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Rural Water Resource Development Planning and Management Using GIS and Remote Sensing for Policy Making

K S R Murthy

Andhra University, Vishakapatnam

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RURAL WATER RESOURCES DEVELOPMENT, PLANNING AND MANAGEMENT USING GIS AND REMOTE SENSING FOR POLICY MAKING

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BY

DR. K.S.R. MURTHY PRINCIPAL INVESTIGATOR
DR. D. SRINIVAS CO-PRINCIPAL INVESTIGATOR
DR. CHARLES OMOREGIE CO-PRINCIPAL INVESTIGATOR

In Collaboration with

DR. B. RAMACHANDRA YOGI RESEARCH ASSISTANT
MR. U. SIVA RAMA KRISHNA FIELD ASSSISTANT
DR. U.N. MURTHY CONSULTANT ECONOMIST
DR. V. VENKATESWARA RAO HONORARY ADVISER

DEPARTMENT OF GEO-ENGINEERING &
RESOURCE DEVELOPMENT TECHNOLOGY
COLLEGE OF ENGINEERING
ANDHRA UNIVERSITY
VISAKHAPATNAM – 530 003
INDIA.

Preface

Water is the essence of existence of life. Human survival is primarily dependent on sufficient availability of water. Excess or scarcity of water has always lead to devastation and destruction. Water management has become more meaningful and purposeful with the technological advancements made in this field. It is time for all the scientists in the water resources and allied fields to pay their attention on the problems of water resources for the betterment of the entire humanity and the farmers in particular who form the backbone of the Indian economy. Hence an attempt has been made to evaluate the water resources potential in Srikakulam District.

This report entitled "Rural Water Resources Development, Planning and Management using Remote Sensing and GIS Techniques for Policy Making" is an attempt to study the quantity and quality of water resources, tank conditions and socio-economic aspects in improving existing tanks, and people's willingness to pay for providing irrigation water in the three watersheds namely, Peddagedda, lower Nagavali and lower Vamsadhara in Srikakulam District.

The report is organized in to six chapters. Chapter one gives detailed introduction and methodology of the study area. In Chapter two complete water balance studies starting from the rainfall to extractions has been carried out for all the three watersheds. Chapter three presents water quality in the area. In chapter four, detailed studies on tanks including cost benefit analysis have been carried out. The fifth chapter covers the analysis on willingness to pay by the farmers in the three watersheds using Contingent Valuation Method. Finally, chapter six sets out the results and discussions.

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Andhra University | K.S.R. Murthy
Department of GERDT | D. Srinivas
Visakhapatnam | Charles Omorogie

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INTRODUCTION

India is one of the few countries endowed with number of perennial rivers, adequate rainfall, and vast fertile alluvial plains. The average annual precipitation of the country is around 4000 cubic km, spread over an area of 328 million ha. of which 188 million ha. is cultivatable. The average annual water resources in various river basins are 1869 cubic km (Narasimha Murty, 1998)[i]. Out of total water resources of the country, about 690 cubic km of surface water and 450 cubic km of groundwater per year is available for irrigating about 140 million ha. of gross area per year. Irrigation potential created in the country at present is 85.0 million ha. including 31.1 million ha. from major and medium projects. The present utilization of water in the country is about 550 cubic km. (including 460 cubic km. for irrigation) which is likely go up to 1050 cubic km. (700 cubic km. for surface and 350 cubic km. from ground water) by the year 2025 A. D.(Bhagirath, 1998)[ii].

Water is an important and scarce common property natural resource for which demand is increasing day by day due to population explosion, increase in the living standards, and agriculture development. Irrigation is a technique of supplying sufficient water and reduces uncertainties associated with the irregular rainfall, and ensures cultivation of land otherwise not suited for agriculture. Adequate irrigation facilitates enable full use of the land under cultivation and increase in crop productivity due to sufficient supply of water. Keeping in view the importance of agriculture sector in the Andhra Pradesh State economy, much importance has been given in the plans for the development of irrigation.

PROBLEM

Srikakulam district is one of the backward districts of Andhra Pradesh situated between 18^0 20’ to 19^0 10’ North latitudes and 83^0 5’ to 84^0 50’ East longitudes. It is bounded on the south and west by Vizianagaram district, Orissa State on the north and on the east by Bay of Bengal. Total geographical area of the district is 5837 sq. km. The average annual rainfall of the district calculated from the data of 19 years is

1191.34 mm. The rainfall from June to October contributed by the SW monsoon accounts for 81.5% of the annual rainfall. The principal rivers in the district are Bahuda, Nagavali, Vamsadhara, Mahendratanaya, Suvarnamukhi, Vegavati, Gomukhi, and Champavathi. All the rivers are seasonal except the Vamsadhara. Agriculture is the main occupation of the people of this district and about 80% of the population depends only on agriculture for their survival. Unfortunately, there is acute shortage of water for irrigation in the district. Due to irrigation water shortage, rural people are migrating from their villages in search of other employment work to nearby towns for their existence.

OBJECTIVES

Keeping these water resource problems in view, it is proposed to study the following objectives in three watersheds of Srikakulam district.

1. To assess water resources both surface (tanks, canals etc.) and sub-surface (groundwater) and to carryout the water balance studies for effective planning and management of water resources

2. To assess the impact of water quality on human health using secondary data and to estimate the cost of treatment/providing alternate wholesome water.

3. To assess the impact of salinity on agricultural productivity using secondary data and to suggest environmentally safe and economically viable methods to improve the quality of land and crop yield.

4. To evaluate the existing tank conditions and to make a comparative analysis between the cost-benefit involved in increasing the tank capacities and exploitation of groundwater.

5. Finally, to carry out economic valuation of water by primary household surveys using “Contingent Valuation Method”

METHODOLOGY

To fulfill these objectives, the study area is divided in to three watersheds (*Watershed is a unit receiving a particular set of channels*) namely, Peddagedda watershed (PWS), Nagavali Watershed (NWS) and Vamsadhara watershed (VWS). As watershed forms an ideal unit for hydrological studies, all these objectives are intended to be explored watershed wise. The watersheds are divided on the basis of drainage pattern, stream order and the slope. The selected watersheds and mandals (*telugu word for development block*) covered are shown in Table 1.

Table 1. Name of the watershed, area, mandals covered

Watershed	Area (in sq. kms)	Mandals Covered	Rainfall (mm)
Peddagedda	435.72	Laveru and parts of Etcherla, G. Sigadam, Ponduru, Ranasthalam.	1090.50
Nagavali	1403.87	R. Amadalavalasa, S. Kaviti, Rajam and parts of Vangara, Veeraghattam, Palakonda, Seetampeta, Burja, Amd. Valasa, Srikakulam, Gara, Etcherla, Ponduru, G. Sigadam	1082.34
Vamsadhara	947.25	Jalumuru, Narasannapeta, Sarubujjili and parts of Patapatnam, Saravakota, K. Bommali, Polaki, Srikakulam, Gara, Amd. Valasa, Seetampeta, Hiramandalam, Burja.	1194.40

Surface and groundwater irrigation are only the sources of irrigation in these three watersheds. Due to water problems the farmers are slowly changing the water source and also the cropping pattern from paddy to other crops, which require less water.

WATER BALANCE

Hydrological system is a complex system that maintains balance between precipitation, interception, evaporation, transpiration, run-off, infiltration, and other sub features like seepage, soil moisture, soil retention and stocks. The physical accounting of water and individual contributions of sources in Peddagedda, Nagavali and Vamsadhara watersheds has been carried out using water balance approach. The relationships between inputs viz., rainfall, interception, evapotranspiration, run-off, groundwater recharge, and extractions and out flows are studied in water balance studies.

Secondary data regarding rainfall, temperature, irrigation pattern and other socioeconomic data were collected block-wise from different State and Central government organizations and this data has been converted into information for individual watershed. The average monthly rainfall of all the three watersheds for the year 1971 – 95 has been obtained from National Information Center (Srikakulam), and temperature, evapotranspiration, wind velocity were obtained from Indian Meteorological Department observatory at Calingapatnam, Srikakulam district, A.P. Intensive field surveys were conducted to study the tanks in the three watersheds and farmers under the tanks were interviewed using a pre-tested structure to under stand their perception on irrigation, water and other socioeconomic aspects.

Precipitation or rainfall, on which all the hydrological parameters depend is the main driver for the entire hydrological system. Immediately after precipitation takes place, it is intercepted by tree canopy cover and some of the rainfall is retained by the canopy while remaining falls on the ground. Some amount of surface water that touches the ground is stored in tanks and reservoirs and the remaining flows as run-off into the sea. The water percolated during this process is utilized partly in filling the soil moisture deficiency and part of it is percolated down which finally gets stored in the groundwater aquifer. This process of water reaching the water table is called recharge from rainfall to the aquifer and depends on various hydro-meteorological and topographic factors, viz., slope, land use/land cover, soil characteristics, temperature and depth to water table of the area. The obtained field data, secondary data and the norms given by Central Groundwater Board, Indian Agricultural Research Institute have been used for this study.

