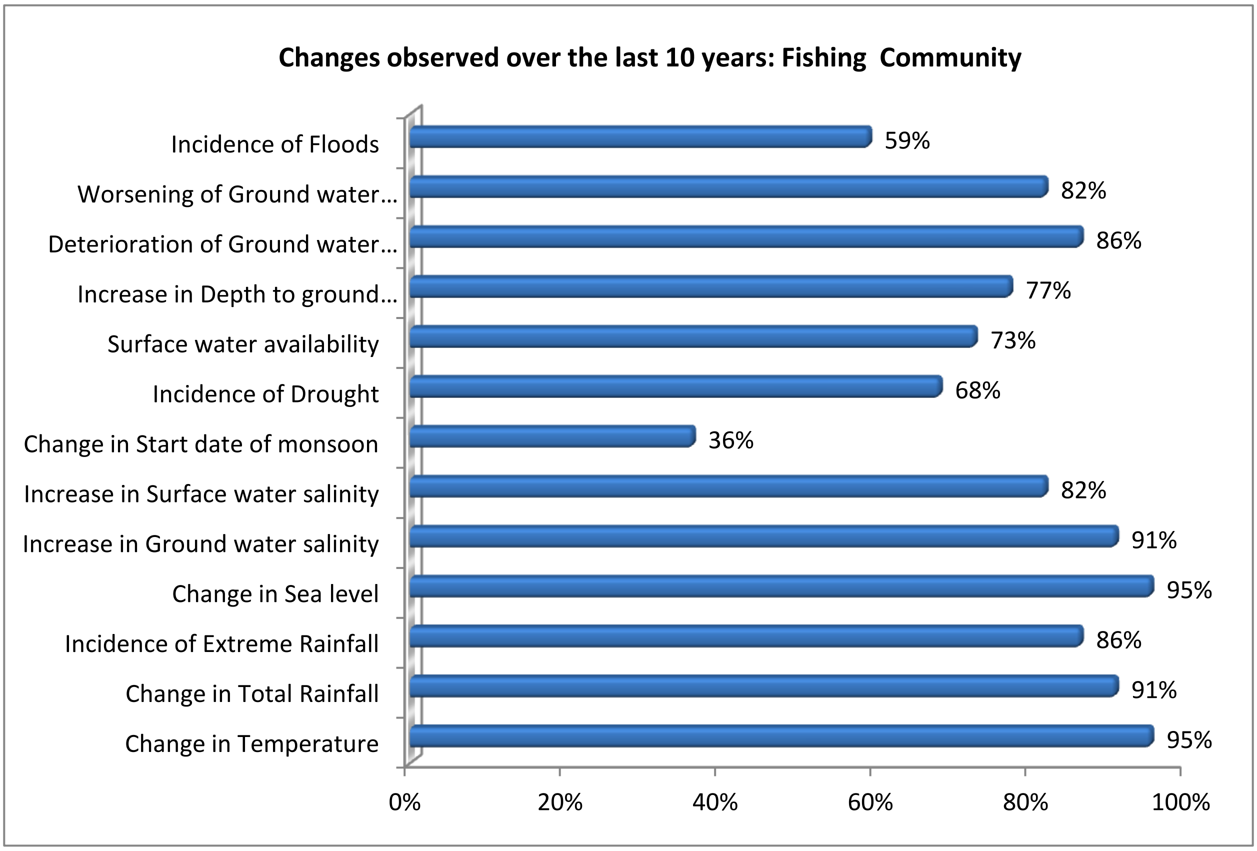
Figure 43 Flood Perception



8. Perceptions about Climate Change

96. A very high perception about climate change exists in fishing community. 95% understand temperature and sea level is changing. 91% say rainfall is changing and salinity also is increasing, 86% think extreme rainfall is affecting productivity and ground water level is changing as well. Surface water salinity increase is reported by 73% households. Perceptions about climate change are shown in Figure 44.

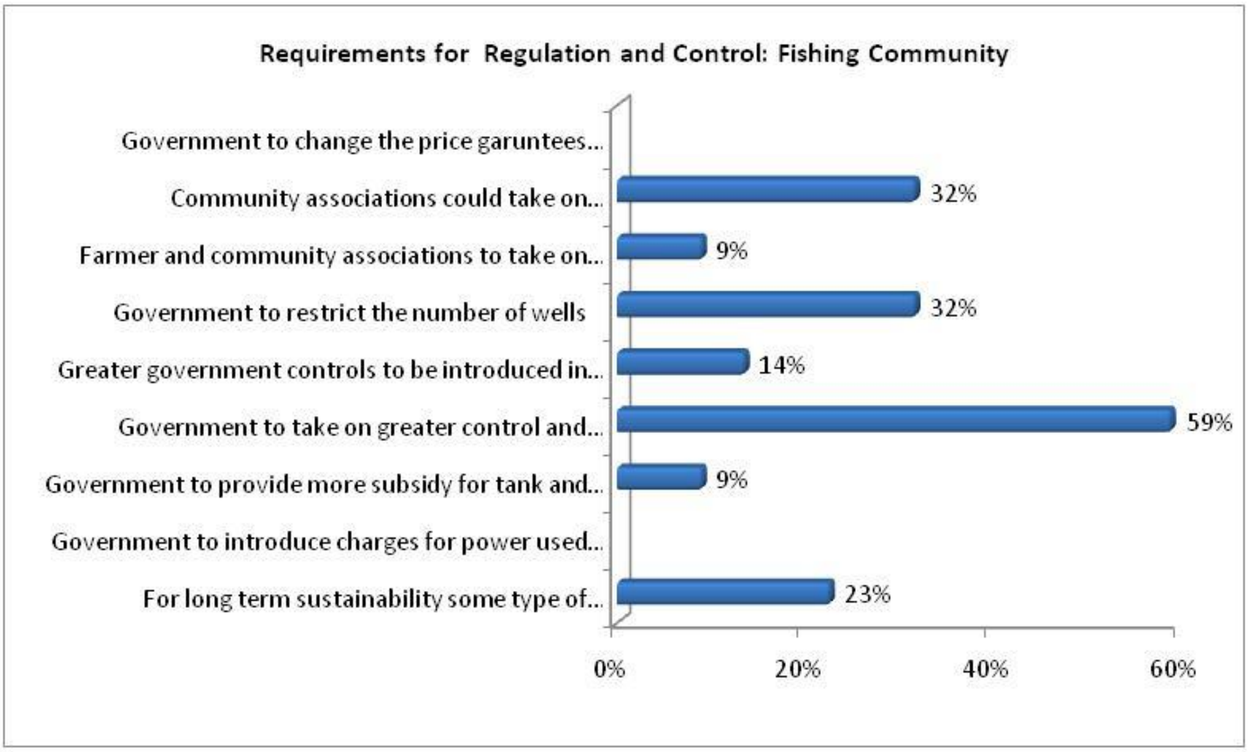
Figure 44 Climate Change Issues Observed by the Fishing Community

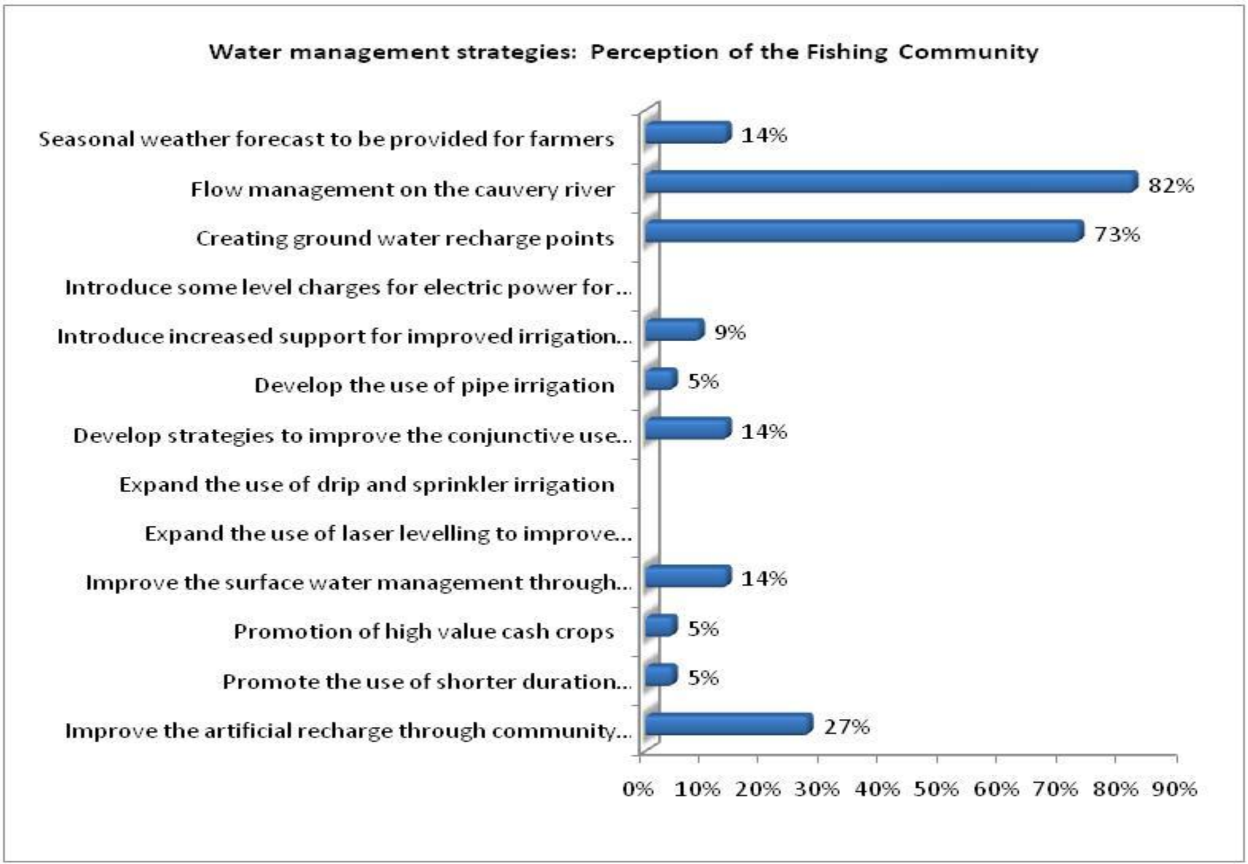


9. Perceptions about control and regulation

97. Government taking control of water is favoured the most (69%) while 32% feel community associations can play major role in operation and management and long term sustainability be the guiding principle. Perceptions amongst the fishing community are shown in Figure 45.

Figure 45 Fishing Community Perceptions for Regulation, Control and Water Management





10. Challenges for the Agricultural community

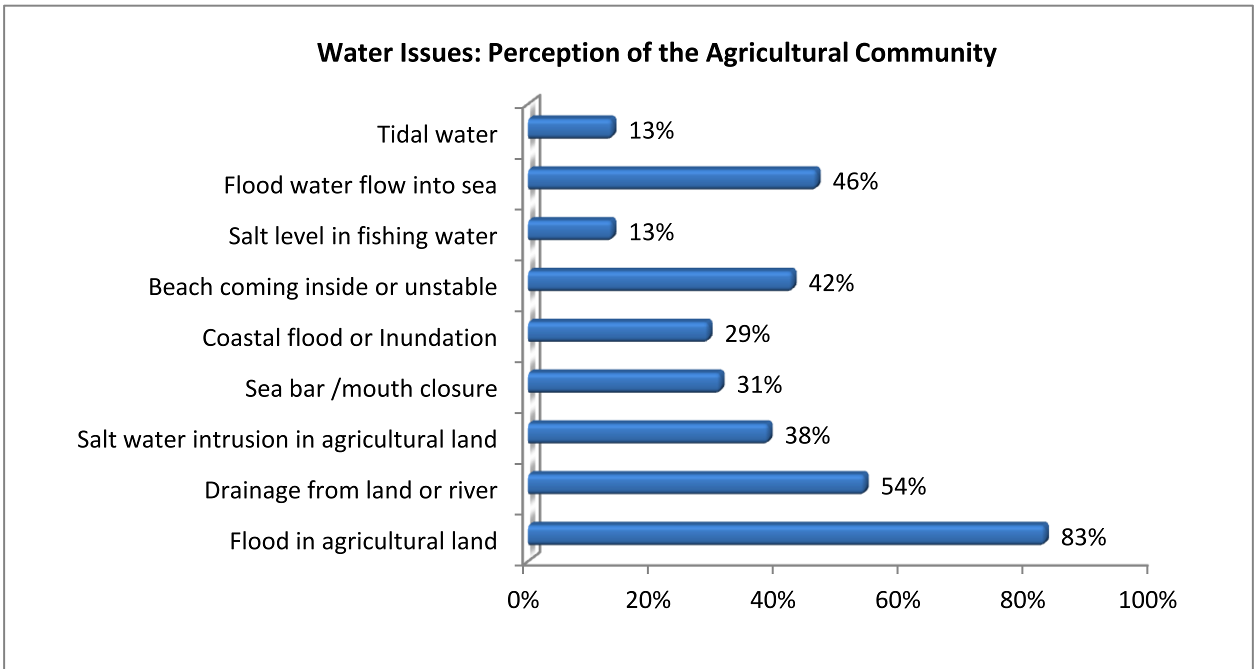
98. Irrigation water access and crop choices and pattern vary depending on location of the village relative to coast line. Key points raised are described below and shown in Figure 46.

- In village Voimedu[11] which is located within a distance of 10-12 km from coast line 50-70% of water demand for irrigation is met by drainage cum irrigation water channel through pumping method. Electric pumps are used (installed in 1962) to lift water 4 meters and then through main canal and tributary canals are distributed to a command area of 1070 acres. Main canal is 5000 meter long and six branches of 300 meter long provide water for Oct-January. Water quality is good as this is the rainy season .
- No ground water is used for irrigation due to salinity in Voimedu village.
- After January sea water enters through the drainage river course so no water is lifted to canals.
- Non agricultural seasons land is used sometimes for grazing and animal rearing to fetch some income from milk production.
- Village- Thondiagadu[12] is within 3-10 km from coast line; most of the population have double occupations; for almost all households: agriculture and fishing is the key source of income. Agricultural holding size is less than one acre. Most of the income from fishing; about 793 families about 4% are not fishing and are dependent fully on agriculture.
- Pump houses withdraw water from drainage river and put in channels and then through tributaries they flow in gravity. Electricity is available only for 3-4 hours free of cost. But there is need for longer hours of electricity. It was felt there was enough water for good one samba crop but cannot be lifted for lack of electricity.
- Being at tail end they feel the value of tail end regulators which used to exist but are now not functioning and need to be repaired as it can help in storage of water and distribution in time of need and will help in managing backflow of sea water as well.
- Pump houses and regulators are old without any repairs being implemented.
- Conjunctive water use is practiced in the villages of Anandhathandavapuram in Nagapatinum district, Mailaduthurai block which is 25 kms away from sea coast. Water is supplied through submersible pumps. But there are some farmers who totally depend on the water flow in the canal for their cultivation and only a few larger farmers use borehole irrigation. Those who are using submersible pumps are those who used canal water in olden days. Now due to lack of supply, they shifted to ground water from surface water. Those who don’t have access on the canals buy water from the neighbours.
- Of total agricultural community surveyed, 15-21% get canal water and about 42% withdraw ground water. Rest are dependent on rain water.
- Though farmers are not dependent on canal for water flow for irrigation, drainage of water during the rainy days is essential. Heavy rain causes flooding in their land due to poor drainage channels. The major problem with the canals is that huge part of the canals are got encroached by the private people and most of the canal disappeared because of the usage of submersible pumps.
- Another important issue is, all the canals which bring the water from river are passing through the city, where wastages are dumped heavily in to the canal water which affects the flow.
- Whenever there a block in canals occurs they are dug up. Now the depth of the canal is becoming deeper than the sea level. So the river water is not entering into the sea in some places. The community feels that instead of deepening the canals, its better expand it by removing the encroachments in the water flow way. So better, protect the shrinking drainage instead of looking for a new one.
- Current water related challenges as shown in Figure 46 reported by agricultural community across villages are different than the fishing community. For the former major issue of concern is flooding of agricultural lands (83% households), followed by drainage water flow problem from land because of lower elevation of land (54%), similarly for flood water flow 42% feel erosion of beach is a major concern, salt water intrusion in agricultural fields is of concern for

[11] PRA (9.2.11) was attended by 17 individuals near pump house open air under a tree
[12] PRA (9.2.11) was attended by 11 individuals near pump house and tail end shutter point under a tree

38% households. Coastal flood , inundation , sea water intrusion is of concern for lower number of agricultural households (29-31%).

Figure 46 Agriculture Key Areas of Concern



11. Crop choice

99. Paddy (samba) is the main crop. Land holding size ranges between 1-8 acres. Only paddy is grown in Voimedu as soil is unsuitable for other crops, horticulture/vegetables are not possible with some failures in past attempts. Pulses and black gram are grown in and dry land only (max 25% can do this). In Pazayapalayam, 6kms away from the sea shore with one crop paddy tried some other crops like cotton, banana trees, and cashew are tried but yield is not up to mark and fulfill the expectations. They also stopped an old traditional paddy called “Otada samba” which is a six month crop and a more energetic food due to water shortage.

100. People are unwilling to move out of agriculture. But responses are not uniform . Aquaculture is not acceptable in some areas where there is no example of inland fishing so there is less knowledge on possible adverse impact on future agriculture potential. For small holding size also it is not economic. Community aquaculture is not a feasible solution as people are individualistic and community activity will not be sustainable due to expected free riding problem. In Pazayapalayam village there are thirty 30 shrimp farms. These shrimp farms are is operated by the farmers not by the fishermen. These farms play a major role in degrading land’s production capacity. Those who shifted to shrimp farming are farmers who don’t receive much income from agriculture.

101. Coastal flooding is problem for 300 acres of land due to lack of drainage in Voimedu village. Silting and the river barmouth closure is major problem during the dry season. Tail end dredging along 8 km is high in demanded to help water flow.

102. Electricity is available for 10 hrs per day free of cost for water lifting so that is not seen as a barrier.

103. Agricultural labour has however become a high cost and difficult to get. Younger ones are migrating as agriculture is becoming increasingly unremunerative. NREGA labour are unwilling to do digging work and the programme is more directed to road construction. So any pond/tanl cannot be done by using human labour.

104. Village- Thondiagadu within 3-10 km from coast line has Samba paddy for August 15-february. Pulse and black gram they can grow but water scarcity and soil quality does not allow.Most of the land (more than 75%) is wetland which can be used for paddy cultivation . 25% farmers grow pulses.

105. Village Anandhathandavapuram is in Nagapatinum district, Mailaduthurai block which is 25 kms away from sea coast is using both submersible pumps and canal water doing two crops.

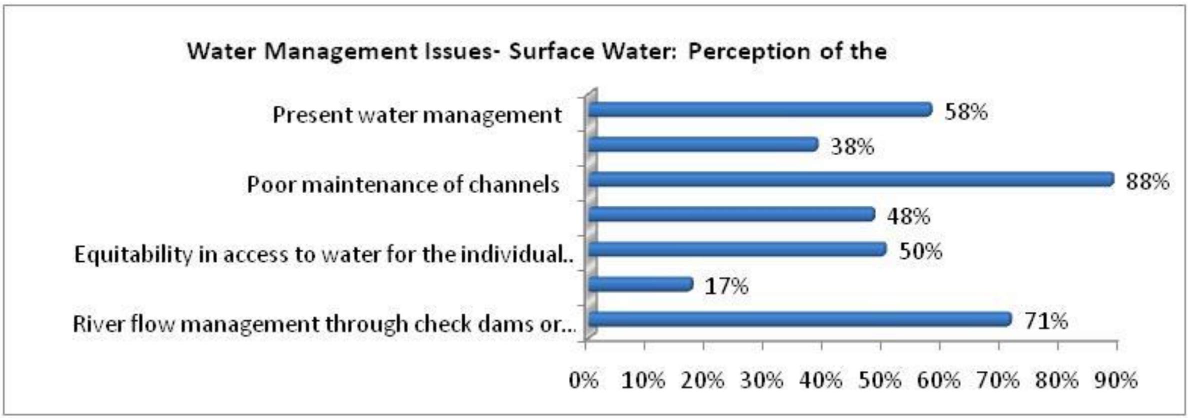
106. Regarding the cropping pattern, it is not only water, but the policy of the government plays a very important role. Govt. of Tamil Nadu wanted to promote sugarcane cultivation. Large number of farmers suffered loss.

12. Participatory Irrigation Management

- Water users association work with PWD for water distribution. There is fairly good equity as they use hourly release for various command areas. Hourly distribution formula applies and there is no dispute so far.
- In water distribution and sharing issue politics does not play a role though water users association are elected bodies with mixed political background of members
- It is felt that in the matter of agriculture water all are treated equally
- Households' awareness level is relatively low nearer the coast away from mainland. Responses are also very low. They understand recharge can happen through tank and prefer subsidy for tank will enhance both surface water and ground water recharge.
- Community wants to participate in water management through high value cash crop, vegetables etc. But understand that drip irrigation will not work given the soil condition and temperature and for paddy cultivation. They are in favour of piped irrigation.
- Water management options as preferred by households are shown in Figure below across districts. District located more inland has higher awareness level and less

107. Household responses water management are shown in Figure 47.

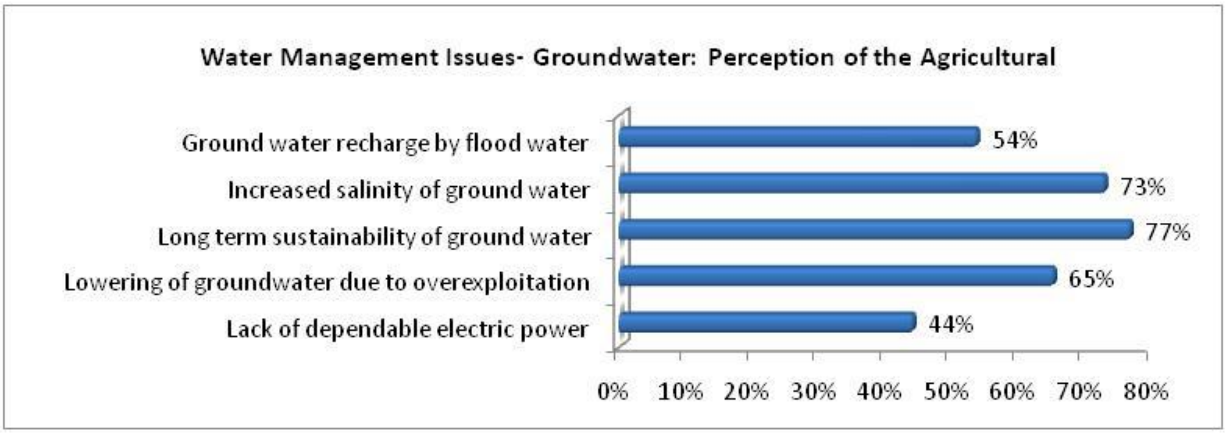
Figure 47 Farmers Perception to Surface Water Management



108. In general surface water management issue concerned among the agricultural households surveyed 58% are happy with current water management system. 88% households complain about poor canal maintenance conditions, 71% about tail end gate repairing need. 48% complain about water quality in land and 38% of saline water intrusion water of rivers and drainage channels. Only 17% favour storage tanks for rain water harvesting.

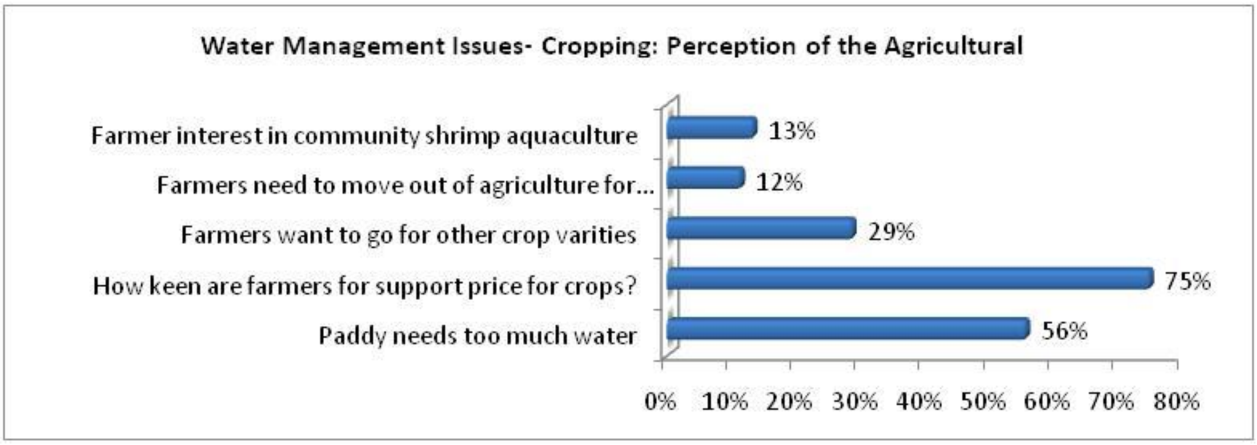
109. For ground water management 77% support long term sustainability strategy, 73% are concerned about salinity in ground water, 65% think due to temperature rise ground water level is decreasing, 54% feel by flood water ground can be recharged, 44% see electricity supply as barrier for ground water access, as shown in Figure 48.

Figure 48 Issues of Groundwater Management



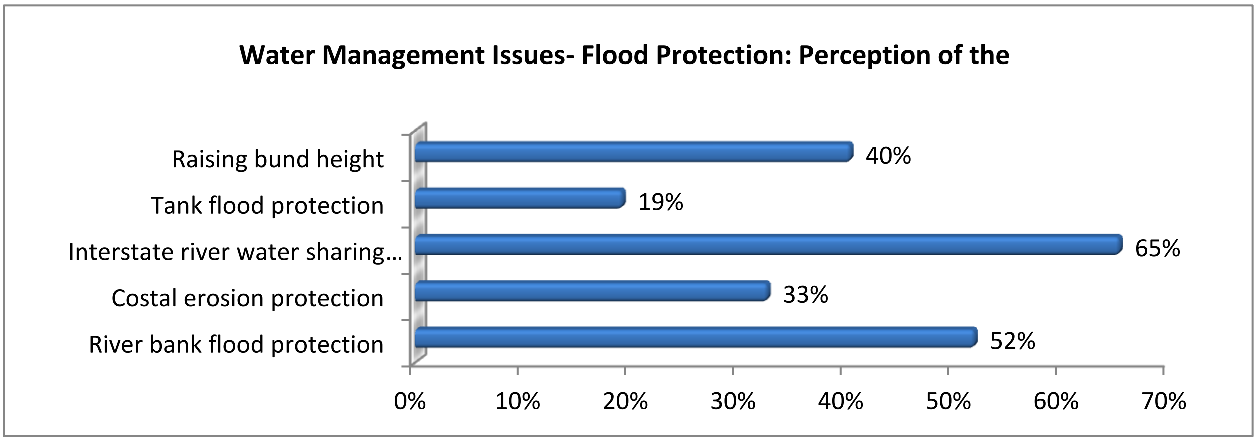
110. About 56% farmers realize paddy requires high water but do not see an alternative. 77% are keen on market support price, 29% farmers are ready to try alternative crop if told, 13% are ready for aquaculture and 12% ready to migrate for alternative livelihood as shown in Figure 49.