This study has been carried out for all the three watersheds in four stages starting from computation of rainfall to the total extractions for irrigation, drinking, domestic and livestock purposes. In the first phase, average annual rainfall for the years 1971 – 95 in the watersheds has been calculated, while the amount of run-off into rivers, water stored in tanks, water out flow through run-off has been calculated in the second phase. In the third phase soil penetration, seepage losses, soil retention and groundwater percolation has been calculated. Finally, in the fourth phase water extractions are calculated and water balance is arrived. The study has been carried out using the data till 1994-95 as the latest data on watershed basis from 1994-95 is not available.

This study has been carried out for all the three watersheds in four stages. In the first phase, average annual rainfall for the years 1971 – 95 in the watersheds has been calculated, while the amount of run-off into rivers, water stored in tanks, water out flow through run-off has been calculated in the second phase. In the third phase soil penetration, seepage losses, soil retention and groundwater percolation has been calculated. Finally, in the fourth phase water extractions are calculated and water balance is arrived.

Total Water Consumption and Balance

Peddagedda Watershed:

Stocks

Surface Water

Tanks : 5928.5 ha-m.

Rivers/Streams : 12278.31 ha-m.

Ground water : 13409.5 ha-m. (excluding irrigation return flow)

Extractions

Surface Water

Tanks : 3241 ha-m.

Groundwater

Tubewells & Dugwells : 2970 ha-m.

Outflow : 12278.31 ha-m.

Balance

Surface water

Tanks : 2687.50 ha-m.

Rivers/Streams : 12278.31ha-m.

Groundwater

10439.5 ha-m. + 2563 ha-m. (recharge from irrigation fields)

Nagavali Watershed:

Stocks

Surface Water

Tanks : 32392 ha-m.

Rivers/streams : 29732 ha-m.

Ground water : 41996 ha-m. (excluding irrigation return flow)

Extractions:

Surface Water

Tanks : 27745 + 263* ha-m..

Groundwater

Tubewells & Dugwells : 6580 * ha-m.. + 263*

Outflow : 29732 ha-m.

Balance :

Surface water

Tanks : 4384 ha-m.

Groundwater : 35416 + 26436 ha-m. (recharge from irrigation fields)

Vamsadhara watershed:

Stocks

Surface Water

Tanks : 22317 ha-m.

Rivers/Streams : 22692 ha-m.

Ground water : 29937 ha-m. (excluding irrigation return flow)

Extractions

Surface Water

Tanks : 18791* ha-m. + 262 ha-m.

Groundwater

Tubewells & Dugwells : 5424 ha-m.+ 262 ha-m.

Outflow : 22692 ha-m.

Balance

Surface water

Tanks : 1931.87 ha-m.

Rivers/Streams : 0.00 ha-m.

Groundwater : 24251 ha-m. + 24889 ha-m.*

(*recharge from irrigation fields)

- It is assumed that 50% of livestock consumption is from groundwater sources and 50% from surface water sources.

Table 2. Source and Crop wise Irrigated area and water Consumption in Peddagedda Watershed (1985-86)

Source	Paddy	Water Consumption	Ragi	Water Consumption	Chillies	Water Consumption	Sugarcane	Water Consumption	Groundnut	Water Consumption	Others	Water Consumption
1985-86												
Canal	1063	559	30	6	41	10	13	7	16	4	2	0
Tank	6127	3225	630	117	440	107	30	17	40	11	13	3
Tubewell	1987	1046	229	43	129	31	8	4	7	2	2	0
Otherwell	3707	1951	437	81	250	61	17	10	12	3	4	1
Othersource	336	177	10	2	13	3	1	0	5	1	1	0
Total	13219	6957	1336	249	874	212	69	39	81	21	23	5
1988-89												
Canal	1114	586	70	13	55	13	12	7	41	11	4	1
Tank	6424	3381	555	103	460	112	33	19	145	38	15	3
Tubewell	2026	1066	200	37	138	34	7	4	32	8	4	1
Otherwell	3781	1990	382	71	264	64	11	6	60	16	7	1
Othersource	357	188	23	4	18	4	4	2	14	4	1	0
Total	13701	7211	1230	229	936	227	67	38	292	77	31	6
1994-95												
Canal	920	484	72	13	67	16	38	22	76	20	0	0
Tank	4042	2127	335	62	748	182	45	25	727	191	0	0
Tubewell	1291	680	111	21	253	61	7	4	235	62	0	0
Otherwell	2410	1269	214	40	480	117	13	7	461	121	0	0
Othersource	298	157	25	5	22	5	10	6	25	7	0	0
Total	8961	4716	756	141	1570	381	113	64	1524	401	0	0

* Area in acres, consumption in Ha-m., N.A. – Not Available

Table 3. Source and Crop wise Irrigated area and water Consumption in Nagavali Watershed (1985-86)

Source	Paddy	Water Consumption	Ragi	Water Consumption	Chillies	Water Consumption	Sugarcane	Water Consumption	Groundnut	Water Consumption	Others	Water Consumption
1985-86												
Canal	62459	32873	1268	236	1088	264	4263	2416	1918	505	213	43
Tank	48427	25488	2172	405	1453	353	1796	1018	1715	451	152	31
Tubewell	3334	1755	126	23	119	29	31	18	181	48	34	7
Otherwell	6829	3594	272	51	232	56	242	137	213	56	30	6
Othersource	5837	3072	174	32	125	30	370	210	137	36	8	2
Total	126886	66782	4012	747	3016	733	6703	3799	4165	1096	438	89
1988-89												
Canal	62394	32839	1084	202	1124	273	2321	1316	2460	647	239	48
Tank	49019	25799	951	177	1409	342	1803	1022	1662	437	123	25
Tubewell	3448	1815	107	20	137	33	83	47	170	45	35	7
Otherwell	6923	3644	190	35	238	58	233	132	242	64	25	5
Othersource	6038	3178	244	45	153	37	67	38	132	35	28	6
Total	127822	67275	2576	480	3060	743	4508	2555	4666	1228	450	91
1994-95												
Canal	57343	30181	1163	217	1082	263	4538	2572	2884	759	NA	NA
Tank	37078	19515	821	153	1234	300	2613	1481	2368	623	NA	NA
Tubewell	5954	3134	134	25	159	39	424	240	324	85	NA	NA
Otherwell	7563	3980	298	55	429	104	450	255	587	154	NA	NA
Othersource	5453	2870	231	43	176	43	229	130	338	89	NA	NA
Total	113391	59679	2647	493	3080	748	8253	4678	6501	1711	NA	NA

* Area in acres, consumption in Ha-m., N.A. – Not Available

Table. 4. Source and Crop wise Irrigated area and water Consumption in Vamsahdara Watershed (1985-86)

Source	Paddy	Water Consumption	Ragi	Water Consumption	Chillies	Water Consumption	Sugarcane	Water Consumption	Groundnut	Water Consumption	Others	Water Consumption
1985-86												
Canal	66975	35250	1301	242	991	241	1252	710	4890	1287	139	28
Tank	33965	17876	483	90	418	102	667	378	1444	380	61	12
Tubewell	4821	2537	153	29	86	21	32	18	559	147	23	5
Otherwell	3999	2105	92	17	64	16	50	29	253	67	10	2
Othersource	22233	11701	233	43	138	33	242	137	2608	686	2	0
Total	131993	69470	2263	421	1697	412	2242	1271	9755	2567	236	48
1988-89												
Canal	69192	36417	3418	636	1056	256	1878	1064	2349	618	0	0
Tank	40472	21301	2511	468	603	147	819	464	785	206	0	0
Tubewell	5154	2713	252	47	68	16	53	30	209	55	0	0
Otherwell	4560	2400	251	47	86	21	86	49	155	41	0	0
Othersource	23875	12566	551	103	179	44	394	223	999	263	0	0
Total	143253	75396	6983	1301	1992	484	3229	1830	4497	1183	0	0
1994-95												
Canal	69248	36446	710	132	623	151	2360	1337	2789	734	NA	NA
Tank	26790	14100	255	48	461	112	938	532	641	169	NA	NA
Tubewell	7412	3901	83	16	79	19	401	227	308	81	NA	NA
Otherwell	2930	1542	25	5	40	10	99	56	113	30	NA	NA
Othersource	23714	12481	318	59	130	32	402	228	824	217	NA	NA
Total	130094	68470	1392	259	1333	324	4200	2380	4676	1230	NA	NA