Figure 49 Perceptions about Cropping



111. For flood protection agricultural households 65% feel unless interstate water distribution issue is resolved problem cannot be solved more so under climate change scenario as water release needs more control. 52% want river bank protection, 40% want raising of bund heights, 33% want coastal erosion protection while 19% want tanks for flood protection.

Figure 50 Flood Protection Perceptions

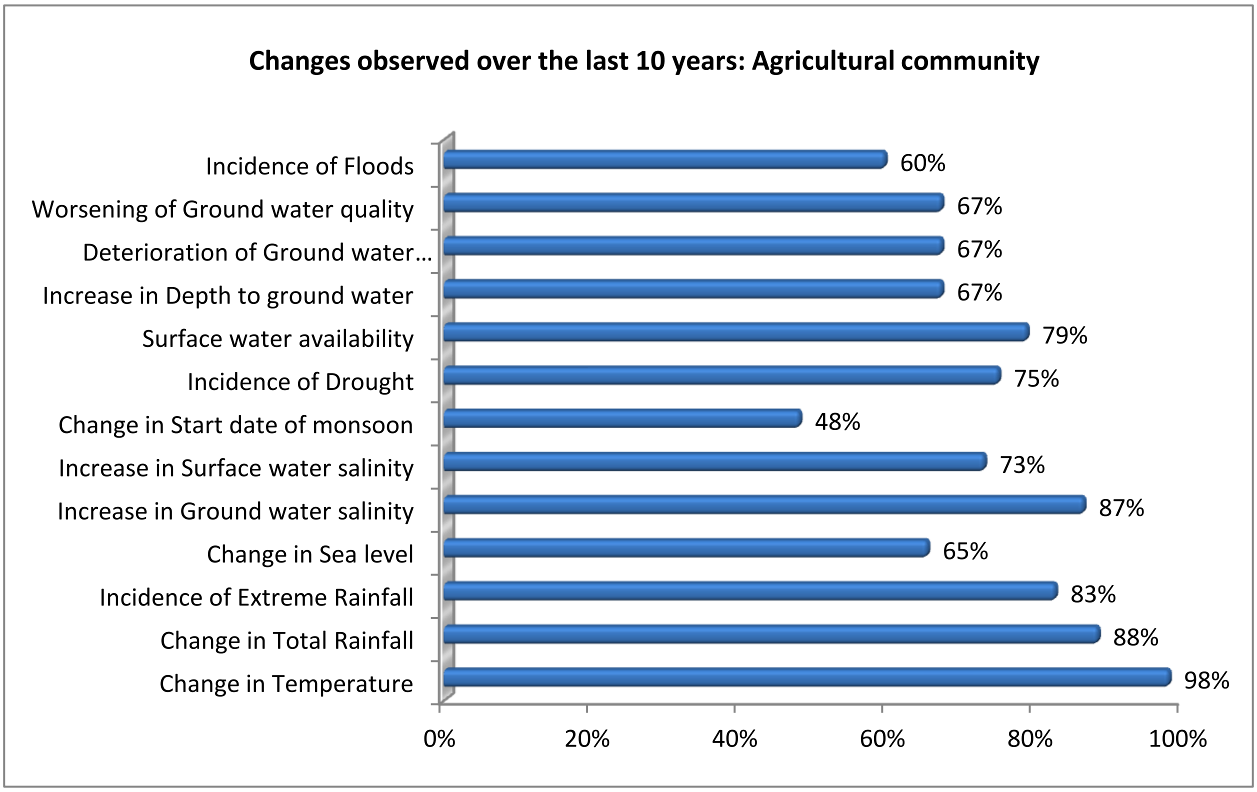


13. Perceptions about climate change

112. Perception about past climate variability varies depending on the distance of district surveyed from coast line. While there is more consensus on temperature change (98%) and rain fall pattern (88%). About 87% feel salinity is increasing with changing temperature and less rainfall. the differences in responses are large on other parameters such as rainfall pattern change, extreme weather events, sea level change, incidence of flood , ground water access etc. The higher vulnerability level is discernible through responses of households. Points are summarised below and in Figure 51

- Village Voimedu is experiencing higher temperatures in May–June with multiple health impacts on humans and livestock due to heat stress.
- Erratic rainfall especially rain in February the harvest time is causing loss up to 50-70%.
- People's perception is that May to June water level goes down to 15ft as compared to 8 ft and salinity goes up.
- Start date of monsoon is getting delayed by sometimes by up one and half months. Earlier monsoons used to start in mid August, now it is getting delayed. Though government is providing short duration seed variety they feel yield is less, and insect infestation is more. They now use 6 times pesticide compared to 2 times for the long duration variety.
- Community feels drinking water stress and crop loss will aggravate with changing climate.

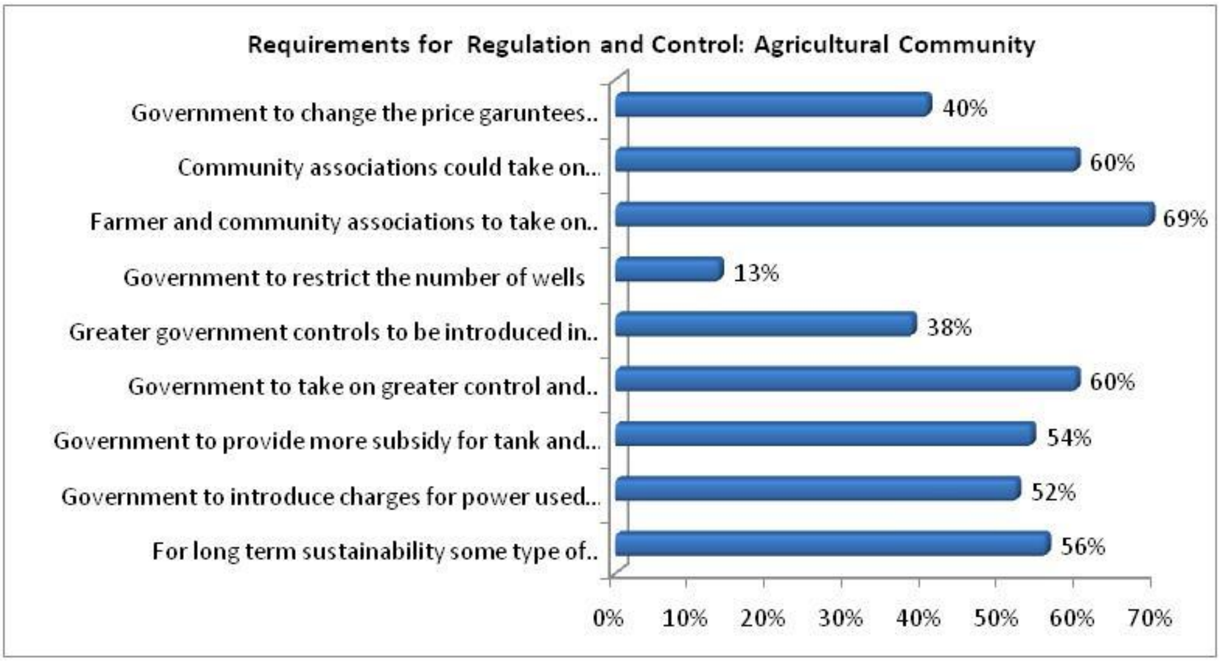
Figure 51 Farmers Changed Perceptions to Climate Change



14. Perceptions about Regulation and Control

113. Perception about community participation and government control in water management varies across communities. While the agricultural community feel the community needs to have major control of water resource management with 69% respondents in favour, 60% feel the government should impose greater control on ground water use, 52-54% feel government need to introduce power charges on ground water withdrawal but with more government subsidy on micro irrigation facilities. 40% feel price guarantee on non paddy crop be introduced. While only 13% feel there needs to be control on boreholes, 38% think it is important for government to work on efficiency measures along with regulation and control. Key points are shown in Figure 52.

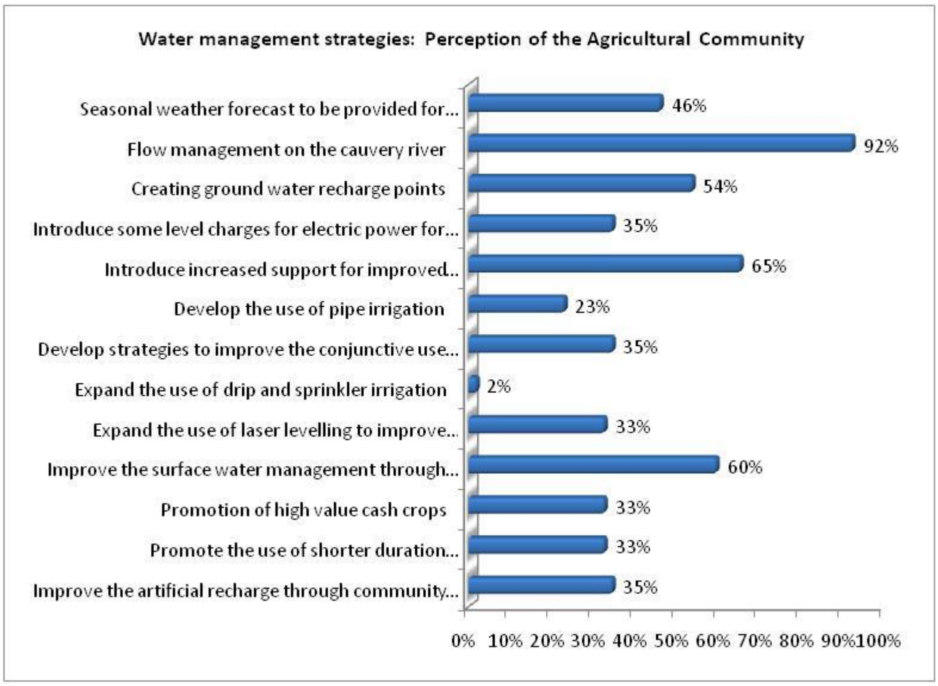
Figure 52 Agriculture Perceptions on Regulation and Control



15. Perceptions about water efficiency.

114. About 92% feel by Cauvery water flow management water use efficiency can be reached, They feel Mettur dam water release must change. Currently it is only used for June-January. They want for all year round. It is an interstate issue and needs to be resolved. 65% see the role of improved irrigation systems by farmers, 60% want surface water management buy tanks, 51% want ground water recharge points, 33-35% want high value cash crop, introduction of charges for power supply etc. 2% feel drip irrigation can have any role. The reason is more soil quality which cannot support these systems. Key points raised are summarised in Figure 53.

Figure 53 Water Management Strategies



- Rainwater harvesting by storage tank creation be tried out. Farm ponds are not possible due to small landholdings. Public land is available which might be used for creating ponds and they feel PWD is doing a good job with water users association so PWD can be given more responsibility for ponds as well.
- Water use efficiency can be enhanced by lining of channels of 4km length in Voimedu . 1 km is already lined.
- The pumps /motors which are from 1962, 3 out of 7 are only functioning now in Voimedu and in Thumacherya village adjacent to Voimedu. With all pumps functioning water lifting and demand management can be better. Urgent necessity is renewal of motors.
- More release of water from Mettur dam will make water availability sufficient for second crop.
- There are instances of 90% subsidy in pond digging in private land but more public tank will benefit small farmers. This they feel will help in lowering salinity of ground water as well. Ponds can be used to store runoff from agricultural field as well. The example they have seen in neighbouring village.
- The farmers are assured of laser levelling from next season by agricultural department .
- Tail end regulator which is currently not functioning but structure exist they feel will solve water management better. The idea was supported by all and neighbouring villagers as well. Both agricultural and fishing community wanted this.
- Access to water and multiple crop is basic demand. Younger generation are taking up agriculture as secondary occupation. With declining labour force they feel mechanisation will help.

16. Training Needs

115. Farmers identified training needs for;

- Fishing net, gear, advanced fishing effort training
- Women want training in packaging and processing
- Desalinisation
- Saline resistant crop variety
- Aquaculture
- Technical training for panchayat to maintain water supply system

116. The strategic action plan needs to address issues pertaining to fishing communities separately from the agricultural farming community. Strategically fishing community can be provided with solutions for drinking water supply with long term aim to meeting good quality residential water supply. Supplementary training support for youths and females can address the issue of resilience through community empowerment through security of income. Youths with better fishing effort and support for barmouth opening, radar for fish search can intensify the catch; and females can in parallel can increase the control of the fish marketing. Free movement of boats along coast line, cold storage in mobile vans or in neighbouring village can enhance resilience. For agricultural community need is for providing better quality irrigation water. This can happen by conjunctive use only beyond 20 km from coast line. Surface water availability and efficient use of should targeted at for the coastal area nearer the sea. Salinity resistant crop varieties should be promoted. Desalination may be a long term strategy although operation costs are very high. A portfolio of actions need to address irrigation infrastructure, market incentive structure and behavioural response towards livelihood diversification simultaneously.

117. A **Road map** for implementation of the strategic plan needs an integrated approach including:

- a water use and supply information base to be created be it drinking water or irrigation water. This can bring the roles of the stakeholders together observationally. Current level of information scattered across different departments cannot lead to integrated approach in strategic action plan on cross cutting issue like water.
- how informal ground water market can be transformed into formal participatory formal water market system needs to be explored further through research and subsequent consultation with the stakeholders.

- what combination of actions in strategic risk minimizing policy portfolio be included for various districts need to be checked through simple cost benefit analysis and verified further through stakeholder consultation.
- subsidy versus PES as strategic policy instrument needs further community consultation.
- How IWRM institution can work towards formalizing informal ground market needs further check.

VII. INSTITUTIONS

118. Tamil Nadu Water Policy like many other states is largely derived from the National water Policy 2002. The State Policy was approved in 1994. The Institute for Water Studies in Tamil Nadu was entrusted with the mandate to implement the above policy. The ultimate goal of the State's Water Policy is to develop a 'State Water Plan', which will be the blue print for state water resources development.

119. The key provisions in the policy are to; (i) establish a Management Information System (MIS) for water resources (ii) ensure preservation and stabilization of existing water resources; including plans for augmentation of utilizable water resources (iii) promote research and training facilities for water resources management (iv) establish allocation priorities for water use by different Sectors with provision of drinking water being of highest priority (v) maximize multi purpose benefit from surface and groundwater, land and other resources; provide adequate water for different users (vi) preserve and enhance the economics of fisheries; (vii) maintain water quality to established standards (viii) promote equality and social justice among users of water for irrigation and domestic water supplies(ix) promote users participation in all aspects of water planning and management and provide mechanisms for the resolution of conflicts between users within and between interstate river basins.

120. Good water governance includes regulatory measures. Regulations are necessary to maximize the economic and social benefits resulting from water use in an equitable manner. Good water resource regulation requires an enabling environment which ensures the rights and assets of all stakeholders and protects public assets such as intrinsic environmental values.

121. Acts In 1987, the Tamil Nadu government enacted Chennai Metropolitan Area Ground Water (Regulation) Act and after a gap of 16 long years, TN ground water (Development and Management) act 2003 was enacted and is implemented by TN Ground water authority. This act is prohibitive in nature and largely depends on permit systems. Most striking feature of this act is that it does not allow the supply of electrical energy from the Tamil Nadu State Electricity Board (TNSEB) for energizing wells sunk in contravention of the provision of the act. The other features are: exemption of wells used for; (i) domestic purposes; (ii) wells sunk by state and central agencies for scientific purposes and (iii) wells sunk by small and marginal farmers. The Act is implemented by the TN ground water authority which has the powers to control and regulate ground water extraction; monitor ground water regime in the mining areas and direct the disposal of mine water suitably; lay down or adopt standards for water quality depending on the kind of water use; alter, amend, cancel of registration. Permit or license. Provision of ground water management by identifying and notifying suitable areas for conjunctive use of surface and ground water

122. PIM act: The scientific and systematic development and maintenance of irrigation infrastructure is considered to be best implemented through farmers' organizations. Such farmer's organizations have to be given an effective role in the management and maintenance of the irrigation system for effective and reliable supply and distribution of water. The "Tamilnadu Farmers Management of Irrigation Systems Act - 2000" of the Tamilnadu Legislative Assembly (Act No. 7 of 2001), was enacted to provide for farmers participation in the management of irrigation systems and for matters connected there with or incidental thereto. The TNFMIS ACT extends to the whole of Tamilnadu State. Participatory Irrigation Management Act provides an enabling environment to the formation and functioning of WUA s in Tamilnadu. Like in most of the states, in TN WUA s has been formed but they have not been able to take their full responsibility as envisaged in Act/Policy. The main constraints are system deficiency, a lack of financial viability, lack of technical knowledge, and complex maintenance requirements, low Irrigation rates, uncertainty of water availability, lack of coordination between WUCS and other water related institutions etc

123. **Institutions**; water development and management of water resources in Tamil Nadu has been a critical challenge evolving various responses including the institutional one over time. To overcome this challenge and for development and management of water resources in Tamil Nadu followed a hub and spoke model approach towards this endeavour. The Multi Department Project Unit (MDPU) constituted the hub and other departments like WRD, Agricultural Engineering Department, Agriculture department, Horticulture and Plantation crop department, Tamil Nadu Agriculture university, Agriculture marketing department, Fisheries department and Animal Husbandry department constituted its spokes and in brief, institutional response to various problems associated with the

development and management of water resources was through a single window approach. In Tamil Nadu, the creation of a Water Resources Organization (WRO) from the PWD; initiation of the separation of cadres between water resources management and buildings; strengthening of the Institute for water studies and the State Surface and Groundwater Data Centre and preparation of detailed spatial knowledge base for water management; setting up of a Reforms Task Force and the initial efforts to implement its recommendations such as rightsizing through Voluntary Retirement Schemes; creation of a multi-sectoral Water Resources Control and Review Council (WRCRC) chaired by the Chief Minister with seven thematic sub-committees which is a precursor for unbundling resource management from service delivery; creation of operational environmental cells in WRO ; decentralization of operational Chief Engineers in a basin/cluster of basins framework, and formation of water users associations have become part of enabling environment to initiate reform process in water sector including the formation of a regulatory authority. Irrigation Management Training Institute is playing a pivotal role in training the WRO Officials, Farmers representatives elected for the management of the irrigation systems, members of WUAs and revenue officials on the process of implementing the Act including conduct of elections for the management committees and functioning of farmers' organizations at different levels.

124. What could be observed based on the review of literature is that institutional weaknesses were significant. There is lack of coordination between concerned department officials (resulting in delays in implementation and implementation without proper technical assessment) as also inadequate technical and managerial capacity of irrigation department staff. The absence or ineffectiveness of Water Users Associations (WUAs), is also seen to be one of the significant contributors to the widening gap between Irrigation Potential created and utilization. The need to increase involvement of WUAs and PRIs in all stages of planning, design, construction and maintenance is widely accepted. This must include systematic training of their members in organizational development, leadership, maintenance of financial and operational records, basic technical components of the canal system and methods of monitoring technical work.

125. An overview of the main institutional mechanism for state-level planning and management of water resources indicates that: there is a lack of conjunctive planning and regulation of surface and ground water, poor understanding of the conjunctive water balance systems. Water quality data is monitored but not linked planning and management and artificial recharge is important but not incorporated into the overall water resource planning. Further, all the agencies see their responsibility as developing water resources for the public good.

126. In conclusion, one could say that any sound policy, acts and mandates of water centric institutions aiming at water resource development and management should recognize in its totality: (i) Information Systems and Resource Planning to provide much needed information about groundwater availability, quality and withdrawal, etc., for use by planners and for the purposes of monitoring and further research (ii) Demand-Side Management for regulating groundwater withdrawals at sustainable levels and such mechanisms to include, for example, licences, laws, pricing systems, use of complementary water sources and water-saving crop-production technologies (In conformity with IWRM principles) (iii) Supply-Side Management to augment Groundwater recharge by means of mass rainwater harvesting and recharge activities and to maximize surface water use for recharge and the introduction of incentives for water conservation and artificial recharge (iv) groundwater management in a River Basin Context to maximize efficiency and the focus of interventions could be expanded (from a very 'local' level to the level of entire river basins.

127. **Water Information Systems**; the hydrology section of the Water Resources Department is responsible for both surface and groundwater data. They participated in HP-1 and now participate in HP-2 also, and thus have computerised databases. They now have 30 years of groundwater data including water levels and water quality. The Public Works Department now has a GIS system, but this does not include the Cauvery delta. Anna University has created a GIS utilising data supplied by the PWD. Anna University is involved in developing the State action plan on climate change. They have been carrying out hazard analysis, are mapping salinity intrusion, and are also mapping shoreline change since 1979.

Appendix 4B Cauvery Delta Sub Basin

Strategic Framework Plan

APPENDIX 4B STRATEGIC FRAMEWORK PLAN

VIII. STRATEGIES TO ADRESS CURRENT ISSUES

A. Introduction

128. The issues of water resources in the Cauvery are complex and include lack of freshwater, flood and drainage problems, salinity intrusion of surface and groundwater and over abstraction of groundwater.

129. There is very limited surface water during the south westerly monsoon; the north easterly monsoon can bring erratic but intense rains which can give rise to flood and drainage problems. There are issues of saline intrusion and low lying land is in parts unable to drain. Groundwater is extensively used to supplement the lack of surface water but now there are issues of overexploitation and salinity. There is no statistical evidence of climate change but farmers report increased levels of salinity, reduced freshwater flows and some changes of the timing of the seasons. Climate change will likely have significant impacts on the delta region including sea level rise. There are localised issues of naturally occurring water quality hazards as well as other contaminants.

B. Strategy for Adaptation Planning

130. The application of climate projections into the development of adaptation planning requires to be cautious and pragmatic. Framework planning for the sub-basins based on three stages:

- **Stage 1: Adaptation Strategies for Current Issues**: The Cauvery Delta has very significant levels of current issues that are affecting long term sustainability. The approach will be to develop an adaptation plan initially focusing on current issues to meet the present climate parameters. Current issues would include the development needs of increasing population and growth of the agricultural production systems

- **Stage 2:Resilience of Adaptation Strategies** against Climate Change Impacts: The resilience of the strategies for present issues will be tested against projected climate change impacts. The incorporation of the projected climate changes into the planning will depend on (i) the level of confidence of the projections; some projections are more robust than others; for example projections for sea level rise are more robust than rainfall patterns; (ii) the type and estimated design life of any investment -major investments/programmes with long design life require to incorporate climate projections beyond 30 years whereas shorter simpler initiatives can be designed to meet present climate variations. Major long term investments based on low levels of projection confidence would be avoided; (jjj) scope for flexibility of the adaptation design; incorporating facilities wherever possible to upgrade adaptation design step by step to meet progressive climate changes and improved accuracy of the projections; (iv) assessment of the incremental costs, where incremental costs are low then it these might be factored into the adaptation design whereas major cost implication maybe left out in the interim. The aspects of safety and implications of delayed action would be assessed.

- **Stage 3: Preparation of a Climate Change Adaptation Framework**: Adjustments will be made to adaptation for current issues based on the assessments under stage 2.

C. Farmers Perceptions

131. The participatory rural appraisal for the delta was completed in February and the final analysis are not yet completed. Farmers during discussions have observed some changes in the climate including the longer winter period as well as observed increased salinity, reduced freshwater and some temperature effects; some salinity effects are reported to be as a result of the Tsunami. Discussions with farmers and fishermen indicate concern over drainage and flooding. The closure of the river mouths is an issue as well as the threat of sea erosion on some of the coastal villages.

D. Cauvery Delta Modernisation Report

132. Government of Tamil Nadu constituted a task force to comprehensively study the Cauvery Delta irrigation canal system and prepared a Cauvery Delta Modernization Project Report (CDMR). The report of the task force was submitted in November 2008, with detailed proposals on modernization of canal system, flood control and drainage system, lift irrigation schemes to serve uplands, on farm development works, ground water recharge, participatory irrigation management, institutional strengthening, operation and maintenance of system and research activities. The cost of the project containing all these proposals is worked out to be Rs 5100 crore ($1.1 billion) with a project implementation period of about 15 years. To date it has not been possible to implement the modernisation project in full although some parts have been taken up through state funding.

133. The Cauvery Delta Modernisation Report (CDMR) provides an excellent basis towards meeting the long term sustainability of the Delta. The modernisation plan is very relevant to the adaptation strategy, the adaptation has reviewed the modernisation plan and the study has tried to use and build on the plan.

E. Surface Water Resources Issues

134. As a result of upstream water resources development in the Cauvery Basin, the pattern of water availability for use in the Cauvery Delta has changed. As a result of reduced inflows, there has been increased groundwater use that has probably contributed to the saline intrusion in the coastal strip. There is also impeded drainage in some areas caused by littoral drift and beach processes blocking drainage outfalls. This is a situation that will have been aggravated by reduced surface water flows through the delta.

135. River flows in the lower reaches of the Cauvery no longer rise in response to the southwest monsoon as they did in the past. Past practice had been to plant a first rice crop in June, with irrigation from the Cauvery. There is now uncertainty about the availability of irrigation water in June, and delays in planting can mean that the crop cannot be harvested before the onset of the northeast monsoon, resulting in crop damages and losses.

136. Saline intrusion now affects a coastal strip of about 20 km. This may have been exacerbated by inundation with salt water during the 2004 tsunami. Groundwater abstraction in critical areas has been stopped, but the reality is that saline intrusion may continue if groundwater abstraction is not halted or managed in other areas as well. As a result of the saline conditions, crop yields in many areas are low. In some low lying parts it is not possible to plant due to salinity and drainage problems

F. Groundwater

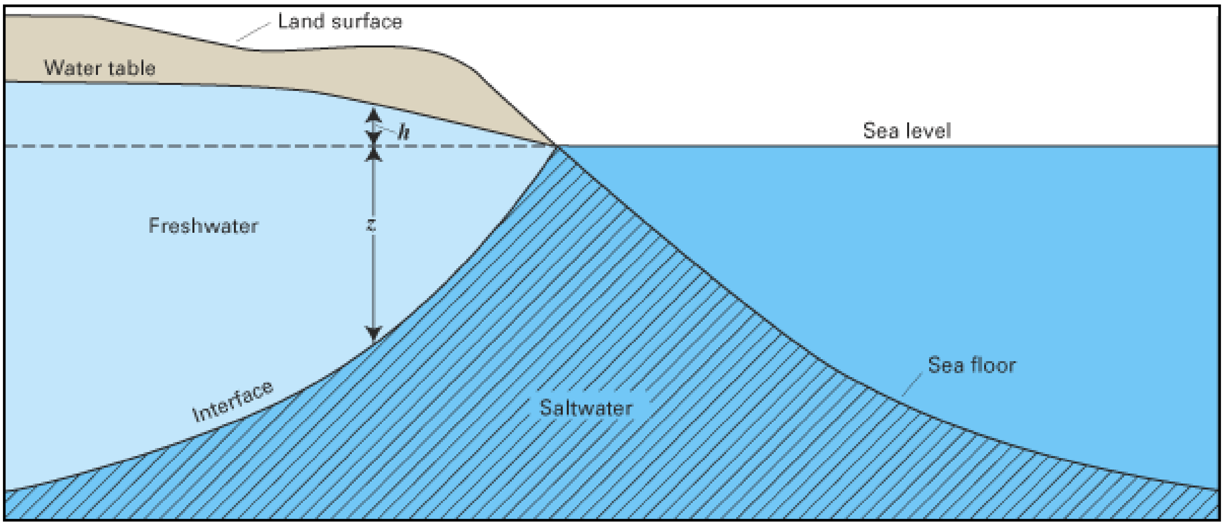
137. Emerging issues include saline water intrusion in coastal aquifers due to over-exploitation of ground water, flooding and inundation due to backwaters and floods, increasing salinisation of land, as well as soil related constraints due to sodicity and salinity.