* Area in acres, consumption in Ha-m., N.A. – Not Available

Table 5. Total annual water consumption by livestock

Peddagedda												
Year	Cattle	Water Consumption (ha-m)	Buffaloes	Water Consumption (ha-m)	Sheep	Water Consumption (ha-m)	Goat	Water Consumption (ha-m)	Pigs	Water Consumption (ha-m)	Poultry	Water Consumption (ha-m)
1985-86	32053	78.385	10700	27.338	19561	9.281	6404	3.039	656	0.407	48972	0.161
1988-89	29825	72.937	9002	23.001	19561	9.281	6405	3.039	656	0.407	48972	0.161
1994-95	30968	75.731	8646	22.090	20318	9.641	5925	2.811	1240	0.769	49376	0.162
Nagavali												
Year	Cattle		Buffaloes		Sheep		Goat		Pigs		Poultry	
1985-86	162834	398.211	58868	150.408	45153	21.425	24973	11.850	8923	5.537	319137	1.048
1988-89	144453	353.259	58367	149.127	45153	21.425	25579	12.137	9923	6.157	319137	1.048
1994-95	146230	357.605	51160	130.713	51095	24.244	23051	10.938	9269	5.751	325203	1.068
Vamsadhara												
Year	Cattle		Buffaloes		Sheep		Goat		Pigs		Poultry	
1985-86	96560	236.139	96560	246.712	32432	15.389	21173	10.047	6005	3.726	272138	0.894
1988-89	100417	245.571	48444	123.775	39387	18.689	21108	10.016	6005	3.726	272137	0.894
1994-95	100045	244.659	42069	107.485	45815	21.739	21057	9.991	5521	3.425	249307	0.819

WATER QUALITY

In this session an attempt has been made to identify and demarcate the groundwater sources with nitrate and fluoride contamination in Peddagedda, Nagavali and Vamsadhara watersheds. As there is no secondary data available for this watershed, water samples from bore wells and open wells, which are maximum used by the villagers for drinking water, were collected during November, 1999. In this area groundwater is recharged during monsoon season and from irrigation fields also. Water levels in these wells are ranging from 5 m to 8 m in pre-monsoon period and 1 m to 3 m in post-monsoon period from the ground surface. The groundwater flow is towards the main river. The chemical analysis of water samples has been carried out for the above samples and results are presented in Tables 6, 7 and 8 for Peddageda, Nagavali and Vamsadhara watersheds respectively.

From the results, it is clear that the groundwater is containing high values of either nitrate or fluoride. The water in the well near Ranasthalam village contains high values of both nitrate and fluoride. From Table 6, the nitrate concentration in groundwater ranges between 25 and 145 mg/l, while the tolerable limit is 45 mg/l, according to World Health Organization (WHO, 1984)[iii] standards. This indicates that out of fifteen samples collected and analyzed, 10 wells excess nitrate concentration. The cattle barns, which act as point sources for nitrate, were reported as main sources for high nitrate concentrations in the groundwater of Vamsadhara watershed (Srinivasa Rao, 1998)[iv]. The agricultural practices and soil conditions in Peddagedda watershed were found to be more or less similar to the Vamsadhara watershed, thus the higher concentrations of nitrate in Peddagedda are also derived from animal wastes near cattle barns.

The WHO has prescribed a drinking water standard of 1.5mg/l for fluoride. However, it depends on climatic conditions. For Indian conditions (average temperature – 27°C), the maximum limit can be taken as 0.8 mg/l. It is found that some of the villages in three watersheds contains excess fluoride. The high fluoride concentrations are attributed to the dissolution of fluoride from geological formations (eg. fluorite, fluorapatite minerals etc.). However, the phosphatic fertilisers are also contributing some fluoride to the region.

Table 6. Nitrate and Fluoride Concentration in the villages of Peddagedda Watershed

Sample No.	Village Name	Nitrate (mg/l)	Fluoride (mg/l)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
1	Uppalavalasa	65	0.55
2.	Patharlapalli	145	0.70
3.	Ranasthalam	80	2.00
4.	Bondapalli	108	0.52
5.	Punnam	87	0.60
6	Batuva	110	0.15
7.	Nimmalavalasa	37	1.80
8	Adapaka	120	0.50
9.	Kottakunkam	115	0.85
10.	Kuppili	80	0.50
11.	Budumuru	135	0.60

Table 7. Nitrate and Fluoride Concentration in the villages of Nagavali watershed

Sample No.	Village Name	Nitrate (Mg/L)	Flouride (Mg/L)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
1	Amadalavalasa	193.00	1.30
2	Mandadi	112.00	0.66
3	Vanajangi	40.00	1.90
4	Mamidivalasa	65.00	0.70
5	Niddam	80.00	1.20
6	Enduva	87.00	0.50
7	Ampolu	125.00	0.60
8	Tampatapalli	275.00	0.35
9	Buridikancharam	55.00	0.85
10	Konchada	90.00	0.10
11	Ponnada	220.00	0.45
12	Mulagalavalasa	58.00	1.20
13	Kusimi	420.00	BDL
14	Gudem	130.00	0.15
15	Singupuram	15.00	1.56
16	Tandemvalasa	8.90	1.56
17	Neelayyavalasa	75.00	0.70
18	Vangara	220.00	0.70
19	Tudi	190.00	0.45

Table 8. Nitrate and Fluoride Concentration in the villages of Vamsadhara watershed

Sample No.	Village Name	Nitrate (Mg/L)	Flouride (Mg/L)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
1	Chinabommidi	45.00	0.74
2	Chodasamudram	62.00	0.70
3	Bhairavanipeta	55.00	1.24
4	Ponnam	69.00	0.30
5	Buravalli	208.00	0.24
6	Ramachandrapuram	50.00	0.95
7	Allada	86.00	0.00
8	Chinadugam	52.00	0.55
9	Lingalapadu	71.00	0.13
10	Timadam	174.00	0.44
11	Bottadasingi	97.00	0.16
12	Dappapadu	324.00	0.64
13	Kaviti	236.00	0.23
14	Badam	75.00	0.16
15	Balaseema	163.00	0.30
16	Devadi	94.00	0.08
17	Jammu	87.00	0.45
18	Kambakaya	199.00	0.30
19	Mamidivalasa	8.60	3.40
20	Narasannapeta	58.00	0.74
21	Jillelavalasa	100.00	0.40
22	Rallagodayavalasa	0.80	1.80
23	Agraharam	0.05	1.60
24	Buridivalasa	0.66	3.50
25	Chinasalantri	0.78	3.40
26	Dakaravalasa	0.68	4.00
27	Eragam	0.00	3.20
28	Lakshmipuram	1.50	6.90
29	Peddasowlapuram	0.00	1.80
30	Purushottapuram	0.27	2.60
31	Sarubujjili	0.86	4.00

COST ESTIMATES FOR FILL-AND-DRAW DEFLUORIDATION PLANT FOR RURAL WATER SUPPLY:

The running cost of the defluoridation varies between Rs: 1.00 and Rs. 5.00 per m^3 depending upon fluoride and alkalinity of the raw water. A typical example of cost estimates for 2000 population is given below:

Population	:	2000
Water consumption	:	@40 liters/day
Total water need	:	80 M^3 per day
No. of operations of each tank per day	:	Two
No. of tanks required	:	Four
Capital cost of the plant	:	8,00,000.00

Water Quality

Fluoride Level upto	:	5.0 mg/L
Alkalinity level	:	400 mg /L

Requirement of chemical doses

Alum	:	600 mg / L
Lime	:	30 mg / L
Bleaching powder	:	5 mg / L

Total Cost per year

-	Depreciation at 5% p.a	Rs. 40000
-	Interest at 12% p.a	Rs. 96000
-	Staff	Rs. 87600
	Chemist 1 at Rs. 2500 p.m	Rs. 2500
	Helpers 4 at Rs. 1200 p.m	Rs. 4800
	Total	**Rs. 7300**

- Annual Maintenance Cost @5% Rs. 40000

Total Annual Cost Rs. 134,900

Cost per day Rs. 722.19

Chemical Cost :

- Alum consumption, 48 kg/d at Rs 7/ kg Rs. 336.00
- Lime consumption, 2.4 kg/d at Re.2.00/kg Rs. 4.80
- Bleaching powder, 0.4 kg/d at Rs. 5.50/kg Rs. 2.20

Total Chemical Cost Rs. 343.00

Electricity Charges:

Electricity consumption, 35 units per day Rs. 43.75

& Rs.1.25 / unit

Total Operational and Maintenance Cost. = Rs. 722 + Rs. 343.00 + Rs. 43.75

= Rs. 1108.75

Operational Cost/M^3 = Rs. 13.85

Running Cost:

Total Running Cost = Rs. 386.75 (Electricity + Chemical costs)

Running cost/m^3 = Rs. 4.83

Thus, the annual running cost of defluoridation per capita is estimated as Rs. 70.51

The costs shown above are subject to price change.

(Source: Nawlakhe, W.G. and Bulusu, K.R. , "Water Treatment Technology for Removal of Excess fluoride" International work shop on appropriate methodologies for development and management of groundwater resources in developing countries")

Water contaminated with nitrate can be treated so that it meets drinking standards. Treatments are expensive, however, and include processes such as reverse osmosis, deionization, and distillation. Boiling, softening, or disinfections will not reduce the water's nitrate content.

The following measures can be implemented to prevent nitrate pollution:

1. The unlined sewage system from various houses in the villages should be lined to help in flow away the drainage water and to prevent seepage which slowly degrades the groundwater quality

2. Fertilizers should be used according to the optimal requirements to prevent percolation of fertilizers to groundwater.

3. Abandoned wells should be closed to stop dumping wastes

4. Finally, animals should be sheltered away from the place of source of groundwater to prevent pollution from animal waste.

TANK STUDIES

The north coastal districts -Srikakulam, Vizianagaram and Visakhapatnam are surfaced with enormous number of tanks. In Andhra Pradesh, Vizianagaram district occupies a record place with 9895 tanks followed by Srikakulam district with 7004 tanks. A large number of tanks which used to irrigate high amount of land in the past are now facing serious silting problem and very good number of potential tanks are now abandoned either leaving the agriculture land under that tank as fallow or decreasing the agriculture yield.

Remote Sensing Studies

In view of the absence of reliable recorded data on these tanks, it was felt essential to carry out a comparative analysis of the tanks on the basis of the satellite data obtained for two seasons of two different years i.e. 1989 (dry and wet season) and 1998(dry and wet seasons). Indian Remote Sensing Satellite 1A, LISS II digital data for the years 1989 for the seasons dry and wet and IRS 1D LISS I data of 1998 were obtained from National Remote Sensing Agency, Hyderabad. This data was used to demarcate the variations in areal extent of water spreads in the tanks over a decade. Since some of the largest tanks irrigating areas more than 400 acres are reported to have almost completely gone dry in summer, a season-wise analysis was thought to be more useful. A total of 23 tanks with settled command areas of more than 100 acres have been selected from all the three watersheds. In order to estimate the benefits of tank irrigation over rainfed irrigation, it was ensured that the sample drawn had farmers who own both irrigated as well as rainfed land.

Economics of Minor Irrigation Tanks

The input output data collected during farm surveys have been used to carry out the benefit cost analysis at the farmer level and project authority level. The gross returns per acre have been computed taking into consideration the value of the main product as well as the by-product, which is mainly fodder. The costs incurred per acre have been computed by taking into consideration the expenses incurred at every stage of farming starting from ploughing to harvesting. On the basis of land holding of individual farmers included in the sample, the weighted gross returns were calculated. Similarly, the weighted net returns were also calculated. These computations were carried out for tank irrigated land and rainfed land at village prices. The net benefit to farmers from tank irrigated land is the difference between the net income from tank irrigated land and that from rainfed land. To compute the benefit-cost ratio, the cost incurred to the farmer for tank irrigated land is taken as the water tax prevalent in the study area. The results of the cost benefit calculations at farmers level are presented in Tables 9 and 10.

Table. 9. Farmers' benefit-cost ratio in Peddagedda watershed

(all costs and benefits in rupees)

Tank No.	Net Benefits (per acre)		Ratio	Increase in land value (per acre)		Ratio	Benefits Due To Tank Irrigation	Cost (per acre)	BCR
	(2)	(3)	(2)/(3)	(4)	(5)	(4)/(5)	(6)	(7)	(6)/(7)
	Tank Irrigated	Rainfed		Tank	Rainfed				
PW1	3862.32	1970.13	1.96	72243.02	37344.47	1.93	1892.19	160.00	11.83
PW2	4509.61	1537.68	2.93	80271.54	41301.69	1.94	2971.93	160.00	18.57
PW3	4347.72	1325.49	3.28	78317.89	39073.98	2.00	3022.23	160.00	18.89
PW4	4208.39	753.92	5.58	89680.39	48535.00	1.85	3454.47	160.00	21.59
PW5	4788.61	1482.71	3.23	79536.02	38153.97	2.08	3305.90	160.00	20.66
PW6	5565.52	1746.92	3.19	82608.99	39615.02	2.09	3818.60	160.00	23.87
PW7	4210.77	1134.79	3.71	91642.30	42337.49	2.16	3075.98	160.00	19.22
PW8	4326.98	1157.03	3.74	88581.86	43350.29	2.04	3169.95	160.00	19.81
PW9	4193.63	1759.50	2.38	98271.69	49524.79	1.98	2434.13	160.00	15.21
PW10	5025.31	1488.72	3.38	76984.06	35950.76	2.14	3536.59	160.00	22.10

Table. 10. Farmers' benefit-cost ratio in Nagavali and Vamsadhara Watersheds

(all costs and benefits in rupees)

Tank No.	Net Benefits (per acre)		Ratio	Increase in land Value (per acre)		Ratio	Benefits Due To Tank Irrigation	Cost	BCR
	(2)	(3)	(2)/(3)	(4)	(5)	(4)/(5)	(6)	(7)	(6)/(7)
	Tank Irrigated	Rainfed		Tank Irrigated	Rainfed				
NWS1	5128.35	1952.85	2.63	92706.12	46930.59	1.89	3175.50	160.00	15.88
NWS2	3785.02	761.89	4.96	93071.18	40304.17	2.34	3023.13	160.00	15.11
NWS3	5498.75	1465.92	3.75	91450.32	49707.99	1.83	4032.83	160.00	18.09
NWS4	5002.23	1384.88	3.61	98982.74	52474.35	1.87	3617.35	160.00	18.09
NWS5	5097.36	1765.67	2.88	92783.14	41098.58	2.22	3331.69	160.00	16.65
NWS6	4901.45	1667.53	2.94	91618.34	44747.53	2.04	3233.92	160.00	20.21
NWS7	5926.42	1753.85	3.38	74886.31	37158.27	2.03	4172.57	160.00	26.08
NWS8	3680.53	1222.01	3.01	64470.33	25524.72	2.49	2458.52	160.00	15.37
NWS9	3054.39	1902.13	1.61	79986.27	46653.83	1.68	1152.26	160.00	7.20
NWS10	3502.82	1548.21	2.26	56522.23	23900.71	2.28	1954.61	160.00	12.22
VWS1	5616.37	2326.95	2.41	122723.74	57802.19	2.17	3289.42	160.00	16.45
VWS2	5074.49	1253.38	4.05	69687.00	34936.11	2.00	3821.11	160.00	19.11
VWS3	4814.89	1759.82	2.73	90378.90	49751.46	1.83	3055.07	160.00	15.26

Table. 11. Employment Generation in Peddagedda watershed

Tank No.	Tank Irrigated (in hours)	Rainfed (in hours)	Additional Employment Due To Tank Irrigation (in hours)	Proportion Of Tank Irrigated Over Rainfed
PWS1	456	254	202	1.80
PWS2	481	246	235	1.96
PWS3	439	216	223	2.03
PWS4	502	247	255	2.03
PWS5	487	234	253	2.08
PWS6	469	221	248	2.12
PWS7	512	304	208	1.68
PWS8	475	231	244	2.06
PWS9	465	260	205	1.79
PWS10	448	222	226	2.02

Table. 12. Employment Generation in Nagavali Watershed

Tank No.	Tank Irrigated (in hours)	Rainfed (in hours)	Additional Employment Due To Tank Irrigation (in hours)	Proportion Of Tank Irrigated Over Rainfed
NWS1	394	214	180	1.84
NWS2	412	230	182	1.79
NWS3	402	195	207	2.06
NWS4	426	225	201	1.89
NWS5	392	188	204	2.09
NWS6	430	242	188	1.78
NWS7	438	216	222	2.03
NWS8	422	220	202	1.92
NWS9	395	189	206	2.09
NWS10	441	231	210	1.91

Table. 13. Employment Generation in Vamsadhara Watershed

Tank No.	Tank Irrigated (in hours)	Rainfed (in hours)	Additional Employment Due To Tank Irrigation (in hours)	Proportion Of Tank Irrigated Over Rainfed
VWS1	481	235	246	2.05
VWS2	506	268	238	1.89
VWS3	446	218	228	2.05

Table 14. Costs and benefits of tank irrigation to the project authority in Peddagedda, Nagavali and Vamsadhra watersheds

Tank	SCA (acres)	Total cost of the Project (Rs. '000)	Cost/acre (Rs)	Present Value/acre assuring 22 yrs life period at 5.75% interest (Rs)	Total cost/acre including Rs. 117/-acre for maintenance and repairs	Revenue collected (Rs/acre)	BCR
				Peddagedda			
PW1	697.9	2381	3411.66	997.2349	1114.235	160	0.144
PW2	500	1657	3314.00	968.6887	1085.689	160	0.147
PW3	500	1410	2820.00	824.2915	941.2915	160	0.170
PW4	400	1625	4062.00	1187.477	1304.477	160	0.123
PW5	200	805	4025.00	1176.515	1293.515	160	0.124
PW6	162	571	3524.69	1030.274	1147.274	160	0.139
PW7	150	603	4020.00	1175.054	1292.054	160	0.124
PW8	140	589	4207.14	1229.755	1346.755	160	0.119
PW9	135	583	4318.51	1262.309	1379.309	160	0.116
PW10	133	403	3030.08	885.6983	1002.698	160	0.160
Nagavali							
NW1	312	1045	3349.35	979.0216	1096.022	160	0.146
NW2	784	2634	3359.65	982.0323	1099.032	160	0.146
NW3	1600	5415	3384.75	989.3691	1106.369	160	0.145
NW4	247	878	3554.65	1039.031	1156.031	160	0.138
NW5	300	1135	3783.33	1105.875	1222.875	160	0.131
NW6	204.7	697	3404.98	995.2823	1112.282	160	0.144
NW7	307	1182	3850.16	1125.409	1242.409	160	0.129
NW8	251	943	3756.97	1098.17	1215.17	160	0.132
NW9	500	1875	3750.00	1096.132	1213.132	160	0.132
NW10	670	2319	3461.19	1011.713	1128.713	160	0.142
				Vamsadhara			
VW1	5400	16879	3125.74	913.6599	1030.66	160	0.155
VW2	478	1755	3671.55	1073.201	1190.201	160	0.134
VW3	1921	6324	3292.03	962.2668	1079.267	160	0.148

WILLINGNESS TO PAY FOR IRRIGATION

An attempt has been in this chapter to assess the level of service required by the villagers in this area to meet their water demands and the extent of their participation in terms of willingness to pay for the services.