138. Groundwater dynamics in the Cauvery Delta are closely linked to surface water dynamics both from upstream freshwater discharges and surface ingress of seawater. Lateral seawater intrusion in coastal areas may be enhanced by surface water bodies connected to the sea, such as estuaries and rivers (which greatly increase the coastline length) if conditions allow seawater to travel inland through these bodies. This is often the case in the Cauvery Delta, with protection measures like tail-end gates either absent or not functioning properly. When the shallow fresh groundwater resources are abstracted and land use changes decrease groundwater replenishment the shallow fresh groundwater head decreases. This can cause up-coning of deeper often more saline groundwater and an inland movement of the fresh/saline groundwater interface. Decreased estuarine river discharge as a result of upstream water allocations may also increase seawater intrusion; the reduced discharges from Mattur dam would likely have had some impact on this. This anthropogenic induced intrusion can be a relatively fast process depending on the hydraulic pressures changes and the transmissivity of the coastal aquifers.

139. The over-abstraction of groundwater inland results in a lowering of groundwater table relative to mean sea level and results in a reduction in the hydraulic gradient. This diminishes the ability of

groundwater (freshwater) to push the saline water seawards. Therefore any changes in the volume of freshwater discharge will result in a subsequent change in the saline-freshwater boundary. In addition groundwater abstraction close to the coastline may actively induce up-coning of saline waters. Previous research on saline water-fresh water interface have identified that at a given point inland in a coastal aquifer the depth to which freshwater extends below sea level is approximately 40 times the height of the water table (the Ghyben-Herzberg principle) – this is due to differences in densities of fresh and salt water[13] as shown in Figure 54 below

Figure 54 Relationship of Height of Freshwater and the Fresh Salt Interface



140. The height of the water table above sea level and the groundwater hydraulic gradient are therefore key factors in determining the freshwater-saline boundary in a coastal aquifer. In the context of climate change sea level rise could also result in a change in the hydraulic gradient (unless there is concomitant increase in groundwater discharge) and therefore a shift of the saline-freshwater boundary inland. It is clear from the Sub Basin Profile report that this migration inland is well underway.

141. Recent 2009 reports on sea water intrusion in Nagapattinam[14], Thiruvarur[15] and Thanjavur[16] districts provide summary information on water levels and water quality for these districts. In Nagapattinam district, which runs alongside the coastline and has maximum elevation of 8m above msl, ten of the forty-nine monitoring wells reported groundwater levels below sea level (maximum -2.82m below msl) during July 2009. In Thanjavur district, located in western part of Delta and a maximum elevation of 20m above msl, six of the twelve monitoring wells reported groundwater levels below sea level (maximum -19.20m below msl) during July 2009. These levels represent significant drops in groundwater head and would facilitate ready ingress of seawater. In Nagapattinam and Thiruvarur districts there are six and two blocks, respectively, classified as saline blocks.

142. In all three reports artificial recharge is identified as the solution to saltwater ingression. The reports also indicate that coastal aquaculture activities should not be encouraged as this is seen as a source of saline contamination for adjacent farmland. There is a need for research work on brackishwater aquaculture farming which may be causing contamination to ground water in the area around them. The outcome of research would provide input to policy framework. All reports indicate the need for further monitoring and recommend additional monitoring bore wells.

[13] www.igrac.net
[14] PWD (2009) Annual report on sea water intrusion study in Nagapattinam district for the year 2009. PWD Ground Water Division, Trichy.
[15] PWD (2009) Annual report on sea water intrusion study in Thiruvarur district for the year 2009. PWD Ground Water Division, Trichy.
[16] PWD (2009) Annual report on sea water intrusion study in Thanjavur district for the year 2009. PWD Ground Water Division, Trichy.

143. The state of groundwater resources development Nagapattinam, Thiruvarur and Thanjavur districts is 128%, 83% and 72% respectively. Over-exploitation of Groundwater Reserves. Concerning the issue of over-exploitation the main area of over exploitation is in Nagapattinam District where stage of groundwater development is reported at 128%. In supply terms this includes developing ways to enhance recharge to aquifers so that depleted aquifer storage can be replenished (through artificial recharge), or on the demand side through irrigation methods that result in groundwater resource savings or changes in cropping patterns.

144. Irrigation in Nagapattinam, Thiruvarur and Thanjavur districts is dominated by canal water with groundwater making up a relatively small amount. However, groundwater reserves has been heavily exploited in Nagapattinam district and all districts have groundwater levels close to mean sea level and sometimes below sea level. The major rivers in the Cauvery basin have been full exploited by means of reservoirs, with dams and anicuts built across them for irrigation purposes, thus reducing the freshwater discharge to the delta region. These factors combined with inadequate surface water protection of sea water ingress limit the ability of groundwater to prevent seawater intrusion.

145. For the continued and sustainable use of this precious resource a combination of supply and demand measures will be required within an overall context of better conjunctive use of surface and groundwater.

146. Artificial recharge (AR) systems are engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers to augment groundwater resources. AR requires good supplies of freshwater permeable surface soils to infiltrate to the aquifers. There are various proposals for groundwater recharge There are some concerns of the viabilities of most of these plans in the Cauvery Delta. Different methodologies for quantifying groundwater recharge should be assessed and if proven viable could be trialed in pilot areas to confirm and improve the current methodology for groundwater resource assessment (Water Level Fluctuation method).

147. In Tamil Nadu, the CGWB Master Plan has no plans for artificial recharge in the Delta area districts of Nagapattinam, Thiruvarur and Thanjavur. Upstream of these districts a number of artificial recharge programmes are envisaged through the use of percolation ponds and check dams. The cost and benefits accrued through this artificial recharge approach will need to be weighed against groundwater resource savings that could be achieved through other means such as demand related savings. Artificial recharge linked to supporting other economic benefits such as tanks are of significantly greater value than stand alone recharge structures, Silting up of artificial recharge structures is a major issue.

148. Therefore artificial recharge will be part of the overall solution in certain circumstances but should not be seen as the panacea for over-exploitation or a justification for not tackling the demand related issues

149. There are a number of options for dealing with saltwater intrusion appropriate to the Cauvery Delta. The approaches would require to be better studied including monitoring and modelling. Of the many potential approaches, the following would appear to be the most viable for the Delta.

(i) Development of tail end regulators to capture and store freshwater and prevent seawater ingress. Water stored in the tail end regulators could be used by gravity or pump as alternatives to groundwater irrigation.

(ii) Controlling the volume of groundwater abstraction by controlling the volume pumped or the number of wells or increasing the efficiency of the irrigation especially the evaporation losses. Develop agricultural systems with lower demand cropping systems

(iii) Salt tolerant crops: adjusting groundwater use to poorer groundwater quality levels. In many agricultural areas where only marginal quality water is available and where soil conditions are negatively affected by salinity, farmers are still able to grow crops profitably by changing to more salt-tolerant crops. Often the crop adaptation is accompanied by nutrients augmentation (fertilizers) and soil quality improvement (e.g. adding gypsum sulphuric acid, and iron pyrite to reduce the negative effects of soil sodicity).

(iv) Conjunctive use of water: in cases of marginal quality groundwater, it makes sense to use the saline water in conjunction with better types of water. The poor quality groundwater could physically be blended with more fresh water to provide water with an acceptable salinity level for application. Alternatively, the poor quality groundwater could be applied in an alternating fashion with better quality water.

(v) Promoting the use of ponds and tanks including farm ponds as an alternative to groundwater. All the ponds in the villages (including the ponds in the temples) are to be desilted with necessary inlet and outlet arrangements

(vi) Many agencies are pumping enormous ground water at various places for drinking water supply schemes in the Cauvery Delta area. This will affect the quality of ground water. Some controls are required to limit these abstractions.

(vii) Development of policies and plans that deal with groundwater salinity in an integrated way. Such a policy should contain an integrated and strategic vision on groundwater salinity management for a certain area and for a certain period. The participation of public is of paramount importance to find ground truth solutions and get the necessary support needed for implementation and compliance. A good example of such an approach is the Coastal Salinity Prevention Cell, a combination of NGOs, the government of Gujarat to combat salinity ingress.

G. Irrigation

1. Surface Water Irrigation

150. There is little possibility of an increased storage allocation on the Cauvery upstream of the delta to provide additional irrigation water for the first rice crop; there are no further suitable large storage sites in that part of the basin in Tamil Nadu. The main opportunities lie in increasing efficiencies, possibly by lining. In the delta there are some issues of lining as many canals operate as drains and defining the impacts of lining on the groundwater recharge. The Delta Modernisation Report proposes lining of main canals and possibly branch canals. Canal regulators are in poor condition and should be repaired.

151. Irrigation efficiencies in the delta region require to be improved, further study is proposed to best assess how this should be achieved. The complexity of the systems and to what level of irrigation rehabilitation is most appropriate. There are options for a complete reconstruction and separation of irrigation and drainage but this is not considered appropriate by the study consultants which is also the findings of the CDMR. There would appear to good argument for an intermediate approach of some remodelling including some straightening and creation of separate canals and drains in critical areas. The cost benefits of lining based on an assessment of the conjunctive benefits (surface and groundwater) should be carried out. The planning of the irrigation systems must be holistic and include irrigation, drainage and how the main system fits with the minor irrigation systems from tanks, groundwater and lift irrigation.

152. In a conjunctive surface and groundwater use situation the only real water savings can be achieved where modifications to irrigations and cropping-practices reduce the non-beneficial evaporation or non-beneficial discharges to saline water bodies. The latter being a particular case in point for parts of the districts of the Cauvery Delta. If more water savings are needed, than consideration should be given to explore options for switching to cultivation of less water-consuming crops or crop-strains (with shorter growing season, or suited to cooler periods when potential evaporation and transpiration are lower). In some areas it may be appropriate to ban cultivation of certain types of irrigated crops in critical areas especially in the critical or overexploited groundwater blocks. Delaying the planting of the Kharif crop can reduce the losses from evapotranspiration.

2. Groundwater Irrigation

153. There is a need to better manage groundwater irrigation especially in the overexploited and critical blocks as well as in the saline areas. Of most potential would appear to be the development of alternative sources to groundwater; options would include (i) small farm and medium ponds and tanks(ii) rehabilitation and expansion of small and medium lift irrigation schemes; and (iii) improved

water conservation and ponding through the tail end regulators. Irrigation efficiencies can reduce the groundwater demand but the emphasis has to be reduction of the evaporative losses. Use of SRI direct seeded rice and other agricultural technologies to improve productivity and reduce the water demand are now becoming more popular.

3. Ponds and Tanks

154. The Grand Anicut Canal system supplements 694 tanks in addition there are a large number of tanks fed by local catchments, it is estimated to be about one third of all tanks are fed by canals and two thirds by catchments; the overall irrigated area from tanks is 33,000ha. In addition there are numerous ponds and more informal tank systems all with potentials to support irrigation and groundwater recharge.

155. The rehabilitation and expansion of ponds and tanks would appear to offer good opportunities to improve the water supplies for irrigation. There is a need to rehabilitate the existing tanks many of which are silted with poor canal systems. Tank and pond development should be implemented as an integrated approach for flood relief described below. Irrigation from tanks and ponds could be by gravity or small low head pump systems, or indirectly by groundwater in the periphery. Ponds can provide supplementary water during low rain periods in the monsoon which can be erratic in the Delta region.

4. Lift Irrigation

156. Lift irrigation was developed to supply water to the high level lands in this area could not be commanded by the gravity systems. The lift schemes were originally operated by the communities but were taken over in 1955 due to persistent representation from the public, the scheme was taken over

157. There are now 29 pumping schemes in constructed in the Cauvery Delta listed All these schemes came into operation between 1951 to 1991. The principle objective of the pumping schemes is to supply water for irrigating the high level command area by pumping the tail end river drainage water, which is going waste into the sea. They provide irrigation facilities to an extent of 21757 acres within the Delta. As a general rule, the pumping schemes commence operation at the onset of the South West Monsoon and continue until February.

158. The present status is that most schemes are meeting only a third of their original command area and many are not operational. The motors and pumps are old and affected by corrosion. There are problems of settlement of the canals lining is in poor condition. Of the 29 pump schemes the benefit area is now 5000ha out of the original 8800ha.

159. The pump schemes require to be made operational; efficiencies are low and maintaining the medium size Government pump schemes in operational status presents a management issue. Farmers are concerned about the risks associated of crop failure due to scheme breakdown. The use of smaller community or individual farmer pumping offers more flexibility and devolvement of operational responsibility. The development of the tail end regulators to raise the water levels which could fill drains offers opportunities for farmers using small portable pumps to irrigate directly to their fields, where gravity supply is not possible Similarly small portable pumps could be used to irrigate from ponds and tanks that are not viably irrigated by gravity.

H. Flood Control and Drainage

160. The flood problems and drainage congestion are caused by North–East monsoon which normally starts in the third week of October with an average rainfall of about 700 mm, the maximum of which occurs in the month of November. The storm direction of North – East monsoon is from the coast towards inland. The heavy rainfall accompanied by depressions and cyclones causes the flooding and drainage congestion in the delta; the lower delta already fully congested with flood when the heavy flow from the upland areas forces additional water into the already flooded areas. Due to wide spread inundation and slow drainages damage to the crops and properties frequently occur. The latest occurrence was in November 2010 with a loss of crop in 25000 ha of land. The lower delta area is very flat topography and many parts of delta mostly in Nagapattinam district are below mean sea level. The tidal variation is in the order of 1.2metres and there in heavy ingress of sea water inland

during high tides. The problem is most severe in the Vennar sub basin. The drainage flow to the sea is also choked due to sandbars formed at several drainage outlets by strong littoral currents in the sea. Another problem faced by farmers and fishing communities is the threats due to the pollution loads discharged into rivers by industries. Drainage channels are in many places severely blocked by weed including water hyacinth.

161. South-west monsoon occurring in June to September does not cause either drainage or flood problems in Cauvery Delta. The South West monsoon is absorbed in the Western Ghats and in the various reservoirs in Cauvery basin in Karnataka. Over flows from these reservoirs are impounded in the Mettur dam in Tamil Nadu, any overflows from Mettur are diverted into the Coleroon river. These various barrages on Coleroon and Cauvery ensures that flood regulation is easily managed in the Delta. The Cauvery Delta receives normally about 300 mm of rainfall during South-west monsoon. These rains are fully utilized by the crops. Irrigation deliveries from the canal are regulated taking into account the effective rainfall.

162. In the Cauvery Delta it is important to see how flood control measures can be integrated with drainage and irrigation. Flood control would require increasing the strength of the river dykes, however in parallel improved drainage and flood diversion needs should be provided.. By combining the functions of flood diversion with some form of retention in tanks or flood relief areas, allows for parallel benefits of irrigation use and groundwater recharge to be achieved. This integrated approach to flood management incorporating drainage and irrigation provides good opportunities to meet multiple objectives that should be further researched.

1. Strengthening of Banks

163. Strengthening of banks of rivers and protective works wherever required are provided are proposed in the modernisation report. These strengthening works include providing gravel roads on top for inspection purposes as well supporting community needs for roads. Banks should be designed with adequate freeboard to meet increased flood levels from sea level rise, alternatively the base section should be widened to allow for increased height to be added at some time in the future.

2. Drainage

164. In the coastal strip there are water logging as well as salinity problems. The tidal range is low (at Chennai it is about 0.4 m on neap tines and 1.2 m on spring tides), and this in conjunction with impeded drainage outfalls results in unfavourable conditions. Keeping drainage outfalls open is a significant problem.

165. Sea level rise will aggravate the existing drainage and salinity problems, and will have more impact on the areas than would be the case in an area with a larger tidal range. Sea level rise could be of the order of 0.3 m by mid-century, but could of course be higher. The closest tide gauge to the delta is at Chennai. An aspect that affects the impact of sea level rise is whether or not the land mass is rising or falling. It is not known the delta land mass is rising (as is the coastline at other locations), or subsiding through compaction and consolidation of sediments.

166. All the drainage channels are silted and many are severely choked by weeds. Maintaining the drainage channels is a routine requirement and adequate funds must be maintained to do this on an annual basis. Many of the drainage channels also operate as irrigation canals and small check structures are required to achieve adequate head for irrigation; ensuring these structures do not affect the drainage capacities is critical. These are 177 major drains and 519 minor drains in the delta; the drainage requirement includes; (i) a highly intensive routine removal of aquatic weeds and proper weed management including spraying and removing roots of weed; (ii) reshaping the drains with required standards; (iii) straightening the meandering courses; (iv) opening more outlets to the sea by straight cutting the drains; (v) opening of additional drains; (vi) outlet structure and escapes; and improvement of the cross regulator structures to avoid impeding the drainage.

167. The Vedaranyan is an old navigation channel, parallel and close to sea coast. It is no longer used for navigation purposes, but provides buffer storage when sea is rough with rising tides. It discharges the stored water during low tides. The CDMR proposes the strengthening of Vedaranyan canal bunds and redesigning of straight cuts to sea have been proposed. The CDMR also proposes

the transfer of flood waters of NE monsoon rains from the basin. Five major drains that join Vennar River from Tiruchi and Puddukotai districts carry heavy flows causing flooding every year. In the year 2005, a maximum discharge of 850 cumecs was carried through these drains that caused extensive damages in the delta. These is a proposed to divert such water during high floods to the rain parched parts of Puddukotai districts. This water can be also used for ground water recharge in that area. The viabilities of these proposals would be confirmed by modelling of the drainage capacities with present and future sea levels.

3. Flood Diversion and Retention

168. A plan exists for additional diversion of flood flows primarily through the Anicut canal, and storage of these in tanks. This proposal needs to be considered further. There could be the possibility providing tank storage on a local scale elsewhere using excess flood flows. There would appear to be potentials develop flood relief and storage tanks at small scale (farm ponds) and medium scales. By combining the functions of flood relief with dry season storage for irrigation and support for recharge the benefits of diversion can be enhanced. The retention functions would be achieved by some form of control gate. Options for flood diversion retention schemes could include; (i) small farm ponds located in individual farmers fields; (ii) existing natural water bodies which could be adjusted to improve their retention capacities; (iii) Vederanyan canal and other major drains; (iv) the low lying lands presently abandoned due to drainage and salinity problems. Irrigation use from the flood retention waters could be abstracted by gravity in some instances but in most cases would require to be supported by abstraction by small individual pumps or indirectly through groundwater in the periphery of the water retention areas.

I. Salinity Control

169. The provision/replacement of tail end regulators (tidal gates) support irrigation, and reduce saline intrusion. Drainage rates need to be improved, and maintaining outfall sections poses a significant challenge. It may be possible to improve the characteristics of some of the distributory channels such that increased flood flows through distributaries could help maintain outfall conditions. This is again would need to have the hydrodynamic modelling discussed above in 2.

170. The need for dismantling and reconstructing all the tail end regulators is an important part of the Delta Modernisation Report . The existing regulators are all very old, The gates are badly corroded affected because of the proximity to the sea. Tail end regulators are meant for three important functions; (i) to head up the irrigation supply adequately with gates closed so that there could be effective withdrawals in the channels above to feed the irrigation lands by gravity or pump. (ii) to allow passing of flood flows to the sea with minimum head loss; (iii) to halt the ingress of sea water inland to protect farms and communities from salinity intrusion. There are 18 tail end regulators, of which 7 are in Cauvery sub basin and 11 in Vennar sub-basin, and 9 in the Lower Coleroon basin. There possibly is a need for additional tail end regulators. The proposed tail end regulators are described in Table 20 below.

Table 20: Tail End Regulators to be Repaired or Replaced

Name of the river	Name of the regulator
Cauvery Basin	
1 Mahimalayar	Kannappan Moolai
2 Mahimalayar	Arabi
3 Cauvery	Melayur
4 Pudumanniar	Pudumanniar surplus
5 Kittiyanai Uppanar	Kittiyani surplus
6 Manjalar	Annappanpettai
7 Southrajan	Pillpadugal
VENNAR BASIN	
1 Vettar	Odacherry
2 Kaduvaiyar	Vadugacherry
3 Vellaiyar	Eravaikadu
4 Harichandra river	Brinjimoolai
5 Adappar	Brinjimoolai

Name of the river	Name of the regulator
6 Mulliyar	Mulliyar
7 Manangodaner	Adahanur
8 Marakkakoriyar	Idumbavam
9 Valavanar	Thondiyakadu
10 Koriyar	Jambuvanodai
11 Paminiyar	Thoppathana
Lower Colroon	
1.Rajan Channel	Kannakkankattai Regulator
2. Vadavar	Fall point Veernam tank-change to electrical gates
3. Khan Sahib Canals system	Seven regulators -two have collapsed
PONDICHERRY	Five tail end regulators

171. These tail end regulators are located taking into consideration primarily the need for holding the flows and creating head for easy withdrawal in the irrigation channels and in many cases quite far upstream of the coast line. Sometimes additional temporary mud korambus are formed below these tail end regulators on these rivers to serve as salinity barriers at locations where the tidal influx ends. While reconstructing, they will all be designed with larger vent ways and easy operating gears involving less manpower. The siting of the tail end regulators is critical to optimise the functions of salinity control and irrigation. Regulators are major structures and would be normally designed for 50 plus years design life (for the main structure) so it is important that sea level rise is factored into the design; the salinity and water level regimes of the lower rivers may affect the optimum location of the regulators as well as the need for some additional freeboard.

172. The tail end regulators to fully function may also require some sea side bunds to protect the farms from higher tides and storm surges; effective drainage through the bunds would have to be incorporated into the planning.

173. The regulators would have some environmental impacts especially for water users water using water below the regulator. The river would become more saline with possible impacts on the coastal and near coastal communities. Reduced flows to the river mouths may increase the build up of the sand bars. Provision of periodic flushing through the regulators should be considered.

J. Agriculture Systems to Meet Adaptation

1. Climarice

174. Development of appropriate cropping systems form an important aspects of adaptation. The Tamil Nadu Agriculture Universally (TNAU) with the support of Govt of Norway is undertaking extensive research on the effect of climate change on rice production and to work out various adaptation measures to safe guard rice productivity in the State; the main part aim of the project namely ‘Climarice’ is assessing climate variability and its impact on water availability and rice production system in Cauvery river basin. The outputs of the climarice project will be researched and will form an important component of the project.

175. The use of saline tolerant seed varieties may be able to alleviate some of the salinity impacts on the rice and other crops.

2. Fresh and Brackishwater Aquaculture in Low Lying Saline Areas

176. Many low lying parts of the coastal area are currently not able to grow any crops due to drainage problems and salinity; other areas are cropped but with very low yields. Sea water rises of up to 30cm by mid century will result in expansion of the low lying low and non productive areas. Some of the areas unsuitable for rice cultivation have been diverted by farmers for brackishwater shrimp[17]

[17] FAO defines shrimp as species that grow in salt water, prawn are freshwater

farming. Such ventures have shown mixed results and there is significant local objection to outsider investors buying land for shrimp culture. Conflicts have also developed between farmers and shrimp cultivators because shrimp is reported to be causing enhanced salinity in the adjoining farm lands and groundwater.. Poorly designed and managed shrimp farms have suffered major losses due to disease. Some local farmers/ fishermen have however formed investor groups and using modern technologies with the support of government department, have flourished with good financial returns. Other farmers are developing freshwater fish culture filling the ponds during the monsoon.

177. Low lying parts of the coastal zone have and will continue to struggle with salinity and drainage problems and shrimp aquaculture does offer potential opportunities where farming systems can not function; sea level rise will increase the problems. Well planned shrimp farms with properly designed supply and separated drainage systems can reduce disease risk and can potentially provide good returns. Support for local farmer owned enterprises, cooperatives or joint ventures will reduce the social tensions. Well designed demarcation of zones for shrimp and rice can avoid the issues of conflict over salinity. The Vietnam Mekong Delta is a good example of integrated development; a zone of low lying coastal lands lying on the sea side of tail end regulators grow shrimp; above the tail end regulators farmers grow rice. There is an intermediate zone where farmers grow wet season rice followed by dry season shrimp. The potentials and appropriateness for shrimp culture needs further research and consultative planning implemented.

178. There are proposals for thermal power plants which are under consideration along the coastal zone. It is important that the thermal plants are located on lower level and less productive land.

3. Crop Calendars and Technologies

179. The changing climate situation and problems flood and salinity may require adjustments of the crop calendars and crop diversification. The Department of Agriculture is presently studying the rice calendars and how better planning of cropping and shorter term varieties could be applied to reduce water consumption and increase resilience to water and climate impacts. Zonalisation of the Kuruvai crop is one aspect being considered to reduce water demand. Medium term weather forecasts could assist farmers with their crop planning; this work is being coordinated with the support of National Centre for Medium Range Weather Forecasting (NCMRFF).

180. Tamil Nadu Rice Research Institute (RNRRI) at Adeethurai, is engaged in conducting diversified research activities to formulate an irrigated water management strategy for rice. Other research activities in the institution include (i) maximizing rice productivity under droughts and floods conditions; (ii) potentials for mechanization of rice-cultivation in delta; (iii) development of technologies for rice fallow pulses; (iii) development of technologies for direct seeded rice.

K. Potable Water

181. Potable water for the rural areas is sourced from shallow tubewells with hand pumps as well as piped water from the rivers. There are major challenges in drinking water; drinking water is distributed through long distance piped network managed by the Panchayat. The piped water is source from the Coleroon river under a central water supply scheme. Water is abstracted from river bed using infiltration wells. Water is supplied to house connections and public standpipes. The use of handpumps is declining. Before the Tsunami hand pumps were used to extract ground water for household consumption and was primary source. Now the tubewells only serve for non drinking and cooking purpose. The supply from the piped system is less than the demand and villagers have to use the stand pipes on occasions. During the dry season even the combined pipe and standpipe systems run short

182. The long term and sustainable water supplies have to be sourced from the river well above any salinity risk. Without major urban areas, the overall water demands are quite low compared with irrigation and sustainable water sources would indicatively be adequate. Water supply systems require to be upgraded to provide adequate properly treated water to Government standards. The tubewells in most areas should be either abandoned or used as secondary sources.

L. Coastal Protection and Management

183. Coastal erosion is an issue affecting quite large parts of the coast along the Delta. The littoral drift is to the North. The delta is made up of quite wide expanse of sand and dunes. Erosion rates vary along the coast and the PWD has been implementing intermittent rubble mound protection works along the coast at the critical points. Tamil Nadu state has taken several projects of rubble mounds, construction of groynes and some dredging of river mouths. The use of rocks on the beach can have severe impacts on the sustainability of the beach and the use of soft more environmentally appropriate measures should be investigated. The reasons for the erosion is not clear but the reduced sediment in the rivers is reported as one of the causes.

184. Alternative solutions are being considered including nourishment with reinforced earth has been also been considered in Cuddalore Devanampattinam coast. The institute of Hydraulics and Hydrology Poondi, Tamil Nadu is carrying out coastal modal studies. WRD Tamil Nadu is carrying out coastal observation at many sites. It is suggested that the environmental effects of coastal protection works may be studied through numerical modelling. Coastal restoration methods like beach nourishment, restoration of littoral drifts, protection and restoration of mangroves etc should be considered as potential measures for protection rather than hard protection which can negatively impact on the beach

185. Blockages of river mouths by sand bars is an issue reported by farmers which can cause flooding at the beginning of the monsoon as well as blocking access to the sea for fishing boats. Reduced dry season fresh water flows to maintain flushing the is the prime cause. The issue needs to be further studied; restricting the width of the mouth with guide walls can help if there is adequate fresh water flow, but this may not work with the very limited flows in the Delta situation. The development of tail end regulators and further restriction of the flows may worsen the situation. How the increase in water level and increased risk of cyclone will affect the erosion requires to be determined.

M. Disaster Preparedness

186. Preparedness for coastal hazards has assumed significanc**e** delta area. Cyclones, floods and drainage congestion has to be tackled with strong community preparedness. Community TV, Cable TV, FM radio, newspapers is sources of weather forecasting in the Cauvery Delta area. Local knowledge like wind movements, cool winds, bird’s movement, cloud formation and sea roughness also give indications about the cyclonic events. Unavailability of accurate weather prediction is major concern expressed by farmers and fisher communities. Arrangement should be developed and improved for timely and accurate predictions. Village level disaster management committees for handling extreme events should be formed for each village with active participation of local communities, NGO’S and government officials, to organize effective disaster management and tackle emergency situations. World Bank aided India National Cyclone Risk mitigation Project has been launched in June 2010 in Orissa and Andhra Pradesh. The project includes (i) early warning dissemination system; (ii) cyclone risk management structures, emergency shelters and evacuation against cyclones, and (iii) national and state level capacity building and knowledge creation. Similar needs for the Cauvery may be appropriate although storm surges are lower in the southern part of the east coast.

N. Other Aspects

The Cauvery Delta Modernization Project has outlined a range of other initiatives to be taken up; these include; on farm development works, formation of water user associations, irrigation flow measurements, performance evaluation of systems, rotational water distribution, ground water management and water quality and environment management. These need to be further assessed.

O. Planning Strategies

187. The sustainability of the Cauvery Delta requires a wide range initiatives; an overview of the key issues and immediate strategies includes:

(i) Drainage issues will be exacerbated by sea level rise, and it will become increasingly more difficult to provide adequate and timely drainage in the lower parts of the delta. However, it is difficult at present to quantify these potential difficulties. Immediate and important actions are:
   - establishment of a permanent tide gauge, preferably in the middle of the delta coastline.
   - establishment of a permanent benchmark that can be linked to a geodetic network to establish whether the delta is experiencing uplift or subsidence; the tide gauge would be linked to this;

(ii) Following establishment of the tide gauge, preparation of a hydrodynamic model for part of the delta . It is proposed that should be done initially on the Vennar system which has more critical drainage and inundation issues. The model would be set up for present and future conditions including a 0.3m sea level rise and increased precipitation and flood flows. From the model it would be possible to assess drainage conditions and future salinity intrusion. The model would need to be supported by an topographic survey of the channels and land elevations in the coastal areas.

(iii) In order to address the saline groundwater intrusion problem it will be necessary to construct a groundwater model of the coastal delta area. It is unlikely that sufficient through flow can be created to restore the situation in any short time scale, if at all. It may be necessary to introduce further groundwater abstraction restrictions, and the effectiveness of this may only be properly assessed with a groundwater model. In the first instance, it may be sufficient to construct a 2-D vertical strip model, representing a cross section through the delta and including water quality. This might be followed with a more extensive 2-D plan multi-layered model.

(iv) Putting the results of items (ii) and (iii) together, it should be possible to identify potential future land uses in different zones of the delta - e.g. bio-drainage, brackish aquaculture, coastal protection belts, pumped storage zones, and the horizons at which existing practices are no longer tenable.

(v) It will be necessary to have a coastal management plan and to have some understanding of likely changes to the coastline over the next 50 years. There may be areas in which a managed retreat is required, and others where inland protection zones can be established.

188. A sea level rise of 0.3 m by mid-century could perhaps be coped with by local communities gradually raising the standards to which properties and roads are designed to. The gradual establishment of polders might be a solution in the more coastal areas, but with increasingly impeded drainage lift drainage from polders would probably be required, at least during the northeast monsoon. Water in lower parts of polders could be stored and used for post monsoon irrigation. The economics of this would need to be evaluated. Evaluation of this as a strategy would require the modelling of item (ii) above.

IX. PROPOSALS FOR INSTITUTIONS

189. The sustainable management of water resources in the Cauvery Delta requires a wide range of different approaches involving different sectors. This approach requires an integrated water resources management approach (IWRM). The current functions of the various water sector departments in their present form do not provide adequate operational basis[18] for implementing IWRM. Effective institutions are characterized by its stability and non fragmentation and non-overlapping of responsibilities, clearly defined but separated roles and is supported by strong and comprehensive, but flexible legislation, regulations, decrees, etc. and is lead by an "apex" body with clearly defined regulatory functions.

190. Some transformation in roles/rules and relationship among the institutions is essential which could facilitate; (i) holistic water planning; (ii) review of financial instruments like targeted subsidies to support adaptation; (iii) participation of stakeholders in planning and management; (iv) strategizing environmental management and control measures ; (v) facilitate inter basin planning and management (vi) separation of roles like service provider-managers and regulators; (vii) conjunctive planning and regulation of surface and ground water h) monitoring of quality of water (viii) effective planning for Disaster (flood) management (ix) revenue recovery mechanism to be effective (x) post project performance evaluation (outcome & impact) is not being carried out flow and discharge measuring installations

191. A nodal agency for ensuring coordinated and integrated planning and management approach by various water centric institutions is needed. Improved integration of planning between the departments of groundwater, surface water , agriculture and water supplies all of which are responsible or affected by the surface and ground water management principles.

1. Public/private/community roles and initiatives

192. The roles of the communities in supporting the planning and management are important. Agenda of assistance/support needs to engage with communities and defining their roles and responsibilities is required. The empowerment of water user associations is a key requirement.

193. **Community-based management** raises questions of capacity, financial management and participation. Long term sustainability and better demand- driven services and infrastructure have been the major objective of involving communities in the management of the resources. As support for community systems have moved from household wells to larger-scale and more complex community piped systems, so the challenges have grown. Operations and maintenance and financial sustainability have been the biggest challenges with community managed systems, followed closely by institutional and cultural challenges. Furthermore, recent experience suggests that as rural incomes increase, communities are demanding both higher levels of service and management arrangements that release them from day-to-day decision-making. Nevertheless, community involvement in water resource management remains a significant governance prerogative. Community consultations have indicated a willingness to participate in planning and policies for sustainability.

194. Key issues governance reform to meet the needs of the Cauvery Delta requires integrating the of sector programmes of water resources, agriculture, fisheries and environment. Government and communities need to work together to develop mechanisms for sustainability, combined with maximum productivity from agriculture as well as improved levels of service delivery of potable water.

2. Effective Information Systems for Good Water Governance

195. In the present institutions, participation in decision making is a means to an end, and the goal of informed decision-making requires good & reliable quality information on a range of issues, spatial, technical, social, economic, legal and institutional. This necessitates (i) establishment of an integrated data and information unit & also basin level knowledge centres (ii) capitalization of knowledge

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[18] Source: (ADB TA NO. 7418-IND): Integrated Water Resource Management and Sustainable Water Service delivery in Karnataka- COMPONENT 1 report on Institutional Analysis and Proposed Reforms for IWRM-2010

emerging form various initiatives like Hydrology project supported by the World Bank, land use information developed under different schemes (iii) developing climate related information archives to promote climate literacy among the various stakeholders in general and village panchayat leaders in particular (iv) development of decision support systems for effective water management and (v) establishment of updated design parameters to the impact of extreme events due to climate change (vi) development of data base related to water and climate for carrying out climate research

3. Strengthening of Ground and Surface Water Institutions

196. The institutional framework includes government institutions, local authorities, private sector, civil society organizations, farmers' organizations and other community-based organizations. Capacity building will be needed at each of these levels either through the development of existing water management arrangements or by forming new ones. Some particular issues requiring capacity building within the institutional framework for groundwater include the following:

(i) There is a need to link the current approach to groundwater resource assessment with more hydrogeologically sound approaches. A way forward could be to maintain the current practice of collecting water resources data at the smallest administrative units (e.g. block) but when aggregating these data use hydrological based divides (topographic divides and hydrogeologically connected aquifers units). A precursor to this approach would be an improved understanding of the hydrogeological system particularly concerning regional aquifer flows for shallow and deep aquifers and on the nature of groundwater-surface water interactions. This approach would also require relevant staff at district level to work together to develop these aggregated datasets supported by a wider state body or in the case of interstate water resources a central government agency.
(ii) Different methodologies for quantifying groundwater recharge should be trialed in pilot areas to confirm the viabilities and improve the current methodology for groundwater resource assessment (Water Level Fluctuation method). These improved methodologies could subsequently be applied to the new hydrogeologically sound areas of assessment discussed in the point above.
(iii) There is a need to separate water resources management functions (overall management of water resources as a whole) from service delivery functions (irrigation, water supply and sewerage) to avoid conflicts of interest and encourage commercial autonomy. Capacity building will be needed to support effective water resources planning of surface water and groundwater.
(iv) Effective and early public participation approaches will be required particularly with farmers' organizations to ensure that they are involved in the planning and decision-making processes. Capacity building of Water Users Associations and Panchayats will be particularly important to ensure take-up of new approaches to groundwater use.

4. Capacity Building and Development

197. Based on state consultations a summary of the key capacity building areas towards institutional strengthening[19] , water resource and user institutions development are presented in Table 21

Table 21 Key Areas for Capacity Building

o Water Management practices for sustainable agriculture
o Volumetric supply of water and installation of measuring devises
o Basics of Farmers Managed Irrigation Acts and formation of WUA
o GIS and Autocad applications
o On New Institutional arrangements and the roles to be played by WRD
o Community involvement in managing irrigation infrastructure
o Preparation of thematic maps for the selected basins
o Knowledge on and Utilization of modern equipments for Topographical and cadastral survey
o Modern design on irrigation structure and coastal structure
o Budgeting. accounting and financial management including fund-flow arrangements

[19] Main goals of institution strengthening is the strengthening of management and therefore capacity building areas must cover management issues.

○ Environmental assessment and redressal systems in the social & environmental assessment framework ○ Maintaining MIS ○ O & M of the irrigation assets and allocation of adequate funds ○ Project Planning, Monitoring and Evaluation ○ GIS Applications in Irrigation ○ Modern Survey Techniques (Total Station and LADAR- Laser Detection and Ranging ○ Environmental Impact Assessment & Management (EIA/EMP of irrigation projects) ○ Project Economics ○ Procurement & Contract Management (including procurement procedure) ○ Procurement/ Tendering ○ Planning of Irrigation Projects ○ Modern Irrigation Techniques like Sprinkler/Drip Irrigation ○ Benchmarking of Irrigation Projects ○ Water Use Efficiency/Water Auditing of ○ Irrigation Projects ○ Productivity Enhancement in Command Area ○ Design of Dams ○ Land Acquisition and Encroachment Issues ○ Modern Construction Technology and Techniques ○ Quality Control of Construction ○ Revenue Recovery and Related Issues ○ Canal and Drainage Hydraulics ○ Mirco-distribution Network, Plan & Design ○ Preparation of Operational Plan for Irrigation Projects ○ SCADA - Canal Automation ○ Design & Operation of Canal Flow, Flow Measurement and Control Structures ○ Dam Safety Aspects
OTHER DEPARTMENTS
○ Integrated Farming ○ Adoption of Micro irrigation technology ○ Promotion of Hybrid vegetable and Horticultural crops ○ Promoting fodder cultivation ○ Seed production and seed certification ○ Agro-climatic zones and agronomy ○ Pest Management
COMMON TO ALL DEPARTMENTS
○ Concept, principles and practices of IWRM ○ Basin approach in Planning and Implementation ○ National and State Acts & Rules ○ Formation and functioning of RBO s ○ Legal Issues and Related Software ○ Legal Issues and Use of LIS (Legal Information System) ○ Human Resource Management/Strategic Human Resource Management ○ Right to Information ACT ○ Leadership, Motivation and Team Building ○ Developing Communication Skills ○ Time, Stress and Conflict Management ○ Participatory Irrigation Management ○ Gender Issues and their Integration ○ Management of Organizational Change ○ Building Organizational Culture for Performance ○ Competency Mapping and Management ○ Public Private Partnership

B. The Enabling Environment for Groundwater Management

198. Efforts have been made by the Tamil Nadu Government to effect change concerning groundwater. The CGWA has notified Gangabialli, Thalaivasal and Veerapani blocks of Salem district, Thuraijur block of Trichinapally district, Chengar block of Vallore and Pernampet block of Vellore districts for regulation of groundwater abstraction structures. The Pondicherry groundwater (Control & Regulation) Act 2002 is invoked to regulate and control development of groundwater in whole of UT of Pondicherry.

199. However, a lot more is needed to arrest the over-exploitation of groundwater and to facilitate a move away from groundwater mining to a more sustainable use of this resource within a wider integrated water resources management approach. Areas that need further policy approaches include:

(i) Establishment of a clear legal framework for the management of water resources, such as catchments and aquifers. Whilst the current practice of using administrative units (e.g. districts and blocks) is practical it ignores flows between these units either through natural topographic gradients in the case of surface water or regional aquifer flows in the case of groundwater.

(ii) Policies will need to be developed to determine effective water allocation mechanisms including decision support systems to prioritize water needs. Water allocation approaches will need to adopt the principle of conjunctive use of surface water and groundwater at its core so that all water is managed as one resource. Conjunctive use if implemented judiciously can help maximize the available renewable resource through the storage of excess water in aquifers during times of surplus and the use of this stored water to augment surface water flows for irrigation, environmental flows and other beneficial uses during times of water deficit. Included in this combined approach is a need to develop a surface water regime that helps provide sufficient recharge to groundwater to at least arrest further landward seawater intrusion.

C. Institutional roles:

200. The institutional framework includes government institutions, local authorities, private sector, civil society organizations, farmers' organizations and other community-based organizations. Capacity building will be needed at each of these levels either through the development of existing water management arrangements or by forming new ones. Some particular issues requiring capacity building within this institutional framework include the following:

- As identified above there is a need to link the current approach to groundwater resource assessment with more hydrogeologically sound approaches. A way forward could be to maintain the current practice of collecting water resources data at the smallest administrative units (e.g. block) but when aggregating these data use hydrological based divides (topographic divides and hydrogeologically connected aquifers units). A precursor to this approach would be an improved understanding of the hydrogeological system particularly concerning regional aquifer flows for shallow and deep aquifers and on the nature of groundwater-surface water interactions. This approach would also require relevant staff at district level to work together to develop these aggregated datasets supported by a wider state body or in the case of interstate water resources a central government agency.
- .There is a need to separate water resources management functions (overall management of water resources as a whole) from service delivery functions (irrigation, hydropower, water supply and sewerage) to avoid conflicts of interest and encourage commercial autonomy. Capacity building will be needed to support effective water resources planning of surface water and groundwater.
- Effective and early public participation approaches will be required particularly with farmers' organizations to ensure that they are involved in the planning and decision-making processes. Capacity building of Water Users Associations and Panchayats will be particularly important to ensure take-up of new approaches to groundwater use.

X. CLIMATE CHANGE SCENARIOS

A. Introduction

201. Understanding the effects of future climate under the influence of global warming requires the use of climate simulation models, run with a range of possible emission scenarios and incorporating the uncertainty that exists in climate model forecasts. Scenarios are used in estimating the probable effects of one or more variables and can support the decision making processes for what are the most appropriate adaptation requirements, and are an integral part of situation analysis and long-range planning. In this regard, future climate scenarios have been developed based on assumptions on the change of drivers that would influence the climate system; particularly change in the atmospheric concentration of greenhouse gases which may vary under different pathways of the world development in the future. Long-term future climate projections provide the basis for assessment of climate change impacts on certain sectors in specific areas. The climate state obtained by incorporating an emission scenario in global and regional climate models is called a climate scenario, while the difference between a future and current or recent climate state resulting from consequent changes in atmospheric composition is called a climate change scenario.

B. Summary of Observed Changes to the Present Time

202. An overview of the main climate information is given in the Sub Basin Profile. A summary of the main conclusions are given below. The climate of the Cauvery Basin is complex. The upper part of the basin is strongly influenced by the southwest monsoon, while the southeast and delta region is strongly influenced by the northeast monsoon. The focus of the this study was the Cauvery Delta, and for this reason the summary below is focused on Tiruchchirapalli and Nagappattinam. Tiruchchirapalli is just to the west of the delta, but is probably representative of the upper parts of the delta. Nagappattinam is in the southeast of the delta and more representative of the coastal strip.

203. **Temperature:** at Tiruchchirapalli, mean daily temperatures range from a low of about 25^{o}C in December and January to a high of about 31^{o}C in June. April, May and June are the hottest months with mean daily maximums close to 37^{o}C. The mean daily temperature range is typically about 10^{o}C. A maximum range of about 11^{o}C occurs in April and May. The minimum range of about 7^{o}C occurs in November. Relative humidity is at its lowest in June and July, averaging 50%, and peaks in November at about 73% under the influence of the northeast monsoon The climatic norms at Nagappattinam in the southeast follow a similar pattern to those at Tiruchchirapalli, but are influenced more by the sea. Mean daily temperatures are very similar to those at Tiruchchirapalli although the range in daily temperatrues is lower. The maximum range of about 10^{o}C occurs in June, and the minimum range of about 5^{o}C in December. Relative humidity at Nagappattinam is higher than at Tiruchchirapalli throughout the year and is generally in the range of 80% - 90%. Wind speeds at Nagappattinam are highest between November and March, while at Tiruchchirapalli high winds are experienced between June and September.

204. **Rainfall** in the delta area is of the order of 1000 mm annually. In the coastal areas the highest rainfall months are October, November and December, while further inland the peak monthly rainfall is earlier in October.

205. **River Flows**: ten years of monthly flow data were made available for Upper Anicut and Grand Anicut barrages. Figure 2 shows the annual flow volumes available at Upper Anicut for the last ten years. There is clearly significant inter-annual variability. During the period the mean annual volume was 174 TCM with a coefficient of variationof 0.55. Monthly flow volumes are shown in Figure 55 and Figure 56. It is clear that there is significant variability in June and July flow availability, which must have a significant impact on irrigation of the first crop.

Figure 55 Annual Flow Availability, Upper Anicut

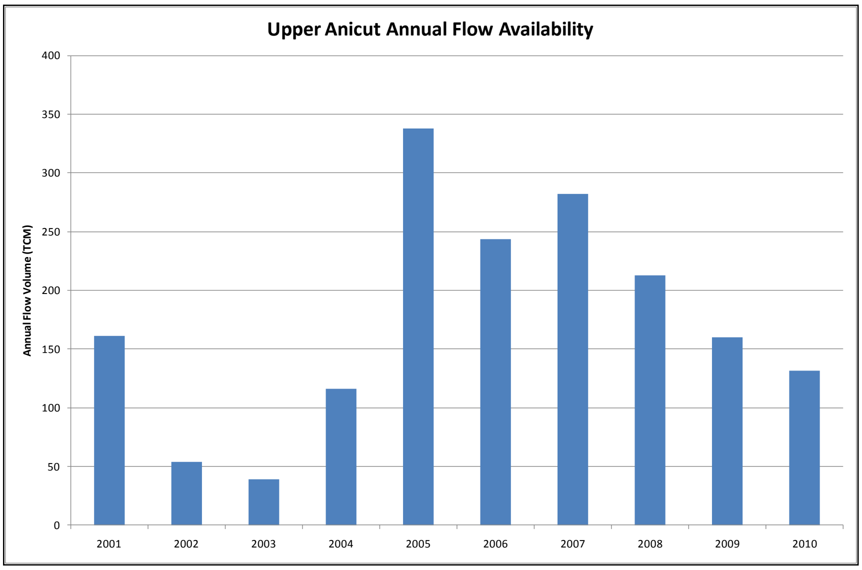
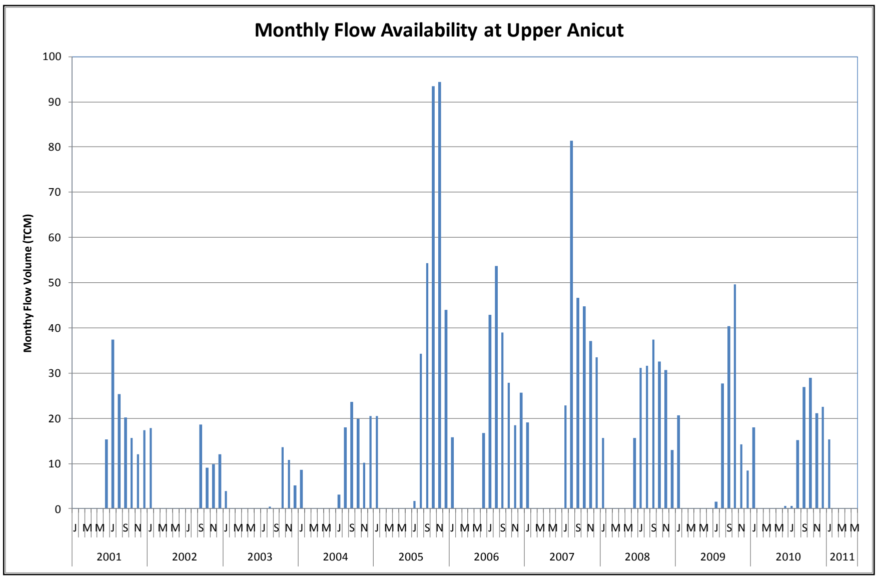


Figure 56 Monthly Flow Availability, Upper Anicut



206. **Sea Level Rise**: The Cauvery Delta is vulnerable to the effect of rising seas levels as a result of climate change. Rising sea levels pose a number of threats including coastal erosion, increased wave energy, salinity ingress to drainage channels and saline intrusion to groundwater. The coastline was badly affected by the 2004 tsunami. There are no available records with which to check historic rates of sea level rise in the delta. These will at least be similar to eustatic[20] sea level rise. It is not known if relative sea level rise in the delta region is higher than the eustatic rise.

C. Present Awareness of Climate Change

207. The consultants conducted a participatory rural appraisal in February 2011 to obtain a better understanding of the issues faced by the farmers. The main points raised by the farmers include: (i) the respondents felt the winter is getting longer, the cold period used to be until January but now continues until February; (ii) rough seas now preclude fishing in February; (iii) it is felt the rainy season is shifted by a month, it used to come in October; (iv) the closure of the river barmouth is extended which affects the period the boats cannot go out; (v) ground water salinity level drastically changed after Tsunami and have become non usable for drinking purpose; (vi) surface water in river

[20] Eustatic" change (as opposed to local change) results in an alteration to the global sea levels, such as changes in the volume of water in the world oceans or changes in the volume of an ocean basin

course drainage channels are getting saline due to backwater flow in the monsoon season with sea water flowing in due to gravity this is affecting the barmouth closure. Nearby lands for agriculture and soils are showing up salt deposition on land; (vii) with changing climatic conditions the loss of workdays by the fishermen is an issue; workdays and sometimes loss of landed fish is becoming more frequent, the increased idle time is causing social problems women are now more dependent on men.

D. Relevant Climate Studies and Findings

208. The ClimaRice project based at Tamilnadu Agricultural University is assessing the rice ecosystem sensitivity to climate change by using high-resolution regional model simulations and simultaneously the understanding of the hydrological changes in the Cauvery river basin, India. The project aims to develop suitable adaptive technologies that will contribute to sustain the rice production in the future climate situations. The project integrates natural, socio-economic and institutional factors that would help in improving the adaptive capacity of the managers and end-users."

209. LOICZ (Land-Ocean Interactions in the Coastal Zone), together with UNEP and others, ran a workshop in Dec 2009 on "Deltas: Coastal Vulnerability and Management", this took place in Chennai and featured the Cauvery Delta prominently. Sediment loads, mud dynamics and mangrove issues were explored.

210. Anna University has a dedicated unit CCC&AR (Centre for Climate Change and Adaptation Research), which is involved in preparing Tamil Nadu's "State Action Plan for Climate Change".

211. MoEF Coastal Zone Management Project; includes a number of coastal management initiatives. Very relevant to the Cauvery is the mapping, delineation and demarcation of a hazard line. The hazard line for the mainland coast of India will be mapped and delineated as the landward composite of the coastal 100 year flood lines (which includes sea level rise impacts), and the 100 year predicted erosion lines. This will involve (i) surveys and preparation digital terrain model of 0.5m contour interval for the entire mainland coast; (ii) collection of historical tide gauge data and analyses to determine 100 year flood levels, (iii) analyses of maps and satellite imagery since 1967 to predict 100 year erosion line, (iv) preparation of composite maps, showing the hazard line on the digital terrain model, and (v) transfer of the hazard line to topographic maps for public dissemination. Once the hazard line is delineated, ground markers will be constructed. This is important as the revenue maps used for local planning purposes are not comparable to topographic maps. The publicly disseminated maps and the ground markers will obliterate the need for each developer and stakeholder to invest in physical surveys and interpretation each time a need for decision regarding applicability of coastal regulations arises. Once mapped and delineated, the hazard lines will be used to determine the landward boundary of the state/local ICZM plans.

212. The IPCC AR4 reported that there would be an increase in temperature under almost all scenarios. Under the A1B scenario there would be (i) an increase of 3.3°C by the end of 21st Century; (ii) lesser warming JJA by about 2.7°C and warming would increase northward within the region. For precipitation under A1B; (i) a decrease in DJF but increase during rest of the year; and the 'Land-Sea T' anomaly to be less prominent in controlling Monsoon. The results have been widely circulated and disseminated.

213. PRECIS simulations for future climate scenarios indicate an all-round warming over the Indian subcontinent associated with increasing greenhouse gas concentrations. The annual mean surface air temperature rise by 2030s ranges from 1.7°C to 2°C in three simulations carried out.

214. From 2011, new and more sophisticated climate model outputs will start to become available in CMIP5 (Coupled Model Intercomparison Project Phase 5) that will be part of the IPCC's AR5, it is likely that the new models will give an improved monsoon description.

1. The PRECIS Model

215. Climate models are mathematical models used to simulate the behaviour of climate system. They incorporate information regarding climate processes, current climate variability and the response of the climate to human-induced drivers. These models range from simple one dimensional models to complex three dimensional coupled models. The latter, known as Global Circulation Models (GCM),

incorporate oceanic and atmospheric physics and dynamics and represent the general circulation of the planetary atmosphere and ocean. The GCMs are usually run at very coarse grid (about 3° x 3°) resolution (dimension of a grid cell of order several 100km), whereas the processes that are of interest for studies such as this one, such as precipitation, are highly influenced by the local features namely orography and land use, and even cloud-microphysics. These local characteristics are not properly represented at the coarse scale of GCMs and contribute to prediction errors on the impact of climate change at the sub-grid scale. Therefore, these GCMs are strengthened with the incorporation of local factors and downscaled, in general with a grid resolution of about 0.5°x0.5° or less. The downscaling can be of dynamic or statistical type. These models are referred to as Regional Climate Models (RCM) and improve the quality of climatic prediction for specific local areas.

216. A RCM is a model of the atmosphere and land surface which has high horizontal resolution and consequently covers a limited area of the earth's surface. A RCM cannot exist without a 'parent' GCM to provide the necessary inputs. The RCMs provide an opportunity to dynamically downscale global model simulations to superimpose the regional detail of specified region. RCM provide climate information with useful local detail including realistic extreme events and also they simulate current climate more realistically.

217. A regional climate model is a comprehensive physical high resolution (~50km) climate model covering a limited area of the globe. The model Includes the atmosphere and land surface components of the climate system including representations of the key processes within the climate system (e.g., cloud, radiation, rainfall, soil hydrology). The (i) advantages of regional climate models include (i) highly resolved information; (ii) physically based character; (iii) many variables; and (iv) better representation of the mesoscale and weather extremes than in GCMs; (ii) disadvantages of regional climate models include (i) computational expensiveness, particularly for long runs; (ii) lack of two way nesting (feedback with the forcing GCM input); (iii) dependence on usually biased inputs from the forcing GCM; (iv) errors in the GCM fields that could result in errors in the regional climate scenarios; and (v) availability of fewer scenarios.