Villages from Peddagedda, Nagavali and Vamsadhara watersheds were selected based on the statistical and GIS analysis. The cluster analysis technique was used considering all the relevant village parameters. From all the three watersheds fifty villages have been selected on the basis of number of households, size of the farmers, water facilities available and other socioeconomic characteristics.

Table. 15. Details of Social Indicators

SOCIAL INDICATORS	PWS	NWS	VWS
No. Households studied	109	342	172
Caste living	OC-9, BC-97 SC-3	OC-13, BC-300 SC- 8, ST-21	OC- 3, BC- 168 SC- 1
Average age of the respondent	49.33	46.71	45.86
Literacy rate (%)	56.53	63.15	63.58
Marital Status	2.72	3.81	4.04
Average size of the family	5.33	5.26	5.49
Average Female/male ratio	1.02	1.02	1.01
Average days worked for main occupation	187	190	167
Average days worked for subsidiary occupation	123	20	36
Outside annual Income per HH in rupees	7848	2906	2245

Table. 16. Details of Agricultural Indicators

AGRICULTURAL INDICATORS	PWS	NWS	VWS
Average Rainfall (mm)	1090.5	1082.34	1194.4
Availability of water in summer	Yes – 16.44% No – 82.56%	Yes – 37.06% No – 61.94%	Yes - 44.94% No – 52.64%
Average land owned (acres) per HH	4.65	6.78	5.94
Average irrigated land	2.13	6.66	4.06
Major crops	Paddy, Ragi, Sugar-cane, Groundnut	Paddy, Ragi, Sugarcane, Groundnut	Paddy, Ragi, Sugarcane, Groundnut
Main source of water	Tanks	Tanks, Canals	Canals, Tanks

5.6. ANALYSIS ON WILLINGNESS TO PAY

The contingent valuation method (Bidding Technique) has been used to elicit preference functions for public supplies such as water, and willingness to pay for the services (water supply in the present context).

Table. 17. Willingness to pay among all and only payers

		% of willingness to Pay positive sum	**Willingness to Pay per HH (Rupees)**	
			Among All	**Among only Payers**
Peddagedda	Capital Cost	92.66	669.72	737.37
	Maintenance	88.99	94.31	100.78
Nagavali	Capital Cost	83.28	491.58	611.78
	Maintenance	82.11	83.44	102.35
Vamsadhara	Capital Cost	76.02	708.72	991.0
	Maintenance	70.76	96.80	136.47

* Capital Cost per HH/only once and Maintenance cost is per HH/year.

Based on the data obtained from the field survey of 109 households from Peddagedda watershed, 341 households in Nagavali watershed and 172 house holds from Vamsadhara watershed, an statistical analysis for willingness to pay for irrigation (WTPICAP) has been carried out.

Table. 18. Distribution of Farmers by willingness to pay towards capital and maintenance cost

(in percent)

Type of farmer	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	33.94	22.87	23.25	26.68
Small (2.5 – 5 acres)	34.86	34.31	30.81	33.32
Medium (5 – 10 acres)	18.18	18.76	15.69	17.54
Large (>10 acres)	5.50	7.33	7.55	6.79
Total	92.48	83.27	77.3	84.35

Table. 19. Average amount of willing to pay by farmers towards capital cost

(in rupees/HH/at once)

Type of farmer	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	406.75 (469.50)	317.34 (608.49)	460.18 (581.91)	394.75 (553.3)
Small (2.5 – 5 acres)	745.12 (944.31)	440.71 (600.85)	764.61 (884.88)	650.14 (810.01)
Medium (5 – 10 acres)	884.00 (1959.25)	538.85 (1227.31)	1165.62 (2088.77)	862.82 (1757.11)
Large (>10 acres)	883.33 (757.40)	1137.87 (4313.37)	478.57 (777.58)	833.25 (1949.45)

* Figures in parenthesis are standard deviations

Table. 20. Average amount of willingness to pay by farmers towards Maintenance cost

(in rupees/HH/acre/year)

Type of farmer	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	105.40 (105.26)	70.00 (80.80)	88.88 (114.78)	88.09 (100.28)
Small (2.5 – 5 acres)	73.43 (55.94)	88.84 (106.16)	84.30 (85.89)	82.19 (82.66)
Medium (5 – 10 acres)	113.12 (143.72)	97.42 (83.66)	107.81 (122.54)	106.11 (116.64)
Large (>10 acres)	91.66 (58.45)	73.48 (97.21)	145.23 (266.41)	103.59 (140.72)

* Figures in parenthesis are standard deviations

Multiple regression analysis has been carried out to understand the relationship between independent or predictor variables and a dependent or criterion variable. In the present analysis six groups of explanatory variables have been chosen and different models are generated. Keeping the dependent variables WTPICAP constant, regression models are generated, by changing the explanatory variables in each group separately as independent variables. Like wise keeping WTPIMAIN as dependent and explanatory variables in each group as independent variables regression models are generated and the result are shown in Table 21 & 22 respectively.

Table. 21. Results Of Multiple Regression Analysis

Dependent Variable	WTPICAP						
Independent Variables	HH_SIZE	MAIN_OCC	NO_DAYS	SUB_OCC	S_NO_DAY	OWN_LA_TOT	W_OP
Coefficient	-0.0236	-0.0048	-0.0226	-0.0431	0.0243	0.3277*	0.0469
t-ratio	-0.6094	-0.1260	-0.5841	-0.9263	-0.5186	8.4126	1.2249

Dependent Variable	WTPICAP			
Independent Variables	RESP_AGE	EDUCA	MAR_STA	COMM_PART
Coefficient	0.0200	0.004	0.0223	0.0551
t-ratio	0.4944	0.0105	0.5505	1.3669

Dependent Variable	WTPICAP					
Independent Variables	RAIN_CHANGE	DEC_TANKS	DEC_CAN	DEC_WELL	DEC_IRR_AREA	DEC_YIELD
Coefficient	0.0008	0.0182	0.0109	0.1314*	-0.0533	0.1610*
t-ratio	0.0222	0.4262	0.2777	4.1821	-1.3679	4.0204

Dependent Variable	WTPICAP		
Independent Variables	IRR_NET_COC	DRY_NET_COC	TOT_TAX
Coefficient	0.0514	0.0040	-0.0488
t-ratio	1.1925	0.0965	-1.1729

Dependent Variable	WTPICAP		
Independent Variables	WAT_AVAIL	DIST_TRAVAL	WAT_QUA
Coefficient	-0.0335	-0.0094	-0.0353
t-ratio	-0.8201	-0.2310	-0.8647

Dependent Variable	WTPICAP		
Independent Variables	S_ANN_INC	ANN_YIELD	AVE_INCO
Coefficient	-0.0266	0.0658	0.0279
t-ratio	-0.6572	1.6236	-0.6902

* Significant at 5% level

Table.22. Results of regression analysis among all the significant variables and WTPIMAINT

Dependent Variable	WTPIMAIN				
Independent Variables	RESP_AGE	S_ANN_INC	OWN_ LA_TOT	DRY_NET _COC	RAIN_ CHANGE
Coefficient	-01348*	0.0790*	0.1960*	0.0569	0.0964*
t-ratio	-3.4396	2.0301	4.9942	1.4587	2.4787

* Significant at 5% confidence level

RESULTS AND RECOMMENDATIONS

From the water balance statistics, it is found that in Peddagedda watershed the total water stocks are 13409.5 ha-m. of which contribution by groundwater is about 13,409 ha-m., and 5928 ha-m. contributed by tanks. But the water consumption from tanks is highest (3241 ha-m.) for irrigation, followed by groundwater. The stock in the river water is estimated to be 12278 ha-m. It is observed that this river water is entirely going waste as run-off into the Bay of Bengal. In Nagavali watershed, the total stocks are estimated at as 104,120 ha-m. including river discharge. The groundwater stocks are more, which is estimated to be as 41996 ha-m. From the studies it is found in this watershed that the maximum (86%) tank water is used for irrigation. Run-off in the rivers and streams is estimated at as 29,732 ha-m. Very less amount of groundwater (6580 ha-m) is being extracted for irrigation in this watershed. In Vamsadhara watershed, the total water stocks are about 74946 ha-m. The groundwater stock is estimated at as 29937 ha-m. The amount of water leaving the watershed is about 22692 ha-m. In all the three watersheds together about 64702 ha-m. of water is going waste as run-off. About 95% of the farmers in this watershed are small farmers owning 0.5 to 1 acre land holding and they cannot afford the capital amount to explore groundwater.