218. **P**roviding **RE**gional **C**limates for **I**mpact **S**tudies (PRECIS) is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. PRECIS is the UK's Met Office Hadley Centre portable regional climate model, developed to run on a Linux PC with a grid resolution of 0.44° x 0.44°. The high-resolution limited area model is driven at its lateral and sea-surface boundaries by output from global coupled atmosphere-ocean (HadCM3) and global atmospheric (HadAM3) general circulation models. PRECIS captures important regional information on summer monsoon rainfall missing in its parent GCM simulations. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described and lateral boundary conditions (LBCs) are required at the limits of the model's domain. Information from every aspect may be diagnosed from within the model (Noguer et al., 1998). **P**RECIS can **b**e appli**e**d easily to **a**ny are**a** of the globe to generate detailed climate change predictions and is used for vulnerability and adaptation studies and climate research.

E. Regional Climate Scenarios for India Using PRECIS

219. Indian RCM PRECIS has been configured for a domain extending from about 1.5°N to 38°N and 56°E to 103°E. IPCC SRES A1B Scenario – Q14 QUMP (**Q**uantifying **U**ncertainty in **M**odel **P**redictions) for the time slices of present (1961–1990), mid-century (2021-2050) and end-century (2071–2100) has been made available by IITM Pune.

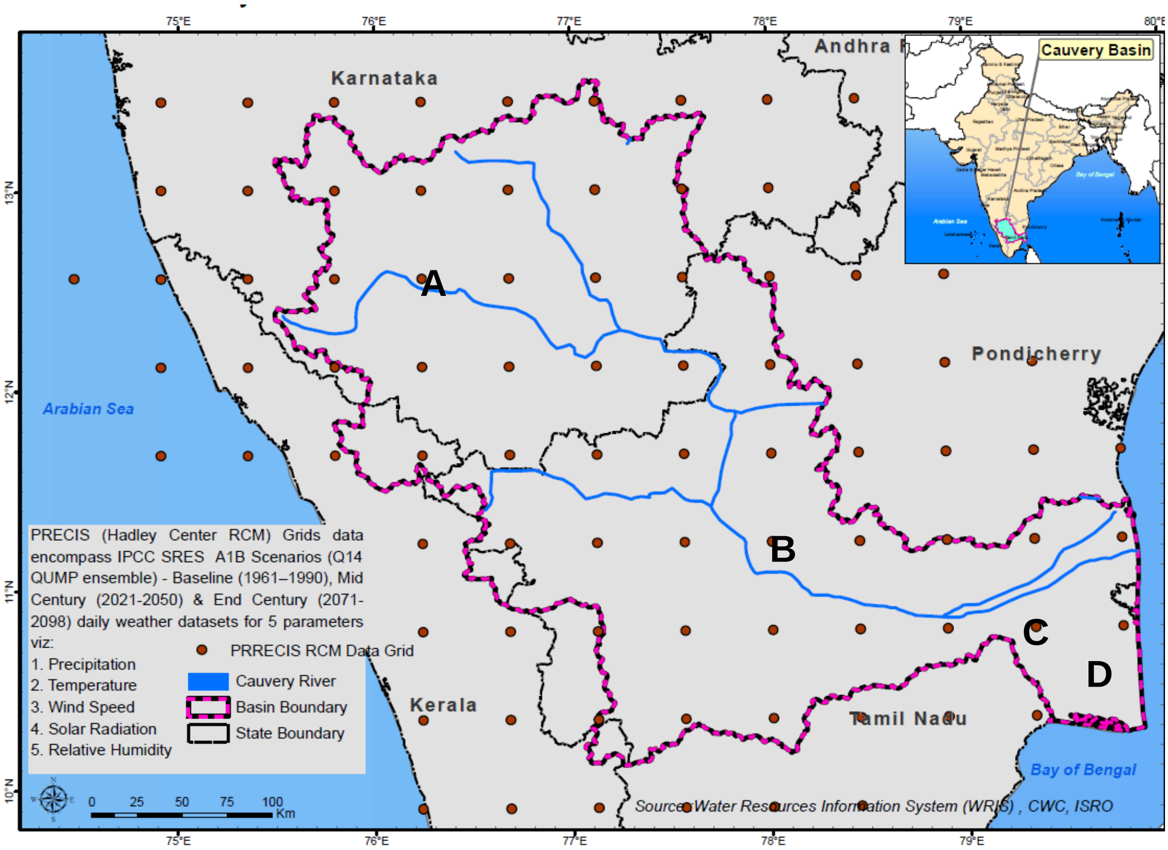
220. Simulations from a seventeen-member perturbed physics ensemble (PPE) produced using HadCM3 under the Quantifying Uncertainty in Model Predictions (QUMP) project of Met Office Hadley Centre have been used as LBCs for 138 year simulations with PRECIS. The QUMP simulations, comprise 17 versions of the fully coupled version of HadCM3, one with the standard parameter setting and 16 versions in which 29 of the atmosphere component parameters are simultaneously perturbed (Collins et al. 2006). Thus far three scenarios have been run with the Indian RCM PRECIS.

F. Scenarios for The Cauvery Basin Using PRECIS

221. For climate change projections in the Cauvery basin, output from one member of the QUMP ensemble (Quantifying Uncertainty in Model Predictions) downscaled using PRECIS was available.

Apart from the baseline (1961-1990) which represents the present, the following two time slices for the future were investigated: mid-century (2021-2050) and end-century (2071–2100); all three time slices use the SRES scenario A1B. In addition, data were available for the SRES A2 and B2 scenarios for the baseline and end-century. The PRECIS grids for the Cauvery are shown in Figure 57.

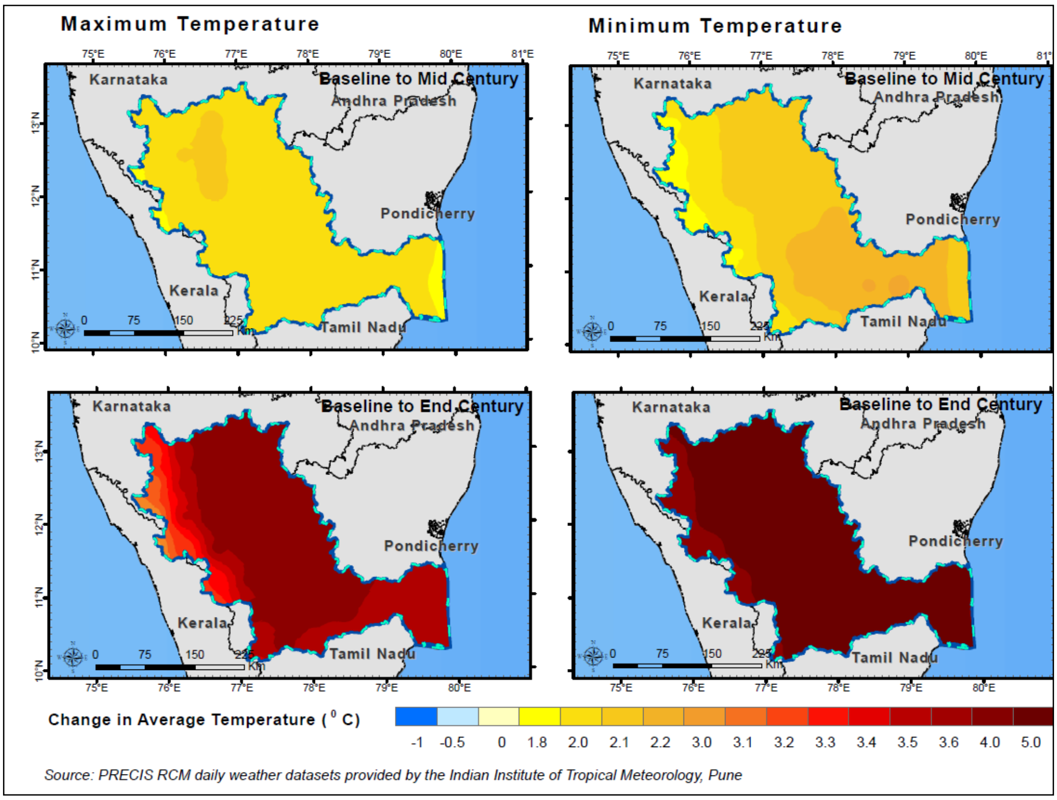
Figure 57 PRECIS grid locations in the Cauvery Basin



1. **Temperature**

222. An assessment has been made of results from the PRECIS A1B scenario for the Cauvery Basin. Figure 58 shows the changes in mean daily maximum and minimum temperatures projected for the middle and end of the century. By the middle of the century the A1B scenario indicates and increase in mean annual temperature of about 2^{o}C. By the end of the century the increase in temperature is forecast to be close to 4^{o}C. Changes in minimum temperatures are generally forecast to be higher than changes in maximum temperatures, resulting in smaller diurnal ranges.

Figure 58 Simulated Changes in Mean Annual Temperatures from the PRECIS A1B Scenario



Changes in seasonal and annual mean daily maximum and minimum temperatures for the Cauvery basin are presented in Table 22.

223. Table 23 presents a comparison of projected changes in temperatures under the A1B, A2 and B2 scenarios.

Table 22 PRECIS Simulated seasonal temperatures, A1B scenario

Time Horizon	Mean daily maximum temperatures (°C)				
	JF	MAM	JJAS	OND	Annual
Baseline (1970s)	31.6	35.0	29.7	29.8	31.5
mid-century	33.5	36.7	31.5	31.7	33.4
end-century	34.8	38.3	33.6	33.0	34.9
	Mean daily minimum temperatures (°C)				
Baseline (1970s)	20.0	23.6	22.6	20.5	21.7
mid-century	23.7	26.3	24.2	22.8	24.3
end-century	26.1	28.3	26.3	24.6	26.3

Table 23 Comparison of projected changes in temperatures, A1B, A2 and B2 scenarios, 2080s

Mean daily maximum temperatures					
Scenario	JF	MAM	JJAS	OND	Annual
A1B	3.2	3.3	3.9	3.2	3.4
A2	3.1	3.0	3.2	3.1	3.1
B2	2.3	2.0	2.3	2.5	2.3
Mean daily minimum temperatures					
A1B	6.1	4.7	3.7	4.1	4.65
A2	4.1	3.8	3.2	3.6	3.7
B2	3.0	2.6	2.4	3.1	2.8

224. Under the A1B scenario the indication is for an increase in mean daily maximum temperatures of about 2°C by mid-century, and of about 3°C by the end of the century. The increases projected in

mean daily minimum temperatures are higher, particulalry in the JF and MAM seasons. The A1B and A2 scenarios produce similar increases in mean daily maximum temperatures at the end of the century. The B2 scenario produces mean daily maximums that are about 1^{o}C lower. The A1B scenario produces higher mean daily minimum temperature increases than does the A2 scenario, and most significantly in the JF and MAM seasons.

225. **Precipitation**: Mean annual precipitation in the Cauvery Basin is shown in Figure 59 and is further described in the sub basin profile. Annual precipitation is highest in the Cauvery delta and in the northwest of the basin where over 1000 mm occurs. Most precipitation in the northwest of the basin is as a result of the southwest monsoon, while in the delta it is largely associated with the northeast monsoon. Seasonal precipitation is summarised in Table 24. Changes in annual precipitation simu'ated by PRECIS with the A1B scenario are shown in Figure 60. Table 25 presents a comparison of the changes in seasonal and annual precipitation projected with the A1B, A2 and B2 scenarios.

Table 24 PRECIS Simulated seasonal precipitation in the Cauvery sub-basin, A1B scenario

	JF	MAM	JJAS	OND	Annual
1970s baseline	32	146	479	165	822
mid-century	31	155	455	169	810
end-century	52	171	422	230	875

Table 25 Projected changes in seasonal precipitation under the A1B, A2 and B2 scenarios, to 2080s

Scenario	**JF**	**MAM**	**JJAS**	**OND**	**Annual**
A1B	20	25	-57	65	53
A2	8	18	29	57	112
B2	-4	39	27	-8.6	53

226. To the mid century a small decrease in annual rainfall is forecast, although by the end of the century a significant increase in precipitation is projected for the Cauvery delta, while in the middle of the basin there could be a reduction in annual rainfall. Changes in seasonal rainfall simulated by PRECIS for the A1B scenario are shown in Figure 61. Interestingly some quite significant changes in southwest monsoon rainfall are forecast. These changes could influence demands for supplemental irrigation supplies during the southwest monsoon. In order to consider the possible implications of changes in a bit more detail, changes in simulated mean monthly rainfall at four locations in the basin have been investigated. Four locations chosen (marked as A, B, C and D in Figure 57). Figure 62 presents mean monthly rainfalls at each location for the baseline, mid-century and end of century. Location A is at high elevation in the northwest of the basin. Here precipitation is high and a lot of runoff is generated. Quite a significant reduction in June, July and August rainfall is forecast under the A1B scenario. The reduction in June rainfall has implications for the delta in that existing uncertainty about water availability for planting rice in June may be exacerbated, particularly when this reduction in water availability could be coupled with increased irrigation demands in the middle basin. There is an increase in October, November and December precipitation at this location, but this may have little impact on water resources.

Figure 59 Mean annual rainfall based on IMD gridded data

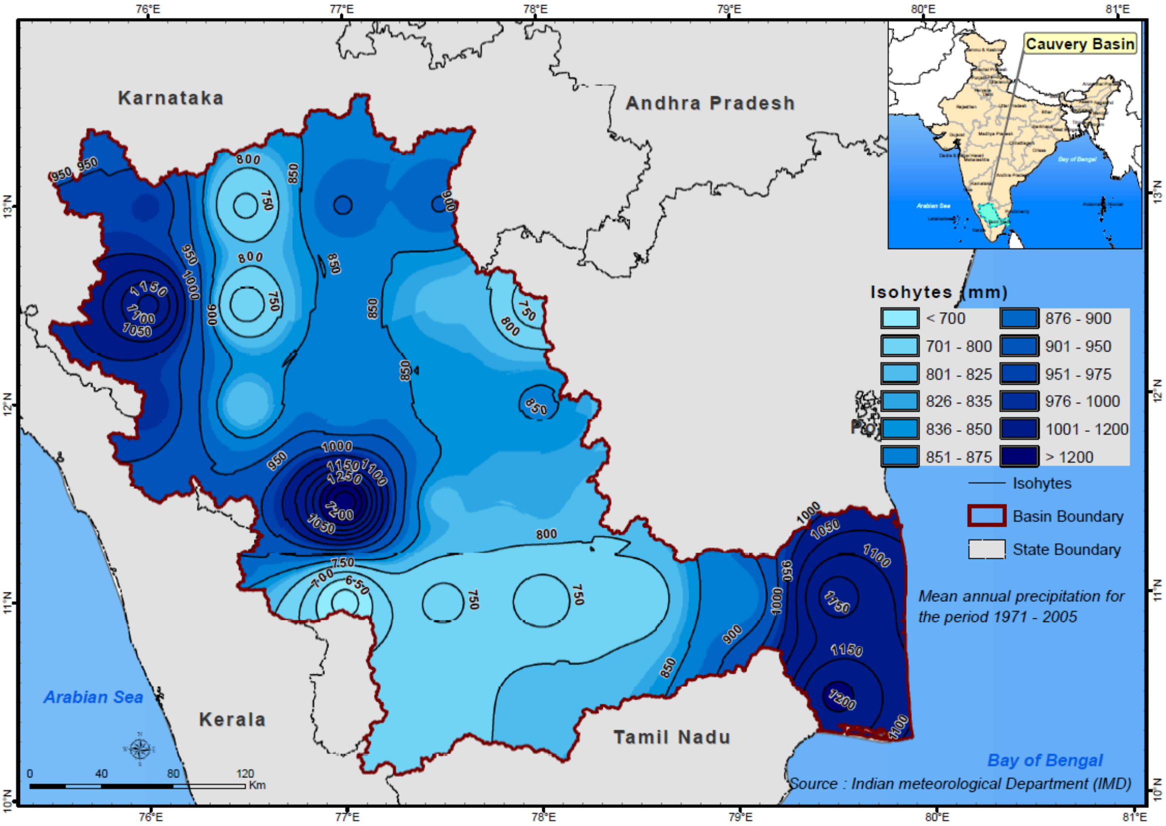


Figure 60 PRECIS Simulated Changes in Mean Annual Rainfall, A1B scenario

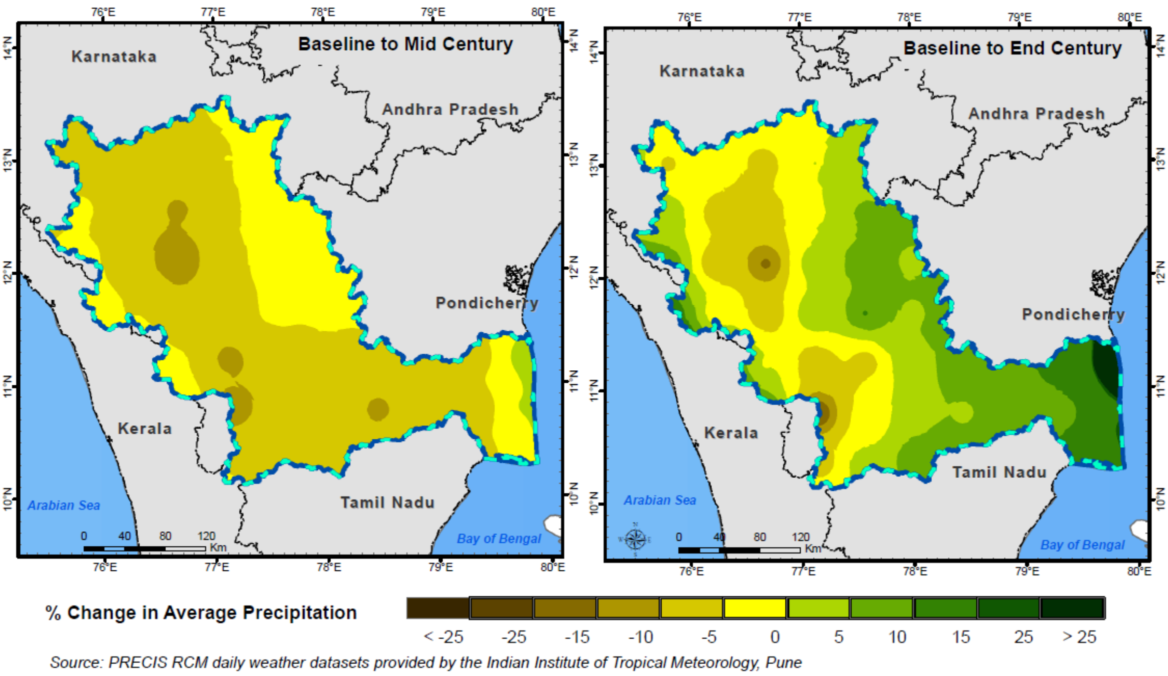
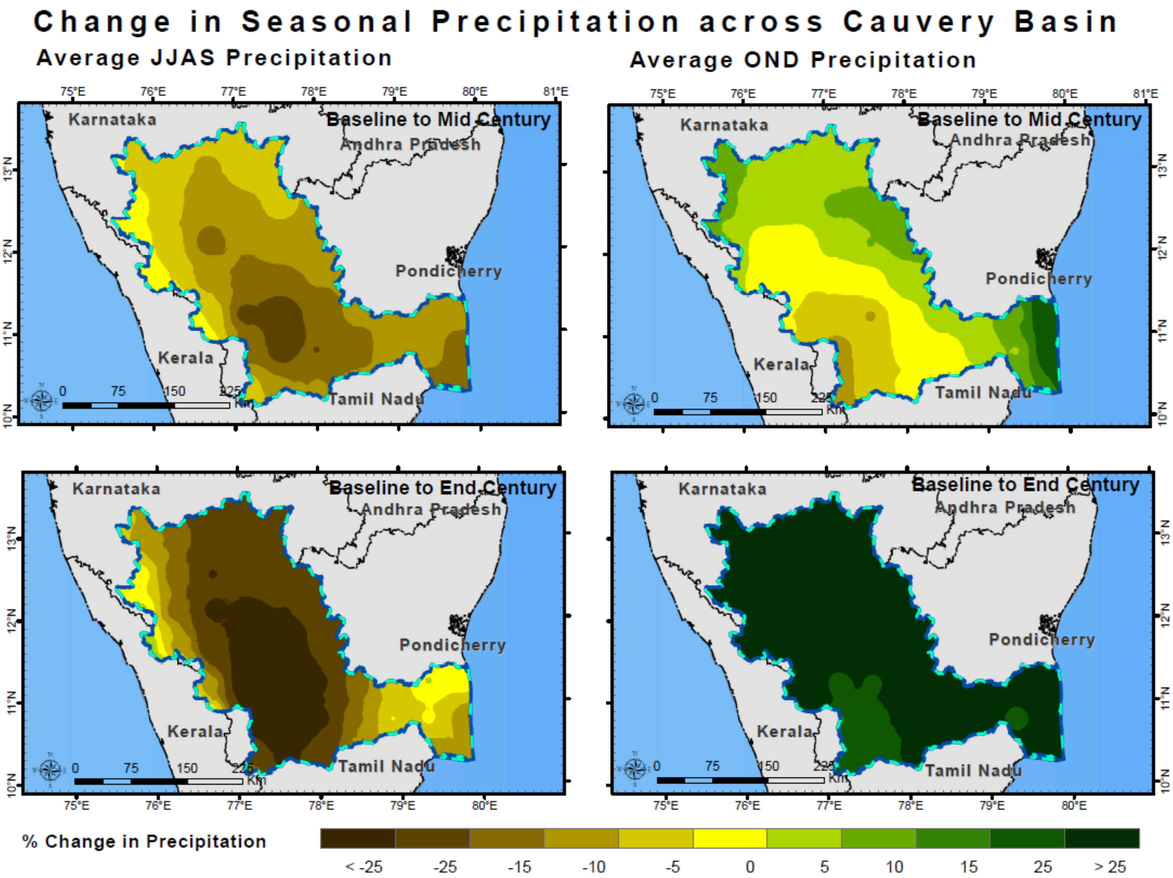
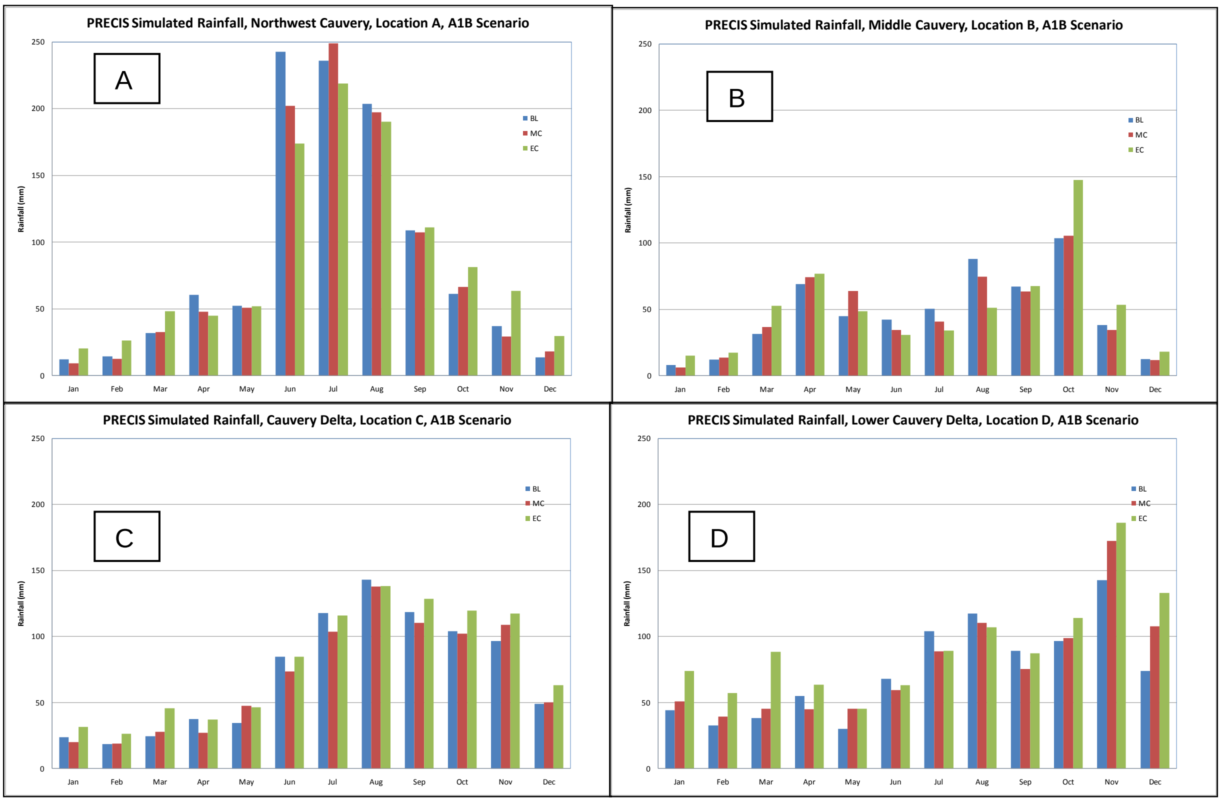


Figure 61 PRECIS Simulated Changes in Seasonal Rainfall, A1B Scenario



Source: PRECIS RCM daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune

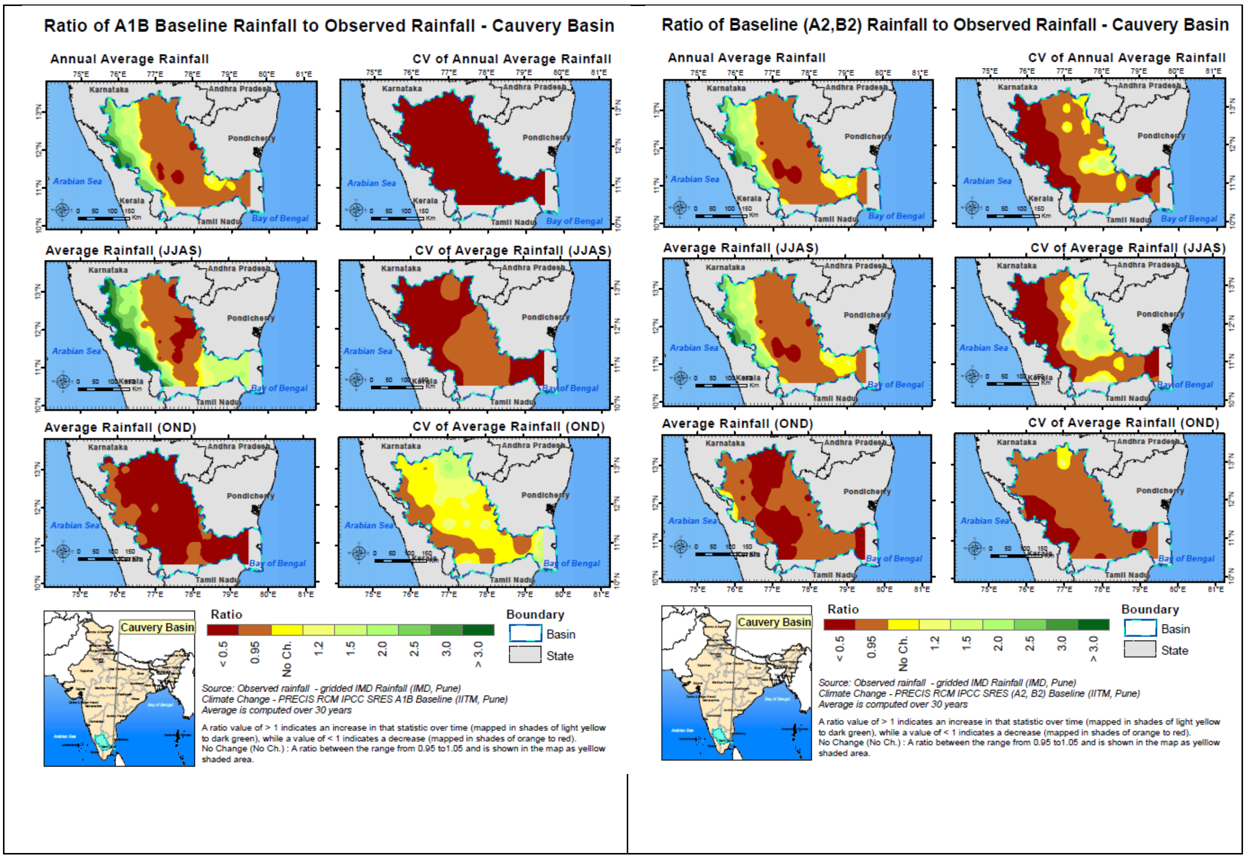
Figure 62 PRECIS Simulated Mean Monthly Rainfall at Selected Locations, A1B scenario



227. At location B there is also a decrease in June, July and august rainfall, that is likely to result in increased demand for supplemental irrigation. Here the highest monthly rainfall occurs in October, and this is forecast to increase. At location C, close to the head of the delta, the reduction in June, July August rainfall is less pronounced, and there is a clear increase in September, October, November and December rainfall. This could improve groundwater recharge conditions, and reduce irrigation demands slightly. At location D which is close to the sea, there is apparently a significant increase in November and December rainfall and through the months of January to April. This could be beneficial from a water resources perspective if not counterbalanced by higher potential evapotranspiration.