To summarize the highest concentrations of fluoride and nitrate are found in the following villages.

Watershed	Village	Flouride Concentration
Peddagedda watershed	Ranasthalam	2.00 mg/l
Nagavali	Vanjangi	1.90 mg/l.
Vamsadhara	Mamidivalasa	2.40 mg/l

Watershed	Village	Flouride Concentration
Peddagedda watershed	Patharlapalli	145 ppm.
Nagavali	Kusimi	420 ppm.
Vamsadhara	Srikurmam	404 ppm.

The study area has a number of tanks of varying sizes. Lack of maintenance by way of disiltation has been observed to be the major problem with these tanks. As a result, only those few farmers who can afford to invest to tap groundwater are using groundwater. A systematic analysis of 23 tanks whose command areas are above 100 acres have been selected for the study from all the three watersheds. These tanks were analyzed for their present performance by computing the performance indicators like effectiveness ratio and deviation factors.

S. No	Tank Name	Village	Mandal	Regd. Bed area	Present bed area (IRS data)	(1/2)	SCA	Present Command Area	(4/5)
				1	2	3	4	5	6
Peddagedda Watershed									
PW1	Narayana Sagaram	Budumuru	Laveru	300.19	103.72	0.35	697.94	225.60	0.32
PW2	Devala Tank	Bejjipuram	Laveru	160.55	132.92	0.83	500	427.64	0.86
PW3	Raju Tank	Punnam	G. Sigadam	30	19.42	0.65	500	206.00	0.41
PW4	Lanka Tank	Patharlapalli	Ranasthalam	50	47.49	0.95	400	150.00	0.38
PW5	Daba Tank	Chinna Murapaka	Laveru	112.91	22.65	0.20	200	73.61	0.37
PW6	Nidigandlam Tank	Adapaka	Laveru	72	15.04	0.21	162	75.31	0.46
PW7	Pedda Tank	Budatavalasa	Laveru	49.4	19.49	0.39	150	63.87	0.43
PW8	Tammi Naidu Tank	Peda Rompivalasa	Laveru	43.2	18.53	0.43	140	57.23	0.41
PW9	Borra Patuvani Tank	Batuva	G. Sigadam	33.96	16.81	0.49	135	73.29	0.54
PW10	Pedda Tank	Batuva	G. Sigadam	40.14	24.72	0.62	133	92.80	0.70
Nagavali Watershed									
NW1	Pedda Tank	Shermohammad -puram	Etcherla	160	96.1	0.60	312	153.04	0.49
NW2	Tamara Tank	Siripuram	Santakaviti	625	311.67	0.50	784	344.84	0.44
NW3	Mandavakuriti Tank	Mandavakuriti	Santakaviti	300	161.9	0.54	1600	673.08	0.42
NW4	Salavani Tank	Seetampeta	Ponduru	58	48.83	0.84	247	165.56	0.67
NW5	Meduri Krishnamma Tank	Boddavalasa	Rajam	66.66	38.31	0.57	300	121.13	0.40
NW6	C. R. Raju Tank	Unukuru	Vangara	92.74	79.1	0.85	204.7	164.15	0.80
NW7	Subbi Tank	Arasada	Vangara	82.69	78.46	0.95	307	251.13	0.82
NW8	Tamara Tank	Ungarada	R. Amadalavalasa	67	67	1.00	251	208.88	0.83
NW9	Gudivada	Lumburu	Palakonda	113	86.01	0.76	500	309.69	0.62
NW10	Yebbaji Tank	Vadada	Gara	125.8	106.78	0.85	670	412.69	0.62
Vamsadhara Watershed									
VW1	Asarla Sagaram	Temburu	Saravakota	368.26	359.3	0.98	5400	3479.98	0.64
VW2	Ranga Sagaram	Poppangi	Saravakota	326.86	302.33	0.92	1920.68	1429.06	0.74
VW3	Pedda Tank	Kottakota	Sarubujjili	175	153.69	0.88	477.95	319.58	0.67

The major findings based on the analysis of willingness to pay are summarized below:

1. Total 622 sample households in all the three watersheds surveyed to study their willingness to pay for irrigation towards capital expenditure and maintenance. The per capita land owned is 1.15 acres.

2. Majority of the farmers in all the three watersheds belong to backward community (87.15% in Peddagedda, 87.68% in Nagavali and 97.68% in Vamsadhara). It is found that 61.46%, 45.45%, 34.30% of farmers fall in below poverty level in three watersheds respectively.

3. The average willingness to pay in three watersheds is Rs. 582/- towards capital cost to be paid at a time once for all and Rs. 49.50/- paid per acre/year/household. About 18% of the respondents expressed their inability to pay due to their low income. It is observed that the willingness to pay is increasing with the increasing land owned from less 1.5 acres (Rs. 388.57) to greater than 11 acres (Rs. 872.72) per household.

4. Community participation is found to be of very low in all the three watersheds. This is partly due to lack of unity among the villagers. However, Water Users' Associations are given fruitful results in some villages. By creating better awareness and education and by providing better leadership, this community participation can be promoted.

5. Loans taken by the farmers are increasing with increase in size of land holdings due to loss in agricultural output.

6. Total agricultural land owned is showing more influence on willingness to pay. Because agriculture land is the wealth of the villagers, it showed positive willingness to pay. They can be assured that the un-irrigated land will also come to irrigation and the willingness to pay would also increase.

7. Change in water level in tanks, canals and wells showed positive influence on willingness to pay. Decrease in tanks and other sources seem to make the

villagers to lose their faith on them in supplying water to their fields. As the villagers know that improvement of these can be a benefit to them.

8. Variables such as total land owned, irrigation output, education, decrease in yield due to lack of water, decrease of water level in wells are positively significant in influencing the peoples' thought on willingness to pay of irrigation water.

9. Variables such as size of the household, number of days in main occupation, age of the respondent, net income and water tax showed negative thought on willingness to pay.

Policy Issues

- River water should be conserved properly by following watershed management techniques, by constructing dams/ barrages/anicuts, and to preserve their reservoir capacities, suitable soil conservation techniques be enforced in all the three watersheds.

- Desiltation works have to be carried out to restore the tank capacities and command areas, wherever possible.

- The release of water from tanks is presently unrestricted in most of the tanks. Hence, proper water regulatory structures have to be constructed for effective water management.

- All the tanks within a watershed should be connected. Though most of the tanks are connected in series by streams/canals. The canals also need to be repaired. This helps the farmers not just in the command area of a single tank, but also protects the riparian rights of the farmers in the down stream of the watershed. Since there are no major irrigation projects in Peddagedda and Nagavali watersheds, the construction of such canal network would be extremely beneficial from the socio-economic as well as environmental aspects.

- The presence of water users associations has significant positive effect on water management. If internal bickering within the association can be curtailed by educating the members of these associations, and also participation of women is made compulsory, and by close monitoring of the working of these associations, more fruitful results can be realized. These associations should be made fully accountable for all the maintenance and repairs works under taken. The engineers of the A.P. Government agencies must advice and help the associations.

- Water User's Associations can also be motivated to monitor groundwater in respect of water level and quality. They can also take up soil fertility, agro-pollutant level. Water quality awareness camps should be organized in the villages to prevent groundwater pollution due to human interference.

- Farmers should be trained for balanced and efficient use of chemical fertilizers, bio-fertilizers, making them clear about environmental issues due to excess use of them.

- The water tax according to present structure is very low when compared to the financial resources required for maintenance of the tanks and in no way reflect the value of water which is scarce. The main reason for not increasing the fees is on the premise that the farmers may not be able to meet the extra financial burden but yet it is inevitable. Water charges should be raised with assurance of water through the infrastructure improvement. Volumetric pricing of water instead of crop-wise pricing would result in more beneficial and can control the wastage of water.

- Since, the villagers are very much interested to contribute for water resources projects, i.e., betterment levy, in all the three watersheds, government can take further steps to improve the living standards of the villagers in this area.

CHAPTER 1: INTRODUCTION

India is one of the few countries endowed with number of perennial rivers, adequate rainfall, and vast fertile alluvial plains. The average annual precipitation of the country is around 4000 cubic km, spread over an area of 328 million ha. of which 188 million ha. is cultivatable. The average annual water resources in various river basins are 1869 cubic km (Narasimha Murty, 1998)[v]. Out of total water resources of the country, about 690 cubic km of surface water and 450 cubic km of groundwater per year is available for irrigating about 140 million ha. of gross area per year. Irrigation potential created in the country at present is 85.0 million ha. including 31.1 million ha. from major and medium projects. The present utilization of water in the country is about 550 cubic km. (including 460 cubic km. for irrigation) which is likely go up to 1050 cubic km. (700 cubic km. for surface and 350 cubic km. from ground water) by the year 2025 A. D.(Bhagirath, 1998)[vi].

Water is an important and scarce common property natural resource for which demand is increasing day by day due to population explosion, increase in the living standards, and agriculture development. But supply of water remains almost limited. Therefore, the importance of water, its judicious use and conservation assumes special significance. In the rural areas the introduction of new farming methods, the spread of irrigation and the excessive use of fertilizers and pesticides causes very high consumption of water (Hashim, 1998)[vii]. The per capita annual availability of water in India is about 2200 cubic meters, which is only 29.9% of the world's average. Water is very essential resource for a large number of productive activities, of which the most important is irrigation and food production. Though water is non-exhaustible resource, due to over exploitation, decrease and irregularity in the rainfall pattern over the past few decades, it has become an exhaustible resource. It is largely acclaimed that water is going to be one of the major issues to confront humanity at the turn of the century and beyond. At present people are facing water crisis in terms of quality and quantity. Proper water management is an important component of sustainable development to meet the needs of the present and future generations. Due to these important and alternate uses, water has become an economic commodity. Hence, water is not a free gift of nature, it has value if not price. Water is made available at cost.

Irrigation is a technique of supplying sufficient water and reduces uncertainties associated with the irregular rainfall, and ensures cultivation of land otherwise not suited for agriculture. Irrigation, as a main catalyst of agricultural development in India, accounts for the largest share in total investment in the agricultural sector. Irrigation helps the development of agriculture by providing assurance to draw suitable cropping pattern, increase in crop productivity, and helps for intensive cultivation. Adequate irrigation facilitates enable full use of the land under cultivation and increase in crop productivity due to sufficient supply of water. The importance of irrigation through out the country is increasing with the increase in High Yielding Variety crops. Irrigation is the crucial input, which influences the use of other supplementary inputs. In the absence of irrigation, the soil and climatic conditions of India permit the production of single crop in the whole agriculture year, from most of the arable land resources[viii]. Hence, it is mandatory to invest major part of money for development of irrigation systems, which can be considered an indirect instrument in improving the living conditions of the rural poor.

In India, irrigation at present accounts for 80 to 85 percent of water requirements as compared to the global average of 69%. The total cultivable area in the country is 188.0 million ha. and agriculture is largely dependent on monsoon rainfall which is unreliable due to irregularity and uneven spatial distribution. Hence, irrigation development has always been accorded high priority and attention by the state and central governments. The net sown area (NSA) of the country is 142,819 million ha. of which only 52999 million ha. is net irrigated area which constitutes 37.10% of net sown area. It is important to notice that at present the average cost of creating one hectare of additional irrigation potential is Rs. 35,000 to Rs. 40,000. This cost still may not assure better standards of rehabilitation. This shows that creating additional potential will be at higher cost. Hence, it is necessary to manage the existing water sources.

Keeping in view the importance of agriculture sector in the Andhra Pradesh State economy, much importance has been given in the plans for the development of irrigation. Andhra Pradesh has inter-state rivers like Godavari, Krishna and Pennar.

The other major and minor rivers flowing through the state number about 45 which carry about 18.45 mllion ha-m. of water into the Bay of Bengal. The rivers Krishna and Godavari together contribute 16.0 million ha-m. of water. The rivers in Andhra Pradesh stand as major surface water sources for irrigation. Besides these rivers, number of lakes, namely, Kolleru lake, and tanks like Pakhal, Cumbhum, Kaligiri, Osmansagar and other tanks are also playing major role in supplying surface irrigation water. The important government projects undertaken in the state for irrigation development are Somasila, Nagarjuna Sagar, Prakasham and Dowaleswaram Barrages, Pochampadu project, Narayanasagaram project on the Nagavali and Gotta Barrage on Vamsadhara river.

1.1. Problem

Srikakulam district is one of the backward districts of Andhra Pradesh situated between 18^0 20’ to 19^0 10’ North latitudes and 83^0 5’ to 84^0 50’ East longitudes. It is bounded on the south and west by Vizianagaram district, Orissa State on the north and on the east by Bay of Bengal (Figure 1.1) Total geographical area of the district is 5837 sq. km. The average annual rainfall of the district calculated from the data of 19 years is 1191.34 mm. The rainfall pattern in Srikakulam district from 1980 to 1998 is shown in Figure 1.2. The rainfall from June to October contributed by the SW monsoon accounts for 81.5% of the annual rainfall. The principal rivers in the district are Bahuda, Nagavali, Vamsadhara, Mahendratanaya, Suvarnamukhi, Vegavati, Gomukhi, and Champavathi. All the rivers are seasonal except the Vamsadhara. Agriculture is the main occupation of the people of this district and about 80% of the population depends only on agriculture for their survival. Unfortunately, there is acute shortage of water for irrigation in the district. Due to irrigation water shortage, rural people are migrating from their villages in search of other employment work to nearby towns for their existence.

Keeping these water resource problems in view, it is proposed to study the following objectives in three watersheds of Srikakulam district.

- To assess water resources both surface (tanks, canals, etc.) and sub-surface (groundwater) and to carryout the water balance studies for effective planning and management of water resources

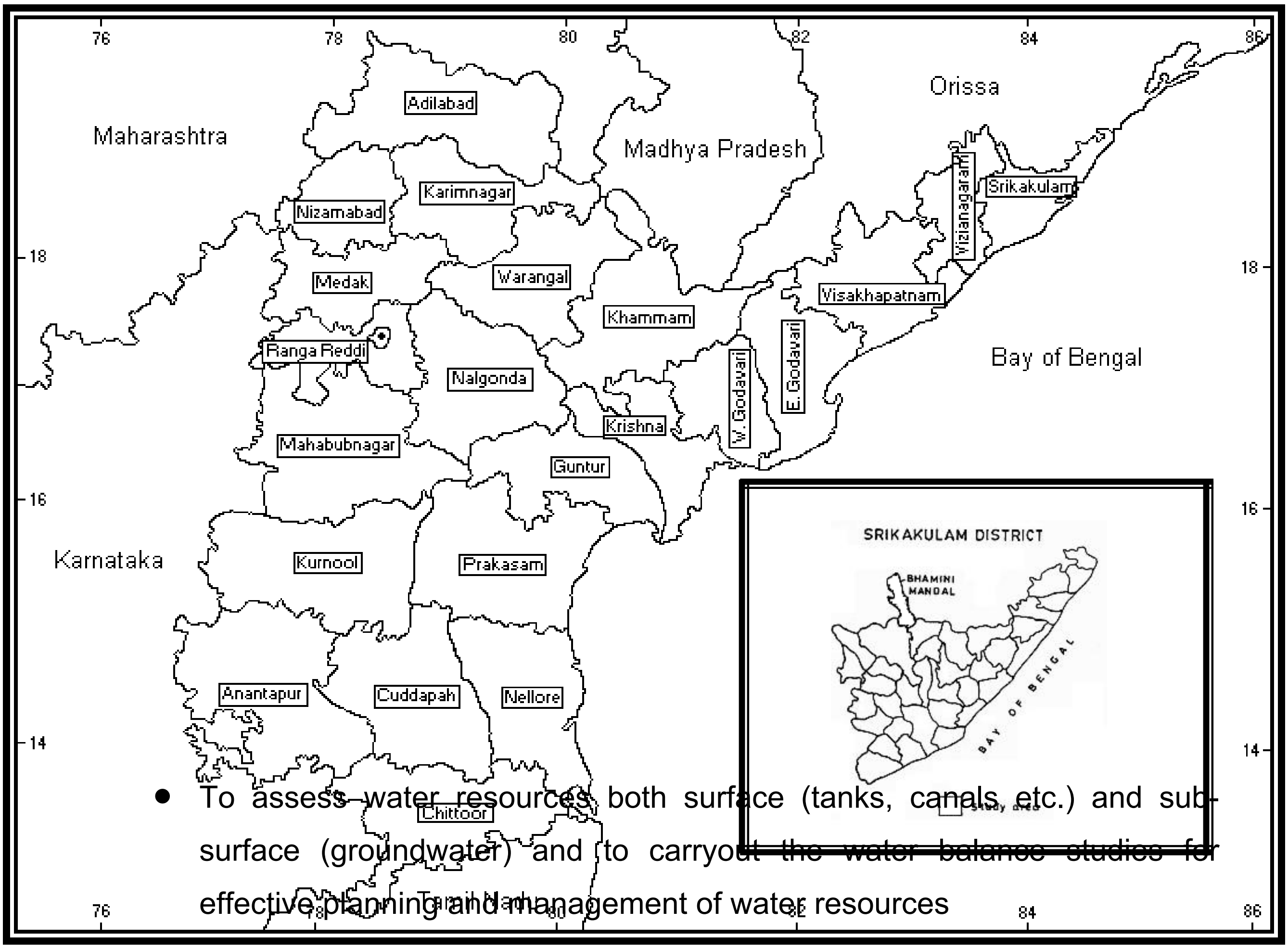


Figure 1.1. Location map of the study area

- To assess the impact of water quality on human health using secondary data and to estimate the cost of treatment/providing alternate wholesome water.