228. An evaluation has been made of the skill with which the PRECIS model represents baseline rainfall in both the A1B scenarios and the A2/B2 scenarios. Figure 63 presents the ratios of baseline observed rainfall to baseline PRECIS rainfall on both an annual and seasonal basis.

Figure 63 Bias in PRECIS Baseline Rainfall Simulations



229.   PRECIS over-estimates rainfall in the west of the basin, and under-estimates it over significant parts of the rest of the basin. It would appear that variance is not well represented either. The A1B baseline and A2/B2 baseline produce similar results. Seasonal rainfall is not well represented and care is required in interpreting PRECIS results in this basin. PRECIS results may be used to interpret changes, but rainfall-runoff modelling could be biased by the PRECIS results. It is likely that the ocean boundaries on either side of this peninsular area lead to difficulties in climate modelling. It would be useful to review results from different modelling systems for this area when they become available.

2. Precipitation Intensity

230.   An assessment has been made of changes in rainfall intensity simulated by PRECIS for the A1B scenario. Consideration was given to the number of rain days per year receiving more than 100 mm, and more than 150 mm of rain. The indication is that there may be an increase in very heavy rainfall events. This could have implications for drainage, particularly in the lower parts of the delta.

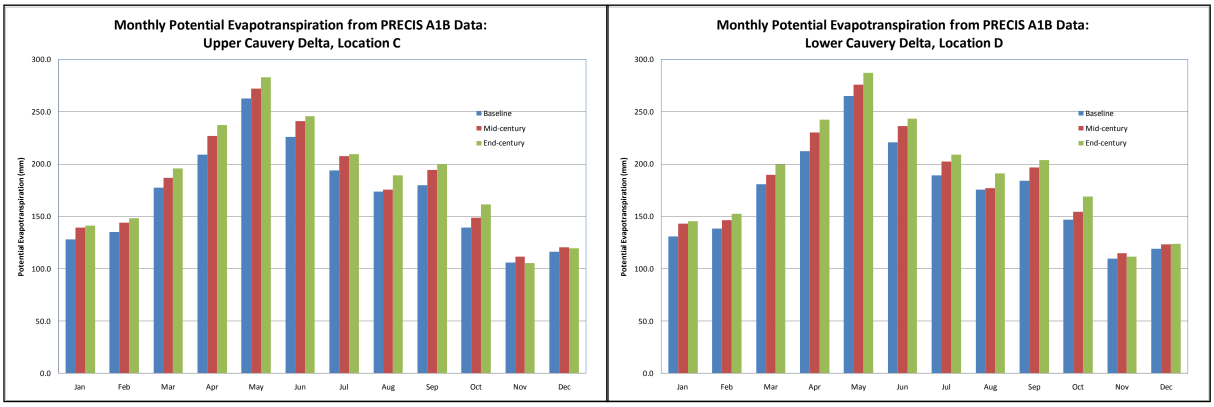
3. Potential Evapotranspiration

231.   Potential evapotranspiration has been calculated for locations C and D in the Cauvery Delta, using parameters simulated by PRECIS for the A1B scenario. A summary of change in annual potential evapotranspiration is given in Table 6 below. Mean monthly potential evapotranspiration for the baseline, mid-century and end-century are shown in Figure 64.   Potential evapotranspiration increases by about 100 mm by mid-century and by 200 mm be the end of the century. There is very little difference in potential evapotranpiration calculated at these two locations. The increases in potential evapotranspiration will be offset by increased precipitation in the delta under the climate change scenario considered.

Table 26 Changes in annual potential evapotranspiration from PRECIS A1B scenario in

	ETo (mm)		
Location	Baseline	Mid-century	End-century
Upper Delta (C)	2047	2168	2236
Lower Delta (D)	2073	2189	2278

Figure 64 Potential Evapotranspiraton Calculated from PRECIS A1B Scenario



G. Sea Level Rise

232. The Cauvery Delta is vulnerable to the effect of rising seas levels as a result of climate change. Rising sea levels pose a number of threats including coastal erosion, increased wave energy, salinity ingress to drainage channels and saline intrusion to groundwater. The coastline was badly affected by the 2004 tsunami. There are no available records with which to check historic rates of sea level rise in the delta. Tidal records are available at Chennai, dating from 1916. The record is not complete and there are many periods of missing record. Nevertheless a regression analysis was carried out on mean monthly sea levels at Chennai. This indicated a rate of sea level rise of about 0.3 mm/year.

233. The Indian Network for Climate Change Assessment in their report "Climate Change and India: A 4 × 4 Assessment" (INCCA, 2010), reported results of several studies of historic sea level rise along the Indian coastline. They presented results for four stations. Vishakhapatanam , situated between Chennai and Kolkata, had a trend of 0.70 mm/year. To this was added a glacial isostatic adjustment of -0.39 mm/year, resulting in net sea level rise of 1.09 mm/year. There is an indication of uplift throughout the Indian coastline

234. The IPCC AR4 give a global mean sea level rise for the period 1963 to 2003 of 1.8 ± 0.5 mm/year, and for the period 1993 to 2003 of 3.1 ± 0.7 mm/year. AR4 also indicates that sea level rise does vary regionally and that in the western Indian Ocean, sea levels have been falling. The available data do indicate that sea level rise along the Tamil Nadu coast will not be as significant as experienced elsewhere, and may be below the forecast changes in global mean sea level. There is an indication of geological uplift along the coast, but in the Cauvery delta this may be counteracted by local subsidence of alluvial deposits that no longer get replenished with a silt load from fluvial floods (much of the silt load will now be trapped in upstream reservoirs). There is at present no reference data against which to assess the possibility of settlement.

235. The IPCC present in AR4 the 5% to 95% probability ranges of sea level rise for six emissions scenarios. These are given below for the end of the century, and are based on the results of a range of AOGCM results. The maximum forecast rise is about 0.59 m as estimated in Table 27.

Table 27 Estimated Sea Level Rise

	Sea Level Rise in m (5% and 95% range) to end century					
Scenario	B1	B2	A1B	A1T	A2	A1F
Rise (m)	0.18 - 0.38	0.20 - 0.43	0.21 - 0.48	0.20 - 0.45	0.23 - 0.51	0.26 - 0.59

Source: Meehl et al., 2007, IPCC WG1

236. In the INCCA 2010 report it is suggested that in the absence of available regional projections, global projections can be used as a first approximation of sea level rise along the Indian coasts. There is debate about uncertainties in sea level rise projections, and some researchers suggest that the AR4 projections may underestimate the potential increases. A recent report by Bayravan et al. entitled "Sea Level Rise: impact on major infrastructure, ecosystems, and land along the Tamil Nadu coast", cited a number of sources that considered AR4 to underestimate future sea level rise, and adopted a rise by mid-century of 1 m. This is a significant contrast with an upper envelope value of 0.3 m that might be inferred from AR4.

237. The Cauvery delta does experience occasional cyclonic events, but those producing significant storm surge most frequently find landfall in the northwest of Bay of Bengal. The INCCA 2010 report considered projected changes in cyclonic activity and storm surge under present and future climate scenarios. There is evidence of a decreasing trend of cyclonic storm activity in the Bay of Bengal. They did, however, report forecasts of increased storm surge heights north of Visakhapatnam of 15 - 20% for a 100 year event. The increase in storm surge heights is greater in regions with a lower tidal range.

238. In adaptation design for sea level rise in the Cauvery delta, it is considered prudent at this time to design, in the short to medium term, on the basis of the IPCC AR4 upper envelope projections (i.e. 0.3 m by mid-century), but to adopt design approaches that can easily be adapted as projections of future global sea level rise improve, and as better information becomes available on the actual situation of relative sea level rise in the Cauvery delta.

H. Cyclones

239. Of special concern is the strengthening of cyclones, a trend of which has already been observed in the Bay of Bengal, especially during November. A WMO sponsored group of experts (TCP) have concluded that while under climate change the overall frequency of tropical cyclones may decrease slightly, there is actually an increase in the number of most severe cyclones to be expected [Knutson, 2010]: "*future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100. Existing modelling studies also consistently project decreases in the globally averaged frequency of tropical cyclones, by 6–34%. Balanced against this, higher resolution modelling studies typically project substantial increases in the frequency of the most intense cyclones, and increases of the order of 20% in the precipitation rate within 100 km of the storm centre. For all cyclone parameters, projected changes for individual basins show large variations between different modelling studies.*"

I. Water Resources

1. Hydrological Simulation Studies

240. Evaluating the potential impacts of climate change on water resources requires the application of hydrological simulation modelling techniques, driven by scenarios of changes in precipitation and potential evapotranspiration derived from global and regional climate modelling studies. As indicated above, precipitation is one of the least well represented processes in climate models at present, and the uncertainty in projections of climate change impacts on water resources is therefore high. Current practice is to try and use a range of different climate models, to create an ensemble of possible futures through which an appreciation of uncertainty can be gained, and the robustness of adaptation responses evaluated. If the near future (2030s) is the main focus, the model projections are largely independent of the emission scenarios, as the changes are mainly due to historical emissions and the slow response of the Earth's climate system. However, inter-model uncertainty should be considered

241. The SWAT model was used with climate simulations from the A1B emissions scenario from PRECIS. The model was set up with the IMD 0.5^o precipitation and temperature data, as well as the PRECIS data.

2. Background to the SWAT Model

242. The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998[21], Neitsch et al., 2002[22]) is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the hydrological response of un-gauged catchments to natural inputs as well as the manmade interventions. Water and sediment yields can be assessed as well as water quality. The model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration and therefore can be used on un-gauged watersheds (in fact the usual situation).

243. The SWAT model is a long-term, continuous model for watershed simulation. It operates on a daily time step and is designed to predict the impact of land management practices on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial details by allowing the watershed to be divided into a large number of sub-watersheds. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. The model has been validated for several watersheds.

244. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into unique soil/land-use characteristics called hydrologic response units (HRUs). The water balance of each HRU in SWAT is represented by four storage volumes: snow, soil profile (0-2m), shallow aquifer (typically 2-20m), and deep aquifer (>20m). Flow generation, sediment yield, and non-point-source loadings from each HRU in a sub-watershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Hydrologic processes are based on the following water balance equation:

$$SW_t = SW + \sum_{i=1}^{t}(R_{it} - Q_i - ET_i - P_i - QR_i)$$

where SW is the soil water content minus the wilting-point water content, and R, Q, ET, P, and QR are the daily amounts (in mm) of precipitation, runoff, evapotranspiration, percolation, and groundwater flow, respectively. The soil profile is subdivided into multiple layers that support soil water processes, including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a storage routing technique to predict flow through each soil layer in the root zone. Downward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer. If the temperature in a particular layer is 0ºC or below, no percolation is allowed from that layer. Lateral subsurface flow in the soil profile is calculated simultaneously with percolation. The contribution of groundwater flow to the total stream flow is simulated by routing a shallow aquifer storage component to the stream (Arnold, Allen, and Bernhardt 1993[23]).

245. SWAT also simulates the nutrient dynamics. Sediment yield is calculated based on the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975[24]). The movement of nutrients, i.e. nitrogen

[21] Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. 1998. Large-area hydrologic modeling and assessment: Part I. Model development. J. American Water Res. Assoc. 34(1): 73-89

[22] Neitsch, S. L., J. G. Arnold, J. R. Kiniry, J. R. Williams, and K. W. King. 2002a. Soil and Water Assessment Tool - Theoretical Documentation (version 2000). Temple, Texas: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station.

[23] Arnold, J.G., Allen, P.M, and Bernhardt, G.T. 1993. A comprehensive surface groundwater flow model. Journal of Hydrology, 142: 47-69

[24] Williams, J.R. 1975. Sediment routing for agricultural watersheds. Water Resources Bulletin, 11 (5): 965-974.

and phosphorus is based on built in equations for their transformation from one form to the other. The total amounts of nitrates in runoff and subsurface flow is calculated from the volume of water in each pathway with the average concentration. Phosphorus however is assumed to be a relatively less mobile nutrient, with only the top 10 mm of soil considered in estimating the amount of soluble P removed in runoff. A loading function is used to estimate the phosphorus load bound to sediments (McElroy et al, 1976[25]). SWAT calculates the amount of algae, dissolved oxygen and carbonaceous biological oxygen demand (CBOD - the amount of oxygen required to decompose the organic matter transported in surface runoff) entering the main channel with surface runoff. CBOD loading function is based on a relationship given by Thomann and Mueller (1987)[26]

246. The SWAT model possesses most of the attributes which are identified to be the desirable attributes that a hydrological model should possess. The SWAT model is a spatially distributed physically based model. It requires site specific information about weather, soil properties, topography, vegetation, and the land management practices being followed in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modelled by SWAT using these input data. This approach results in major advantages, such as:

- Un-gauged watersheds with no monitoring data (e.g. stream gauge data) can be successfully modelled.
- The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, etc.) on water quantity, quality or other variables of interest can be quantified.
- The model uses readily available inputs. The minimum data required to make a SWAT run are the commonly available data from local government agencies.
- The model is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money.
- The model enables users to study impacts on account of human interventions which makes it very suitable for scenario generation.
- The model is also capable of incorporating the climate change conditions to quantify the impacts of change.
- The model has gained a wide global acceptability. Currently 720 peer reviewed papers have been published based on the SWAT model (http://swatmodel.tamu.edu). The current rate of publication is about 120 peer reviewed papers per year. There are more than 90 countries using the model for practical applications and at the least, more than 200 graduate students all over the world are using it as part of their M.S. or Ph.D. research program. In the U.S alone, more than 25 universities have adapted the model in graduate level teaching classes.
- SWAT is a public domain model actively supported by the Grassland, Soil and Water Research Laboratory (Temple, TX, USA) of the USDA Agricultural Research Service.

3. SWAT Model Setup

247. Spatial data and the source of data required for the study area include:

- Digital Elevation Model: SRTM, of 90 m resolution[27]
- Drainage Network – Hydroshed[28]
- Soil maps and associated soil characteristics (source: FAO Global soil)[29]

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[25] McElroy, A.D., Chiu, S.Y. and Nebgen, J.W. 1976. Loading functions for assessment of water pollution from nonpoint sources. EPA document 600/2-76-151, USEPA, Athens, GA
[26] Thomann, R.V. and J.A. Mueller. 1987. Principles of surface water quality modelling and control. Harper & Row Publishers, New York
[27] http://srtm.csi.cgiar.org
[28] http://hydrosheds.cr.usgs.gov/
[29] http://www.lib.berkeley.edu/EART/fao.html

- Land use: Global Map of Land Use/Land Cover Areas (GMLULCA), IWMI's Global Map of Irrigated Areas (GMIA) (source: IWMI) [30]

248. The Hydro-Meteorological data pertaining to the river basin is required for modelling the catchment. These include daily rainfall, maximum and minimum temperature, solar radiation, relative humidity and wind speed. These Weather data were available as per following details

- IMD gridded weather data (1971–2004) – 5 years of weather data was used as warmup/setup period for the Cauvery basin model thus outputs were available from 1976 to 2004
- Climate Change: PRECIS Regional Climate Model outputs for Baseline (1961–1990, BL) , near term (2021-2050, MC) and long term or end-century (2071-2098, EC) for A1B IPCC SRES scenario[31] (Q14 QUMP ensemble)

Water demand and abstraction data

- Current management/operation practices, existing irrigation as per crop demand. *Note: Current crop management practices include irrigation sources from Surface and Ground water*

249. **Mapping the Cauvery System**: The ArcSWAT (Winchell et al., 2007[32]) interface was used to pre-process the spatial data for the Cauvery river system. A brief description of the steps undertaken for pre-processing is given below. The DEM from the SRTM that has been used for generating the Cauvery basin catchment boundaries and topographic characteristics is shown in Figure 65. The topographic statistics of elevation of the Cauvery River basin is given in Table 28

Table 28 Elevation Summary – Cauvery Basin

Parameter	Elevation (m)
Minimum Elevation	-20
Maximum Elevation	2629
Mean Elevation	570

250. **Basin Delineation – Cauvery Basin**: automatic delineation of watersheds uses the DEM as input, with a target outflow point selected interactively. The Cauvery river basin has been delineated using 1,000 ha as minimum stream threshold resulting in 73 sub-basins. These sub-basins are shown in Figure 66. The basin area of the Cauvery up to the basin outflow point is 8,471 km^2. Care was taken to incorporate the locations of stream gauge measurement locations while undertaking the delineation process

[30] http://www.iwmigiam.org/info/main/index.asp
[31] http://www.tropmet.res.in/static_page.php?page_id=51
[32] Winchell, M., Srinivasan, R., Di Luzio, M., Arnold, J., 2007. ArcSWAT interface for SWAT2005. User's Guide. BRC, TAES, USDA-ARS, Temple, TX

Figure 65 Digital Elevation Model of Cauvery Basin

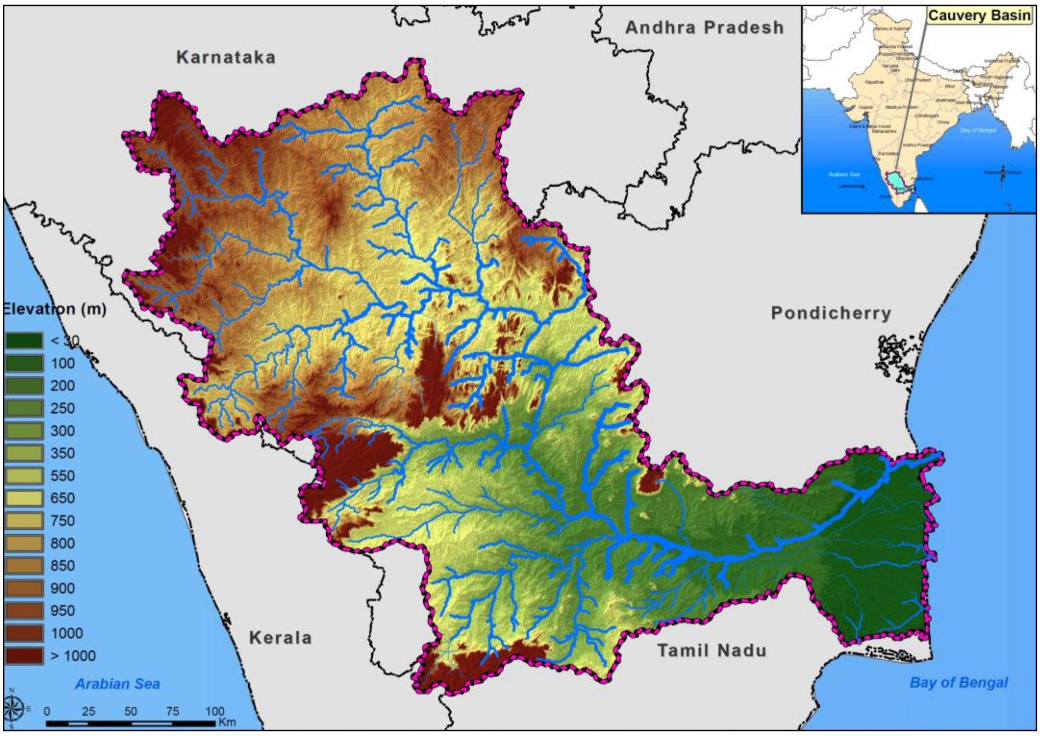
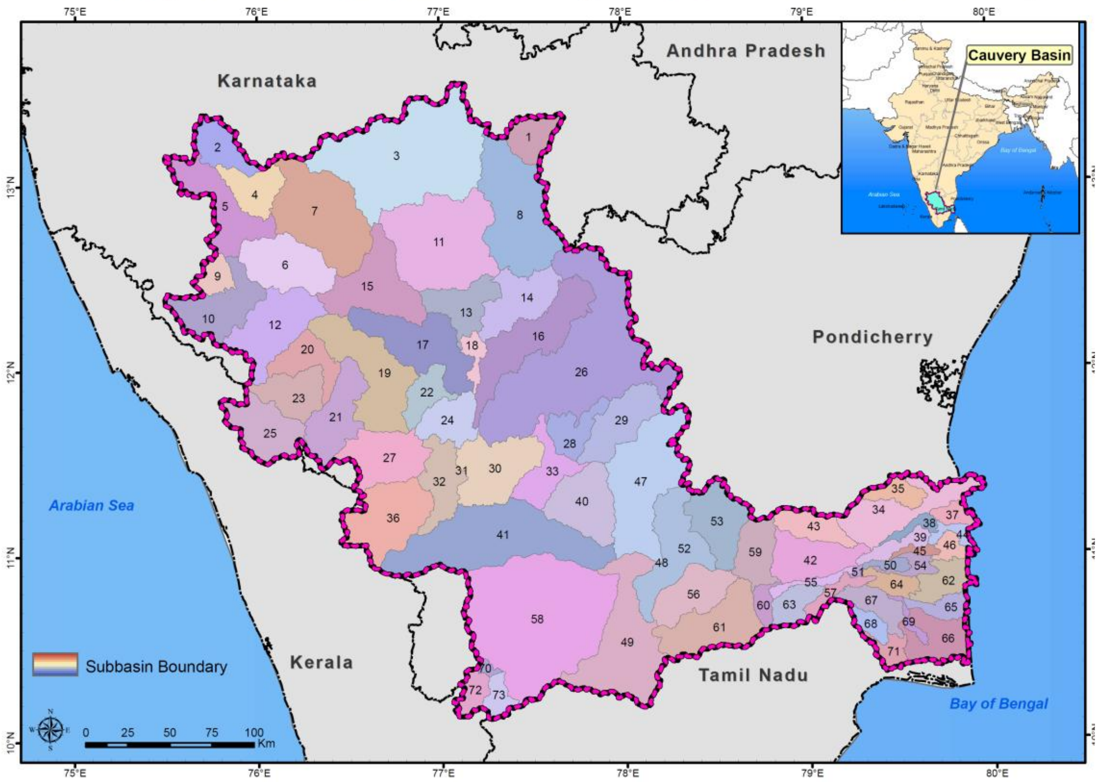


Figure 66 Sub Basin delineation using DEM



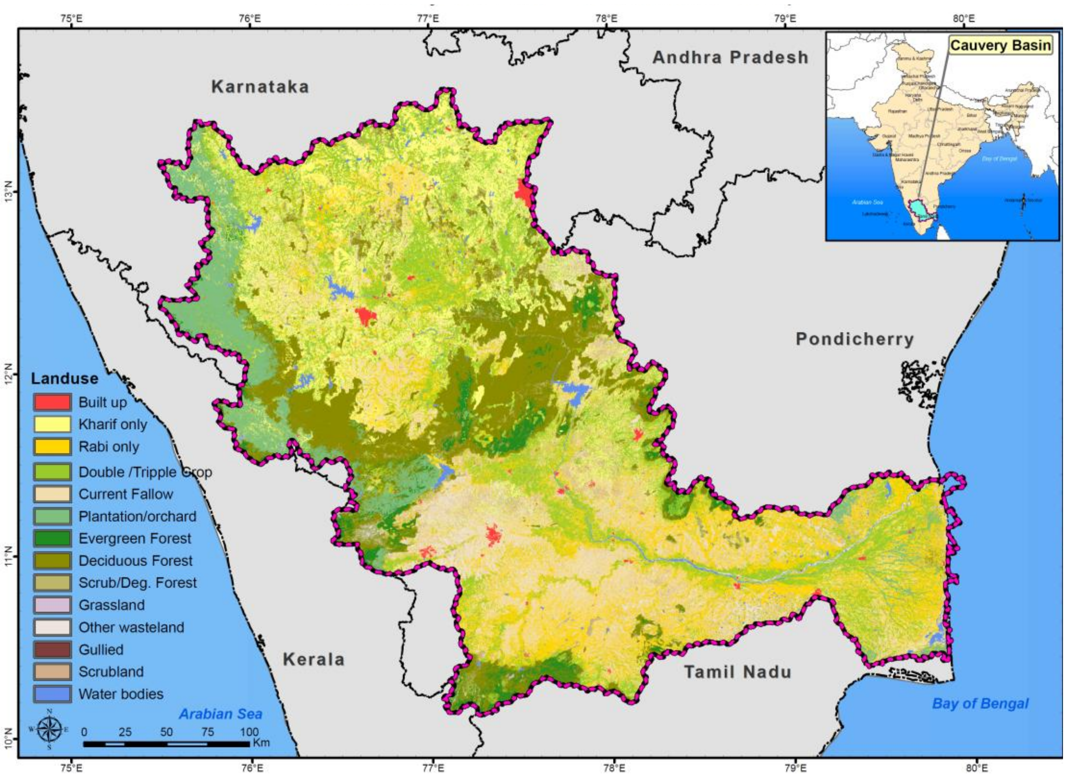
251. **Land Cover/Land Use Layer – Cauvery Basin**: Land Use/Land Cover is another important segment of data that is required for pre-processing. The merged landuse and irrigation source map

from NRSC[33], as shown in Figure 67, was used. Table 29 gives the land use categories and the area covered under each category of land use for the Cauvery basin. The major part of the basin is under agriculture land use, and rice is the predominant crop.

Table 29 Landuse Categories – Cauvery Basin

Land Use	Area (ha)	% of Watershed Area
Rice	4217384	49.8
Lentils	1346269	15.9
Forest-Evergreen	258917	3.1
Forest-Deciduous	1240628	14.7
Forest-Mixed	409069	4.8
Orchard	580835	6.9
Water	134117	1.6
Residential	40698	0.5
Industrial	233287	2.8
Pasture	9898	0.1

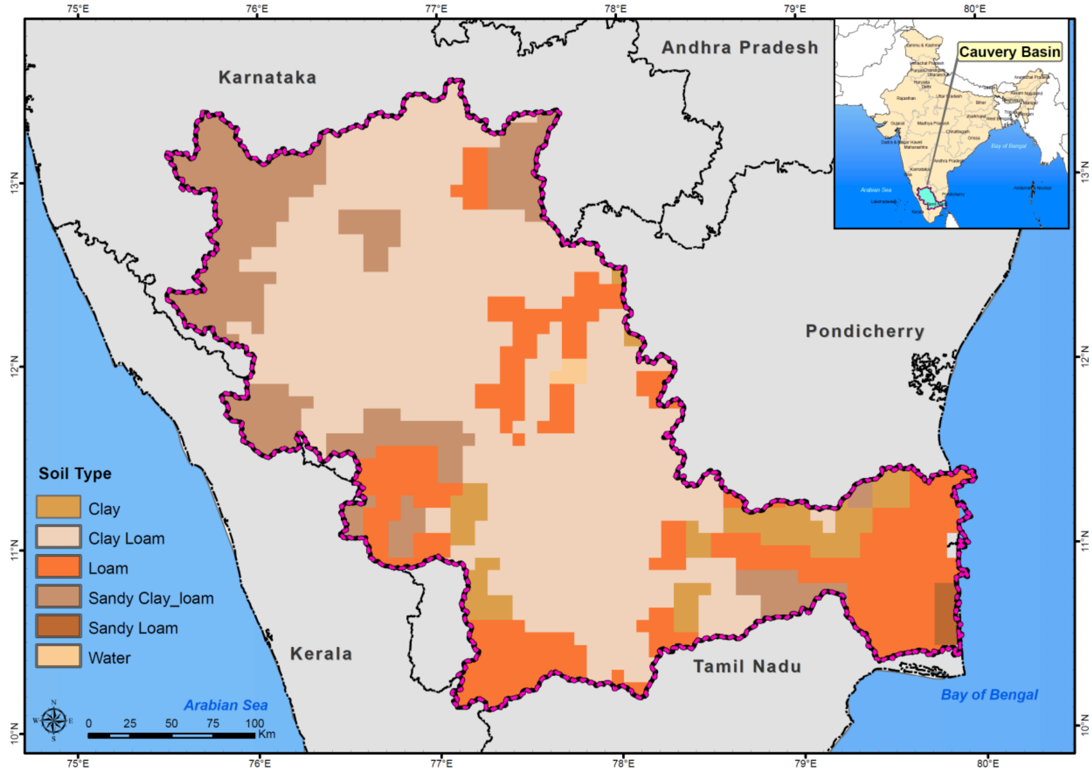
Figure 67 Cauvery Basin – Land use map



252. **Soil Layer – Cauvery Basin**: Information on the soil profile is also required for simulating the hydrological character of the basin. In the absence of high resolution soil data, the FAO global soil map has been used for the modelling of the Cauvery basin (Figure 68). The soil is predominantly clay loam.

[33] BHOOSAMPADA - An Information Portal of ISRO http://applications.nrsc.gov.in/products.asp

Figure 68 Cauvery Basin – Soil map



4. SWAT Model Performance for Cauvery Basin

253. The model was not calibrated due to the presence of large number of upstream impoundments (reservoirs, dams and diversions). However, a performance evaluation of SWAT hydrologic budget has been made using the observed data for the period 1976-2004 at monthly scale. For this purpose data from 5 stream flow monitoring stations (Figure 69) were used.

254. Before performing statistical comparison of streamflows, the reasonableness of the model for general evapotranspiration, runoff, base flow/return flow, and crop yields against district averages were analyzed and found satisfactory. The SWAT model results and time series plots are presented in Table 30, Figure 70 and Figure 71 for each observation stream flow station.

255. The long-term simulated mean monthly flows are over simulated. This is mainly because reservoirs, diversions and irrigation water use were not included. This simulation can be considered as virgin flow. PBIAS measures the average tendency of simulated data to be larger or smaller than the observed discharge. Positive values indicate model overestimation bias. It is evident from Table 31 that all the gauges show over simulation because of the upstream storage project and water use. However, the trend (R^2) is very well simulated. Inclusion of all reservoirs and diversions within the Cauvery basin in the SWAT model would further improve monthly streamflow simulations, but is a major undertaking that was beyond the resources of this project.

Figure 69 Cauvery Basin – Observed Stream gauge locations

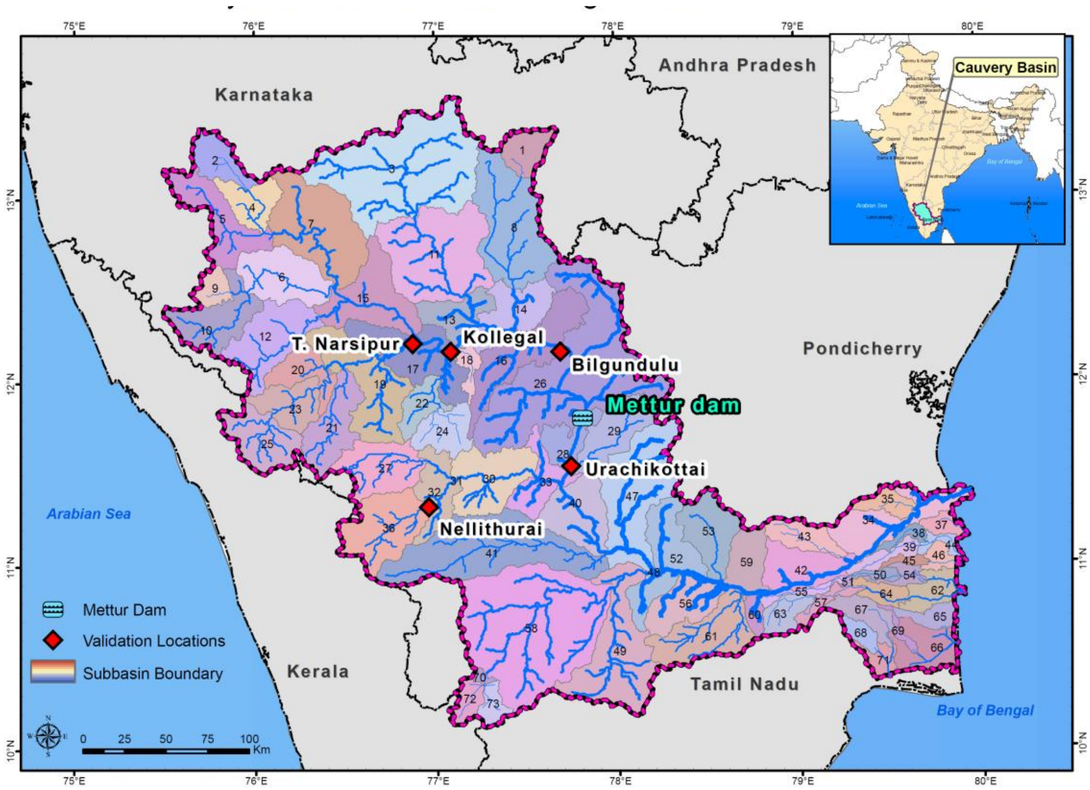


Table 30 SWAT output comparison Locations and model efficiency parameters for the Cauvery Basin

Gauge Site	Catchment Area*(Sq km)	Mean Flow*	Start Year	End Year	COE**	Correlation coefficient	Area Difference (%)	Flow Difference (%) PBIAS
Kollegal	21082 (21744)	178.49 (233.95)	1976	2004	0.29	0.67	3.1	31.1
Biligundlu	36682 (37410)	220.4 (363.73)	1976	2004	-0.7	0.63	2.0	65.0
Urachikottai	44100 (44801)	232.15 (427.79)	1976	2004	-2.02	0.57	1.6	84.3
Nellithurai	1475 (1749)	44.62 (56.48)	1976	2004	-0.79	0.77	18.6	26.6
T Narsipur	7000 (6290)	90.32 (95.79)	1976	2004	0.56	0.77	-10.1	6.1

* Model value is shown in bracket, ** Nash-Sutcliffe coefficient

Figure 70 Cauvery Basin – SWAT output comparison

Cauvery Basin – SWAT output comparison Locations and model efficiency parameters at Biligundlu (Upstream of Mettur dam)

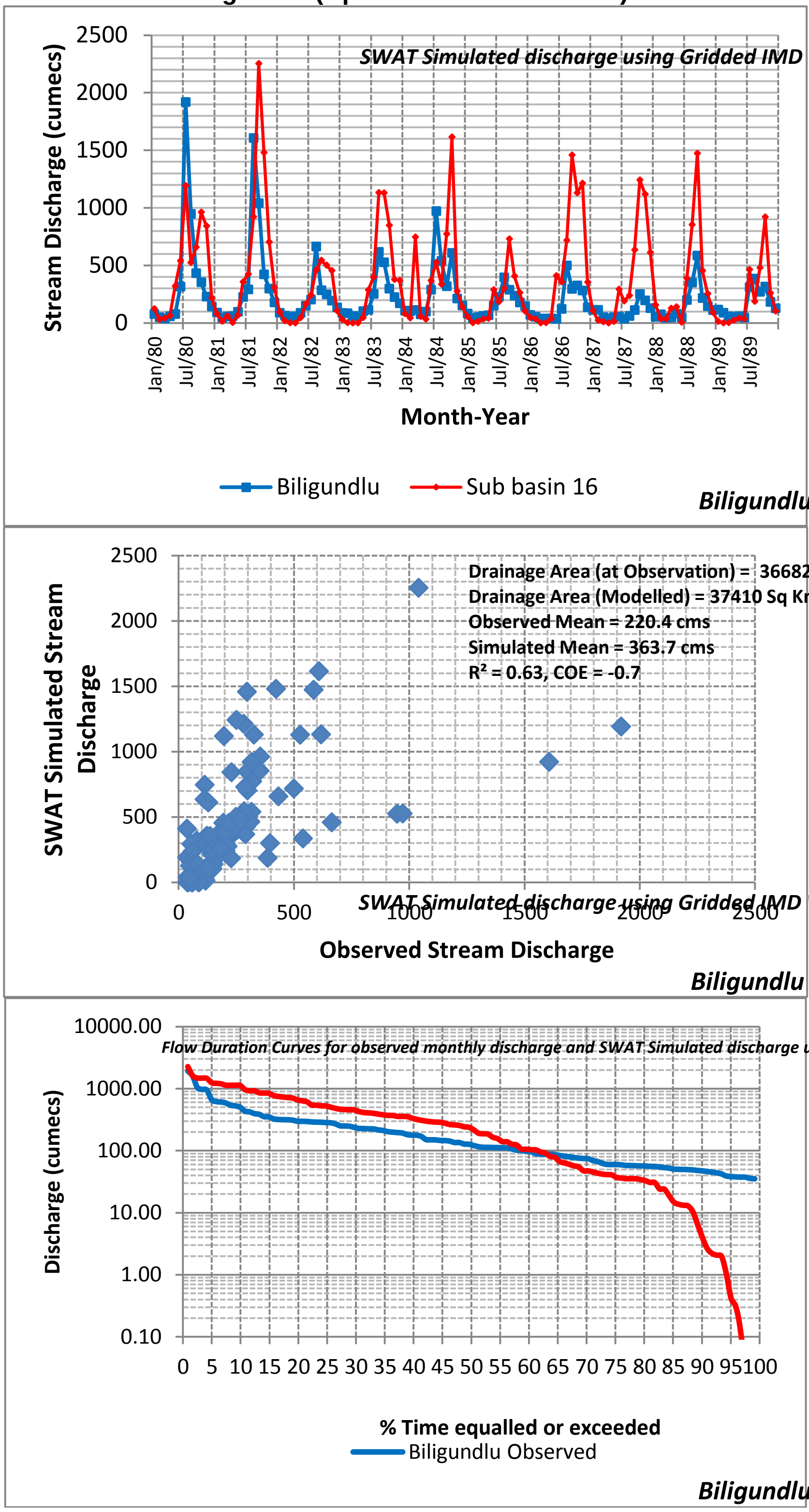
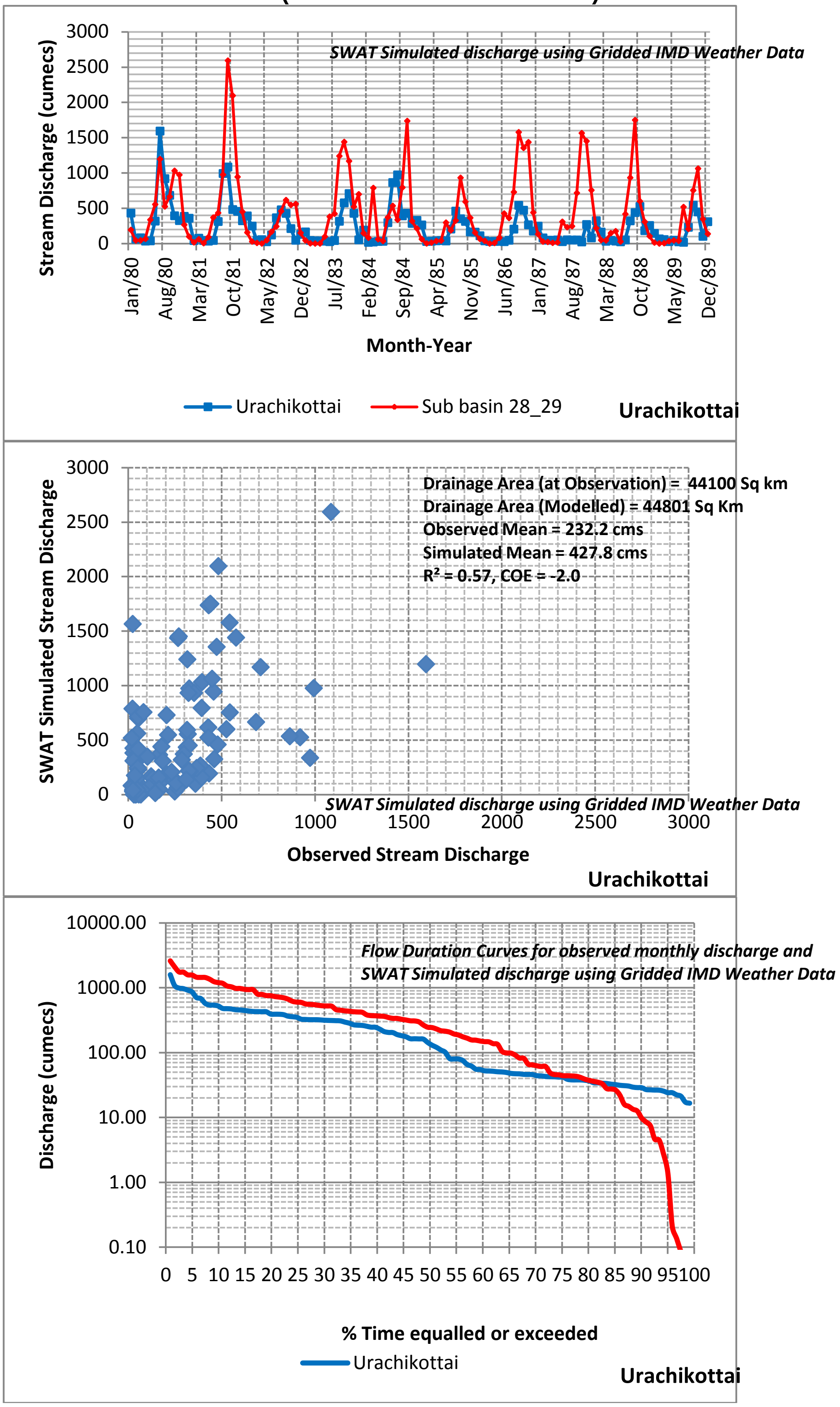


Figure 71 Cauvery Basin Swat Output

Cauvery Basin – SWAT output comparison Locations and model efficiency parameters at Urachikottai (Downstream of Mettur dam)

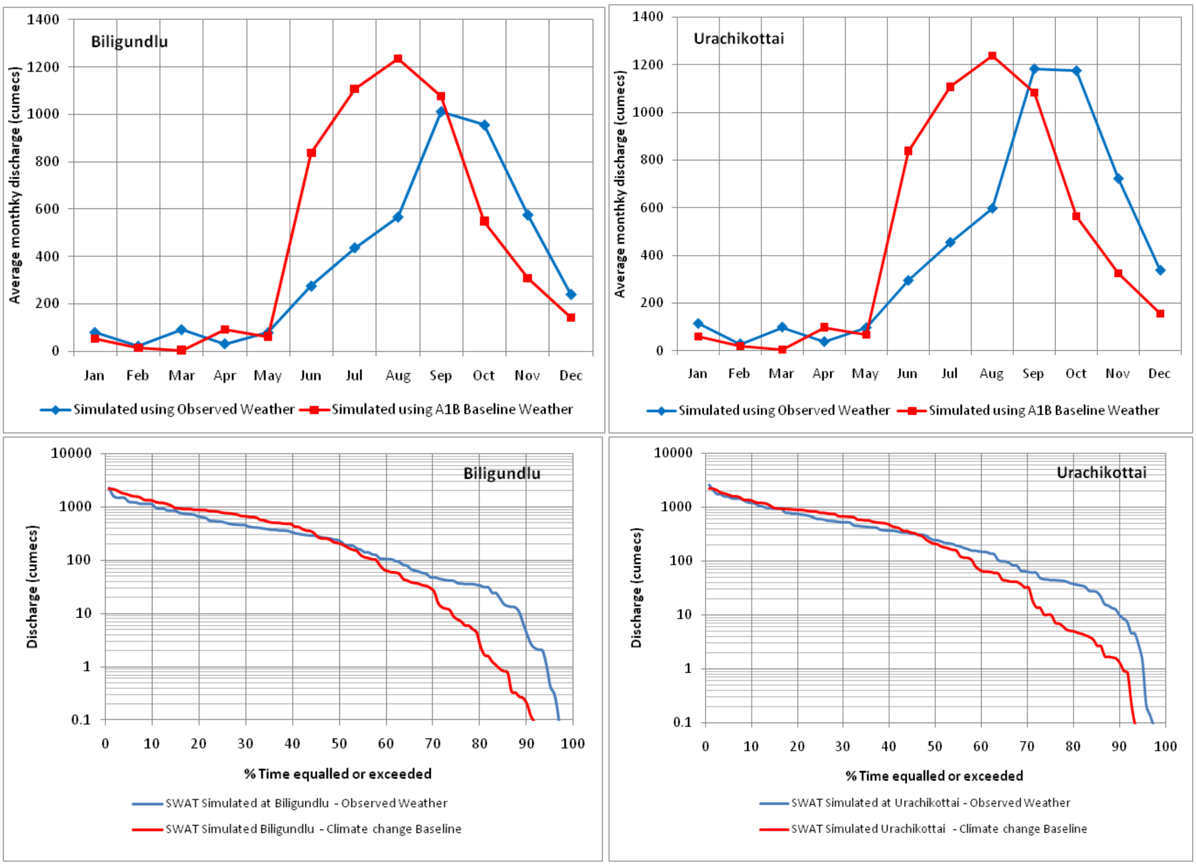


5. Modelling Climate Change Impacts on Hydrological Response

256. **Simulation with A1B baseline**: Prior to analysis of climate change scenarios, and assessment was made how well the characteristics of SWAT streamflows simulated from the PRECIS A1B

baseline weather, matched with those simulated from observed weather. Mean monthly flows simulated using observed weather and A1B scenario baseline are compared at Biligundlu (upstream of Mettur dam) and Urachikottai (downstream of Mettur Dam) for the simulated discharges. Results are presented in Figure 72. With PRECIS simulated weather the seasonal timing of runoff is poorly represented, and the annual volume of runoff over-estimated. The issues with PRECIS precipitation simulation in the Cauvery basin have been discussed earlier, and clearly influence the simulated hydrological response significantly. The indication is that even comparative analysis of climate change impacts should be treated cautiously.

Figure 72 Cauvery Basin – SWAT simulated discharge comparison at Biligundlu and



Urachikottai

257. Projected changes in precipitation in the Cauvery basin have been discussed as part of the Climatic Scenario assessment of this report. The detailed outputs of the SWAT hydrological model were analysed with respect to the major water balance components of surface runoff, baseflow, actual evapotranspiration and ground water recharge. These are significantly influenced by the intensity and temporal distribution of precipitation, and by the weather conditions dictated by temperature and allied parameters.

258. **Analysis of Change in Water balance components**: The outputs have been analyzed with respect to the baseline considering possible impacts on the runoff, baseflow, actual evapotranspiration and ground water recharge to mid-century and end-century Table 31 gives the summary of changes in water balance components as percentage distribution of the change in precipitation from baseline to mid century.

Table 31 Summary of Change in water balance++ expressed as percent change in precipitation

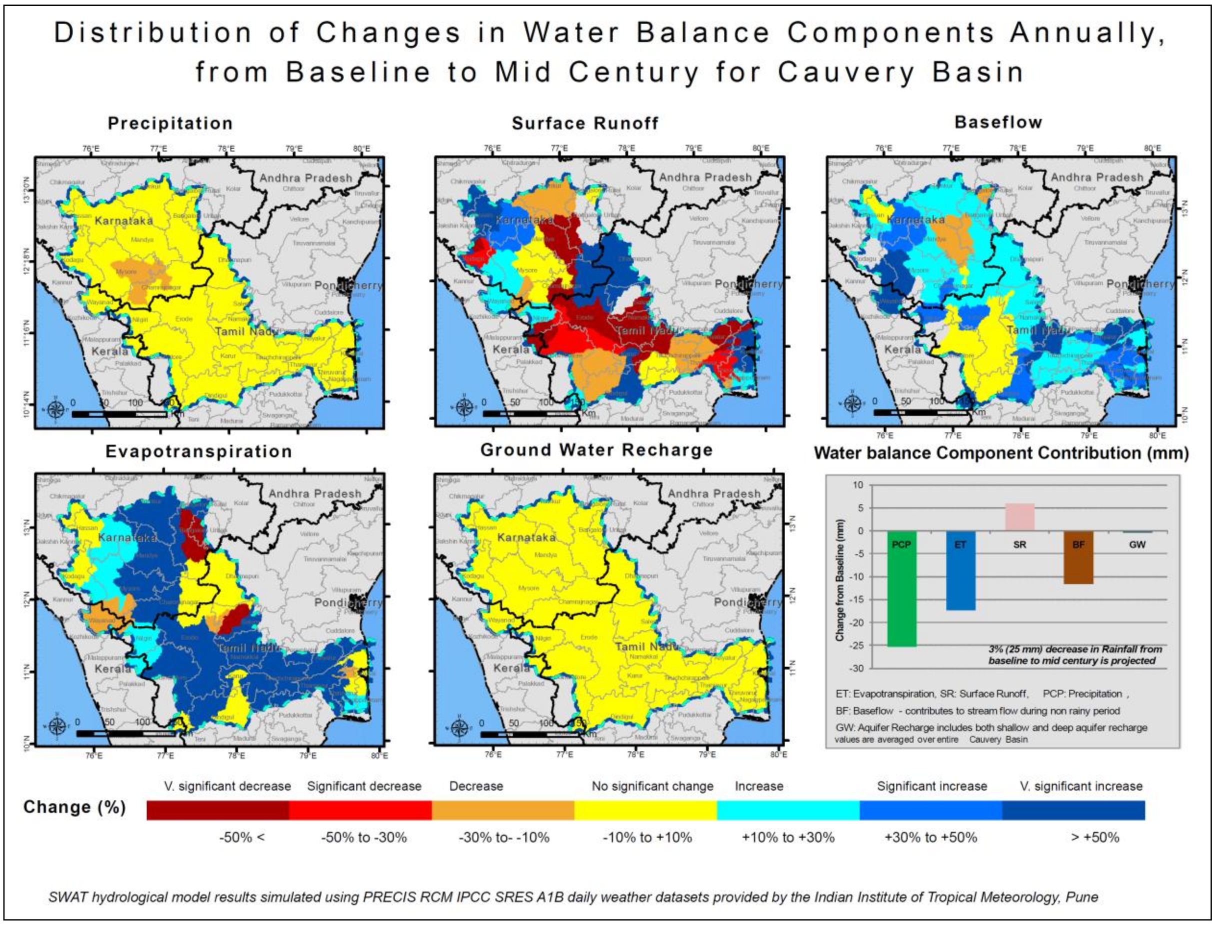
Scenario/Season	Precipitation	Evapotranspiration	Surface Runoff	Baseflow+	Total Water Yield*	Ground water Recharge**
Avg Annual (A1B-Baseline)	935	654	156	121	294	127
Avg Annual (A1B-Mid Century)	910	637	162	110	287	115
Percent Change in precipitation	-3					
Net change (mm)	-25	-17	6	-12	-7	-12
Change (%)***		68	-24	46	27	47
Avg JJAS (A1B-Baseline)	551	238	123	61	196	96
Avg JJAS (A1B-Mid Century)	517	225	123	56	190	90
Percent Change in precipitation	-6					
Net change (mm)	-34	-13	0	-5	-5	-6
Change (%)***		40	0	14	16	19
Avg OND (A1B-Baseline)	201	148	22	47	73	26
Avg OND (A1B-Mid Century)	202	149	24	42	69	21
Percent Change in precipitation	0					
Net change (mm)	1	1	2	-5	-4	-5
Change (%)***		100	200	-500	-400	-500

+: Baseflow: contributes to stream flow during non rainy period
* Water Yield (streamflow): surface runoff+baseflow+lateral flow
** Groundwater Recharge: shallow and deep aquifer recharge
***Distribution of water balance components as percentage of change in precipitation
++ All units are in millimetres

259. The PRECIS A1B scenario indicates a decrease in annual precipitation in the Cauvery basin of about 3% (about 25 mm) by mid-century. The model results indicate that the decrease in precipitation will result in decrease in actual evapotranspiration and baseflow. However, a slight increase in surface runoff is projected, and must be related to sequencing of rainfall events and intensities.

260. Figure 73 shows the distribution of changes in the major water balance components to mid-century under the A1B scenario expressed in percentage terms. The figure also shows the water balance component averaged over the entire basin and expressed as a depth (mm).

Figure 73 Change in Annual Water Balance to Mid Century



261. Projected precipitation changes vary locally in magnitude, sign, and seasonal details in the Cauvery basin. Seasonal changes in precipitation and its effect on water balance components simulated by the SWAT model for JJAS (south west monsoon) and OND (North east monsoon) are included in Table 31. It can be seen that there is a decrease in JJAS precipitation in the Cauvery basin of about 6% by mid-century. The model results indicate that the decrease in rainfall results in a decrease in all the water balance components. Baseflow, which contributes to stream flow during dry period decreases by 14%, aquifer recharge by 19%, and evapotranspiration by 13%. A marginal (0.4%) decrease in surface runoff is projected. Figure 74 shows the projected change in the seasonal water balance components expressed in percentage terms. The bar chart depicts the water balance component changes averaged over the entire basin expressed as depth (mm).

262. During the Rabi season (OND), there is negligible change in precipitation (0.3%). This results in marginal increase in actual evapotranspiration and surface runoff. The model results indicate a slight decrease in baseflow and aquifer recharge as shown in Figure 75.

Figure 74 Change in JJAS Water Balance to Mid Century

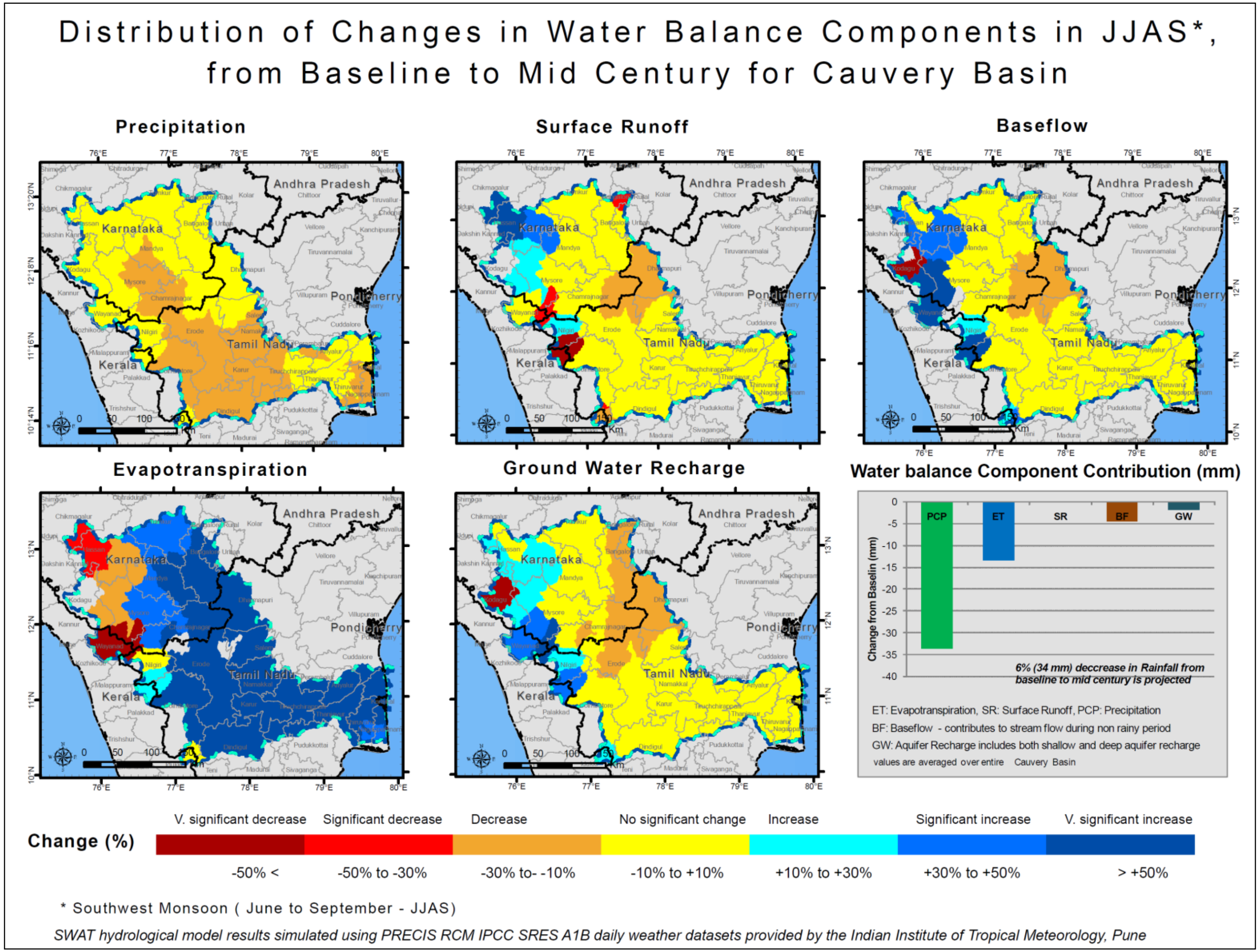
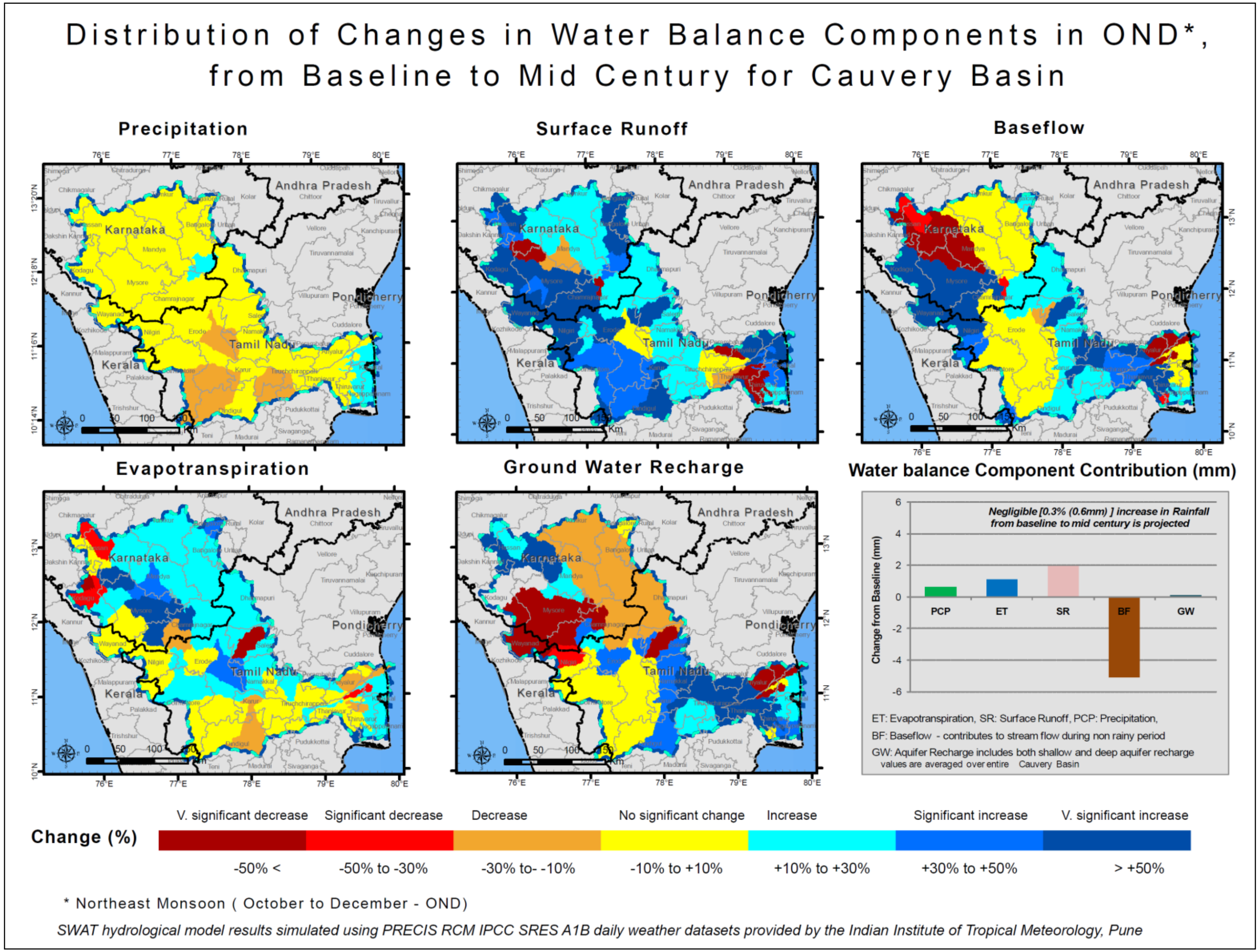


Figure 75 Change in OND Water Balance to Mid Century



263. **Drought analysis**: drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness effecting water sensitive economies. The Palmer Drought Severity Index (PDSI) is a widely used index that incorporates information on rainfall, land-use, and soil properties in a lumped manner (Palmer 1965[34]). The Palmer index categorize drought into different classes. PDSI value below 0.0 indicates the beginning of drought situation and with a value below -3.0 as severe drought condition.

264. A soil moisture index has been developed (Narasimhan and Srinivasan, 2005[35]) to monitor drought severity using SWAT output to incorporate the spatial variability. This has been used to focus on agricultural drought where severity implies cumulative water deficiency. Weekly information has been derived using daily SWAT outputs which in turn have been used for subsequent analysis of drought severity.

265. The severity of drought is proportional to the relative change in climate. For example, if a climate that usually has very nominal deviations from the normal even experiences a moderate dry period, the effects could be quite dramatic. On the other hand, a very dry period would be needed in a climate that is used to large variations to produce equally dramatic effects. In the current context scale 1 (Index between 0 to -1) represent the drought developing stage and scales 2 (Index between -1 to -4) represent mild to moderate and extreme drought conditions.

266. For this study, the Soil Moisture Deficit Index (SMDI) was calculated for 30 years of simulated soil moisture data from baseline (1961-1990), MC (2021-2050) and EC (2071-2098) climate change scenarios respectively. The spatial distribution of percentage change (baseline to mid century and baseline to end century) in drought weeks is shown in Figure 24. Weeks when the soil moisture deficit may start drought development (drought index value between 0 to -1) as well as the areas which may fall under moderate to extreme drought conditions (drought index value between -1 to -4) have been assessed.

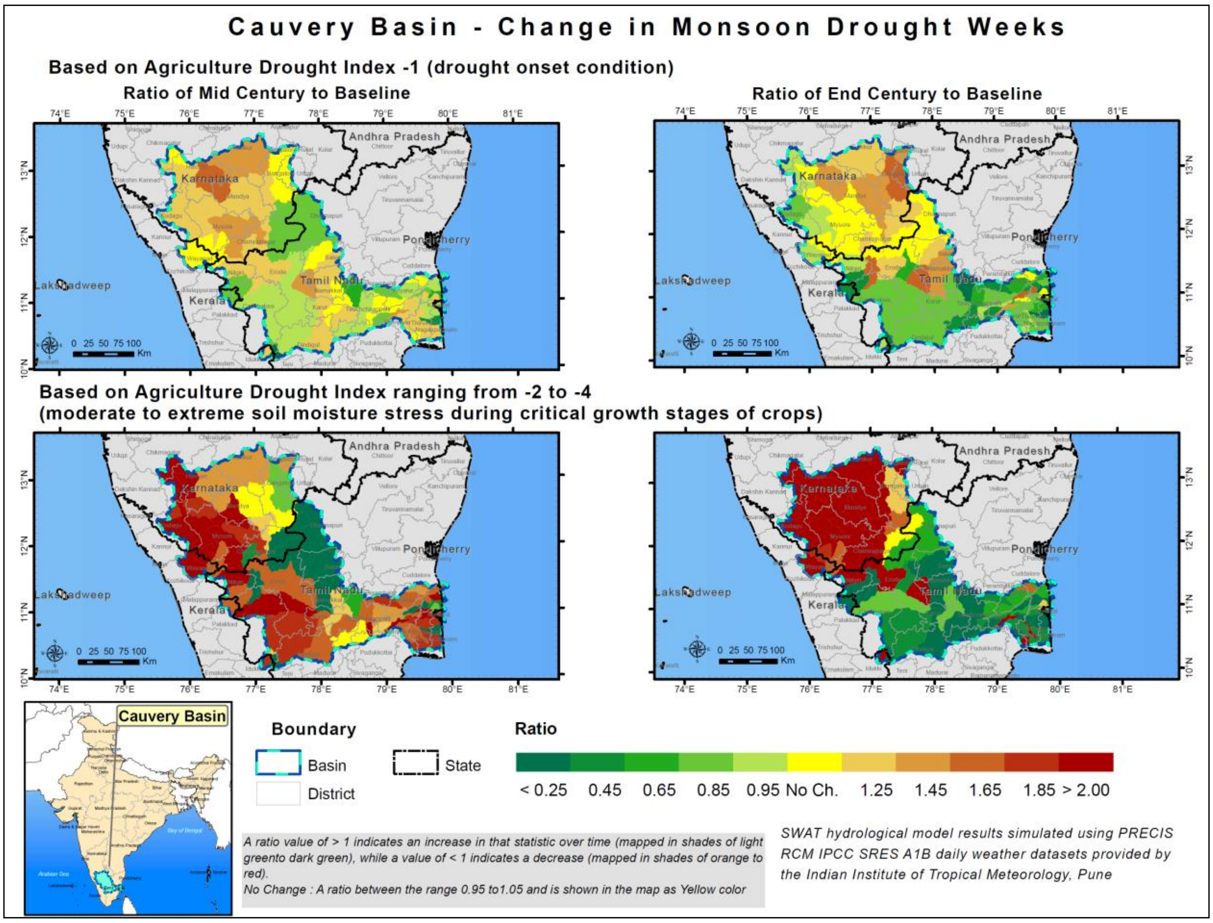
267. The concept of a drought week is reflective of the change in the normal moisture condition of a location. In this sense, if a dry or desert area is analysed which has uniform conditions over a long period, it shall declare all the weeks to be normal weeks since there is no change in the character of the area on the basis of the conditions prevalent in the specific week of the year over a long period e.g., 30 years.

268. Figure 76 shows that the number of drought developing or mild drought weeks marginally decreases for both mid-century and end century horizons relative to the baseline. However, moderate to extreme soil moisture deficit shows an increase in the northern part of Cauvery basin for both mid-century and end century horizons, reflecting greater variability in climatic conditions and more extreme extremes.

[34] Palmer, W.C., 1965. Meteorological drought. Research Paper 45. U.S. Department of Commerce, Weather Bureau, Washington, D.C. 58pp.

[35] Narasimhan, B. and Srinivasan, R., 2005. Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring, Agricultural and Forest Meteorology 133 (2005) 69–88

Figure 76 Change in Drought weeks towards 2030s and 2080s with respect to 1970s

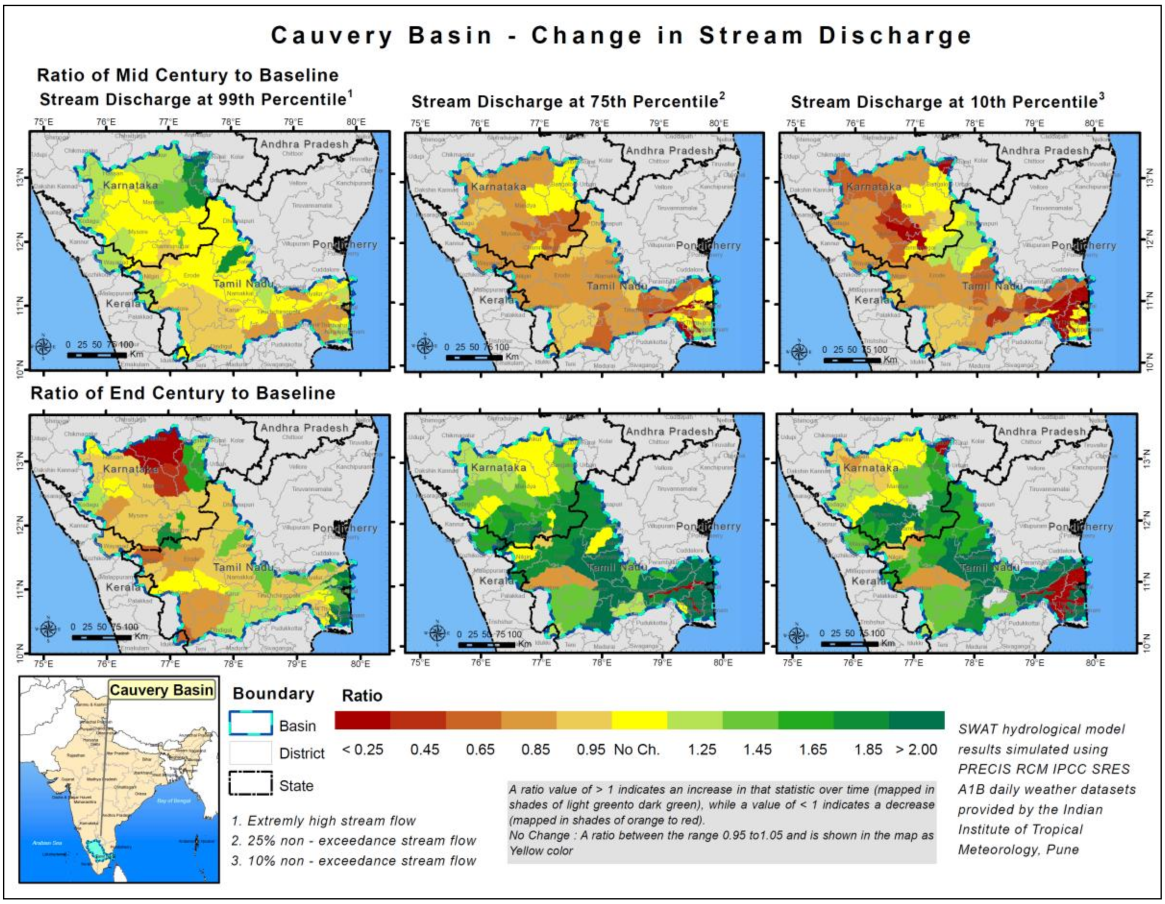


269.

270. **Flood Analysis**: the vulnerability assessment with respect to the possible future floods was carried out using the SWAT simulated daily discharges for each sub-basin. Analysis was performed to identify the basins where flooding conditions may deteriorate under the A1B climate scenario. The analysis has been performed to ascertain the change in magnitude of flood peaks 99% non-exceedance probability on the flow duration curves between the baseline (1961-1990), mid-century (2021-2050) and end-century (2071-2098) horizons. Results are shown in Figure 25. The indication is that in the majority of sub-basins there is no change to marginal increase in the flood magnitudes at mid-century. The situation changes to certain extent by end-century when a slightly larger decrease in flood magnitudes is indicated. This result is at variance with the findings in other basins, and in view of the poor performance of PRECIS in representing baseline precipitation in the Cauvery basin, should not influence any form of planning.

271. Impacts on low flows were also investigated, and included in Figure 77are changes in flows at 10% non-exceedance. There flows are either remaining similar or are slightly decreasing at the mid-century horizon and are projected to increase at the end-century horizon, under the A1B scenario.

Figure 77 Change in Flow Dependability towards 2030s and 2080s with respect to 1970s



XI. HYDRODYNAMIC AND GROUNDWATER MODELLING OF THE VENNAR SYSTEM

A. Introduction

272. As a result of upstream water resources development in the Cauvery Basin, the pattern of water availability for use in the Cauvery Delta has changed. Reduced inflows has resulted in increased groundwater use and increased saline intrusion in the coastal strip. There is also impeded drainage in some areas caused by littoral drift, beach processes blocking drainage outfalls, inadequate drain capacities and high weed growth and lack of maintenance. The situation has been aggravated by reduced surface water flows through the delta.

273. River flows in the lower reaches of the Cauvery no longer rise in response to the southwest monsoon as they did in the past. Past practice had been to plant a first rice crop in June, with irrigation from the Cauvery. There is now uncertainty about the availability of irrigation water in June, and delays in planting can mean that the crop cannot be harvested before the onset of the northeast monsoon, resulting in crop damages and losses.

274. Saline intrusion now affects a coastal strip of about 20 km. Groundwater abstraction in this area has been partially stopped, but saline intrusion may continue and increase under conditions of sea level rise. As a result of the saline conditions, crop yields in many areas are low.

275. **Drainage:** In the coastal strip there are water logging as well as salinity problems. The tidal range is low (at Chennai it is about 0.4 m on neap tines and 1.2 m on spring tides), and this in conjunction with impeded drainage outfalls results in unfavourable conditions. Keeping drainage outfalls open is a significant problem. Sea level rise will aggravate the existing drainage and salinity problems, and will have more impact on these than would be the case in an area with a larger tidal range. Sea level rise could be of the order of 0.3 m by mid-century, but might be higher.

276. It is not known the delta land mass is rising (as is the coastline at other locations), or subsiding through compaction and consolidation of sediments.

B. Requirements for Support Studies

277. The implementation of the climate change adaptation will require well coordinated activities including studies, participative planning and policy decisions, and implementation of programmes. At this stage, the plan is outline and more work is required to technically assess and define all the options before moving onto detailed programme design and implementation.

278. Subject to agreement and endorsement of the report, it would be necessary to implement a programme of follow-on studies and design of the proposed investments for the Cauvery Delta. These would be feasibility studies to verify the technical and financial viabilities of the proposals including extensive consultation and participation at all levels to ensure acceptability. Based on the outputs of the studies, it is proposed to implement some pilot projects to validate the proposals and make adjustments before embarking on up-scaling. Regular review of the strategy is proposed based on monitoring, studies and improved climate projections.

C. Proposals for Modelling of the Cauvery Delta

279. The complexities of the water systems in the Cauvery Delta requires the development of modelling systems to support planning including simulation of sea water rise, changes in precipitation in the south west and north east monsoon. Three modelling systems will be required (i) a hydrodynamic model of the surface irrigation network; and (ii) a coupled surface/groundwater model to investigate groundwater systems including groundwater response to different water management practices; and (iii) a 3 dimensional hydrodynamic model of the coastal processes including facilities to assess sediment transport. The modelling would be incorporated into a Decision Support System to review various development options for the coastal areas of the Cauvery Delta.

280. The outputs of the model would be designed to address key issues from climate change including: (i) possible approaches to arrest saline intrusion in groundwater; (ii)) development of sustainable drainage systems; (iii) optimum siting of salinity regulator structures for salinity control; (iv)

options to prevent or reduce blocking of the river outfalls to the sea; (iv) support for land use planning with special reference to operationalising of low lying non or poorly productive land; (v) options for flood control and management including dykes, flood alleviation and retentions zones; (vi) options for shoreline protection and management; and (vii) siting of freshwater abstraction points for water supply and irrigation to ensure they are out of the saline zones.

281. The modelling work will require to be implemented prior to initiating detailed design of sub projects; adequate resources and time need to be made available to carry out this work.

D. Proposal for Hydrodynamic Modelling of the Vennar System

282. It is proposed to initially focus on the Vennar system which has been identified as the most critical part of the Cauvery Delta. To set up a hydrodynamic model for the coastal part of the Vennar system of the Cauvery delta will require surveys of the canal and drainage network, establishment of a DEM of the land area and additional observations of discharge and water levels. Wherever possible existing data would be sourced and applied. The extent of the surveys and time requirements would have to be assessed. The requirements will include:

(i) Cross sectional surveys of main and canals / drains; depending upon regularity of channels, cross sections at 250 or 500 m intervals might be required in the first instance to get a model established; further refinement could be introduced in areas of particular interest or in areas in which specific issues have been identified.
(ii) Cross sectional surveys of secondary canals / drains-cross sections could be at approximately 250-500m intervals initially.
(iii) Identification of the drainage areas.
(iv) Survey of structures for inclusion in model.
(v) Land surveys; existing topographic mapping is not sufficiently accurate and establishment of a DEM of the drainage area would be required, with vertical accuracy of about 0.15m. This could be carried out using a Lidar survey but this might be prohibitively expensive; the alternative would be to survey transects using dGPS. Information is required identify knowledge of flooded areas under different scenarios of drainage improvement, sea level rise and information of flood retention;
(vi) Establishment of water level observations at key locations to permit model calibration; because of tidal influences it is recommended to use pressure transducers and data loggers, recording at15 minute intervals;
(vii) Flow measurements at selected locations through a tidal cycle, and concurrent measurements at different locations down the main canal / drain; would be useful to introduce ADCP equipment for fast and accurate measurements.
(viii) Hydrological analysis to establish precipitation and runoff / drainable surpluses at a range of return periods; this would be carrying out rainfall depth-duration-frequency analysis and setting up a simple model to produce inputs to the hydrodynamic model.
(ix) Following model calibration, running with existing drainage characteristics a selection of design rainfall events, with a range of tide boundary conditions - assess flood depth-duration-area-frequency ; model drainage improvement scenarios and assess improvements in terms of reduced flooded areas;
(x) Economic analysis to assess flood damage; for the agriculture would to have flood depth-area-duration relationships, linked to land use and probability of flooding at different stages of crop growth;

E. Groundwater Vertical Strip Modelling

283. Groundwater studies would be implemented in parallel to the surface water hydrodynamic model and would include the following features:

(i) To develop a model that represents a cross section running west to east through the delta, with sea level providing the eastern boundary; the model would have to represent salinity;
(ii) The model could be set up initially with limited available data and used to try and establish an understanding of sensitivities; the model could be developed in stages.
(iii) The model would represent recharge from rainfall and possible a western boundary, and would also represent abstraction;
(iv) There would need to be an inventory of well numbers in the study area, and an assessment of current abstraction rates; a basic water balance should be attempted to assess recharge rates; this could be done with the WEAP model.
(v) The model could be used to look at sustainable abstraction rates, as well as the influence of abstraction at different distances from the sea; the model could also be used to explore alternative recovery strategies - e.g. surface irrigation only in coastal strip;

F. Hydrodynamic Coastal Modelling

284. Hydrodynamic coastal modelling will be required to understand and define the coastal processes. This would implemented through 3 dimensional hydrodynamic model of the coastal processes including facilities to assess wave and coastal currents, littoral drift, sediment transport etc. Using modern computer models of coastal processes can provide close predictions of waves, currents and sediment movement. When adequately confirmed by field data, computer simulation models can provide an good understanding of physical processes and the cause of coastal issues; erosion, closing of river mouths etc as well assessing the appropriate measures for remediation. Scenarios of sea level rise and storm surges can be simulated to assess potential climate impacts. Assessments of the stabilities of the beaches and dunes under increased sea water levels need to be implemented.

285. The locations, requirements and scope of coastal hydrodynamic coastal modelling require to be defined based on more detailed studies of the coastal issues.

G. Indicative Scope of Work

286. It is proposed to focus the hydrodynamic and groundwater modelling initially in the Vennar system. The requirements and locations of the coastal modelling would need to be defined. The areas and length of the coastal area including the Vennar system are summarised in Table 32 below.

Table 32 Sub Basin Areas and Lengths of Rivers.

Basin Name	Area Km^2	Length of River (Km)
Vennar	2376	552
Grand Anicut - I (South of Vennar)	844	92
Cauvery (North of Vennar)	1830	229
Lower Coleroon	745	1257
Total Area	5795	2130

287. Surveys cost would be quite high due to the large area and extensive lengths of rivers and drains. Commercial survey costs based on verbal quotes are indicatively Rs75000/km2 ($1600/km2). dGPS elevation surveys points could be cheaper. Land layouts could be derived from existing maps and satellite imagery with dGPS levels at one point per km2 might cost of the order of Rs5000 ($110/km2). Cross sections surveys indicatively could cost about Rs20, 000/cross section ($440/cross section). The large area and the use of a competitive tender could likely result in lower rates.

H. Proposed Approach

288. The surveys and modelling of the coastal area of the Cauvery Delta will take time and resources. Design of sub projects in most cases will require some modelling work to be implemented

as a part of the process of the design of sub projects. It is important that simulation of climate change effects; sea level rise and changes in precipitation are incorporated into the detailed planning and design. To move the planning and design process of drainage, flood protection and tail end regulators forward it is proposed as a priority to initiate hydrodynamic modelling of the surface water systems, groundwater and coastal modelling could be taken up later.

The National Water Mission (NWM) of the National Action Plan for Climate Change in 2008 produced a broad range of recommendations towards climate adaptation for the water resources and related sectors. Parts of the NWM are now being taken up; there are however major requirements for strategy and mechanisms to implement an integrated programme for climate change adaptation for water resources. Responding to this gap, the 'Support to the National Mission TA Study' has identified core actions at the central and state levels; building on the NWM recommendations as well as meeting requirements for sustainable water resources, the study has developed proposals towards a viable and workable set of initiatives and programmes for climate change adaptation.