- To assess the impact of salinity on agricultural productivity using secondary data and to suggest environmentally safe and economically viable methods to improve the quality of land and crop yield.

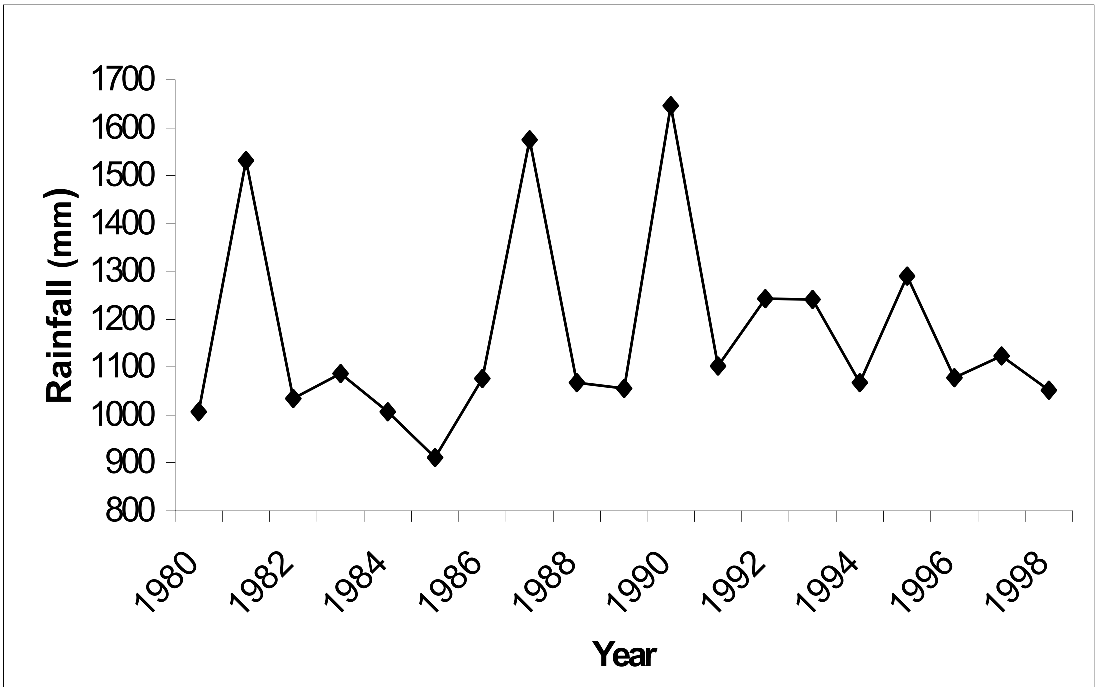


Figure 1.2. Rainfall Pattern in Srikakulam District

- To evaluate the existing tank conditions and to make a comparative analysis between the cost-benefit involved in increasing the tank capacities and exploitation of groundwater.

- Finally, to carry out economic valuation of water by primary household surveys using "Contingent Valuation Method"

To fulfill these objectives, the study area is divided in to three watersheds (*Watershed is a unit receiving a particular set of channels*) namely, Peddagedda watershed (PWS), Nagavali Watershed (NWS) and Vamsadhara watershed (VWS).

As watershed forms an ideal unit for hydrological studies, all these objectives are intended to be explored watershed wise. The watersheds are divided on the basis of drainage pattern, stream order and the slope. The selected watersheds and mandals (*telugu word for development block*) covered are shown in Table 1.1.

Table 1.1. Name of the watershed, area, mandals covered

Watershed	**Area (in sq. kms)**	**Mandals Covered**	**Rainfall (mm)**
Peddagedda	435.72	Laveru and parts of Etcherla, G. Sigadam, Ponduru, Ranasthalam.	1090.50
Nagavali	1403.87	R. Amadalavalasa, S. Kaviti, Rajam and parts of Vangara, Veeraghattam, Palakonda, Seetampeta, Burja, Amd. Valasa, Srikakulam, Gara, Etcherla, Ponduru, G. Sigadam	1082.34
Vamsadhara	947.25	Jalumuru, Narasannapeta, Sarubujjili and parts of Patapatnam, Saravakota, K. Bommali, Polaki, Srikakulam, Gara, Amd. Valasa, Seetampeta, Hiramandalam, Burja.	1194.40

1.2. DESCRIPTION OF THE IDENTIFIED WATERSHEDS

1.2.1. Peddagedda Watershed:

Peddagedda watershed lies between 18^0 7' to $18^0$24' N latitudes and 83^0 32'to 83^0 52' E longitudes covering an area of 435.72 sq. km. The average annual rainfall of Peddagedda watershed is 1090.50 mm., and mean maximum and mean minimum temperatures are 33.7^{0}C and 26.5^{0}C respectively. The river Peddagedda originates near the village Batuva at an altitude of 87 m (above MSL) and flows in the SW-NE direction for a length of about 55 km. and debauches in to the Bay of Bengal near Bodagutlapalem village. This river has two small tributaries Chittigedda and Kuppiligedda. Some of the major villages in this watershed are Laveru, Batuva, Ponnam, and G. Sigadam. The watershed is almost plain with some isolated hills with a maximum elevation of 333 m. The average slope throughout the basin is 10 m. The soils are predominantly alluvial, sandy silty clay, sandy silty loam and marine soils. Laterite soils (Ultisols) are also observed in few pockets. The crops grown in the watershed are paddy, bajra, ragi, sugarcane and groundnut. The irrigation depends entirely on the rainfall. The Peddagedda river is rainfed which is torrential during rains and dry in the rest of the time. This watershed is characterised by nearly about 745 small, medium, and large tanks. Tanks are major source of irrigation in this basin. The two largest tanks in this watershed are Narayana Sagaram tank with a command area of 697.94 acres located adjacent of National Highway near the village Budurumu and Devala cheruvu (*local word for tank*) with a command area of 500 acres located near Bejjipuram village.

1.2.2. Nagavali Watershed

Nagavali watershed is located between 18^0 12' to 18^0 40' N latitudes 83^0 35' to 83^0 59' E longitudes. The area of the watershed is 1403.87 sq. km. The Nagavali river originates in the Eastern ghats of Orissa state and receives water from its tributaries Gomukhi, Vegavati and Suvarnamukhi which join Nagavali at Sangam village, and finally falls in the Bay of Bengal at Kallepalli village near Srikakulam. The northern side of the watershed is covered by hills with a maximum altitude of 707 m (above MSL) and the remaining part is almost plains dotted with isolated hills. The climate is characterized as humid and hot. The mean maximum temperature and mean minimum temperatures are 33.7^0C and 25.3^0C respectively. The average annual rainfall is 1082.34 mm of which 60% contributed by the SW monsoon and remaining from northeast monsoon. The major towns in the watershed are Santhakaviti, Amadalavalasa, Ponduru, Etcherla, Srikakulam. National Highway-5 is passing through the basin and almost all the villages are connected with road network.

The soils are alluvial soils, sandy silty gravel, sandy silty loam and marine soils. The soils are highly fertile with good infiltration capacity. Irrigation in the area is mostly rainfed. Tank irrigation is very predominant in the watershed. It is estimated that there are nearly 2015 small, medium and large tanks. The biggest tanks are Mandavakuriti cheruvu near Mandavakuriti village, Tamara cheruvu near the village Siripuram and Yebbagi cheruvu near the Vadada village. Agriculture is the main occupation of the people in this basin. The crops grown are paddy, bajra, ragi, sugarcane, and groundnut. The entire agriculture in this watershed depends mainly on rainfall and in some places groundwater is used for irrigation. The water stored in the tanks during rains is used for irrigation. The Nagavali left and right canals also contribute to the irrigation needs in this watershed.

1.2.3. Vamsadhara Watershed

Vamsadhara watershed lies between $18^0 17'$ to $18^0 40'$ N latitude and $83^0 51'$ to $84^0 10'$ E longitude covering an area of about 947.25 sq. km. The Vamsadhara river rises in the Eastern Ghats of Orissa state and enters Srikakulam district in Bhamini mandal and finally falls into the Bay of Bengal near Kalingapatnam. The maximum and minimum temperatures in Vamsadhara watershed are 32.9^0 C(May) and 24.7^0 C (January), and the average annual rainfall is 1194.4 mm. About 58% of the rainfall is contributed by the southwest monsoon and the remaining from northeast monsoon and winter rains. The major villages in the basin are Sarubujjili, Jalumuru, Polaki, Gara, Narasannapeta, Tilaru, and Kotturu.

Agriculture is the mainspring of the people in this watershed also. The soils in this area are red ferruginous, alluvial and sandy loams. Half of the area of the watershed is sown with paddy and remaining is sown with other crops like ragi, sugarcane, groundnut. Chillies are also grown in some pockets. The entire agriculture solely depends on rainfall, which is uncertain. Tanks are the main sources of irrigation and 40% of the total irrigated area is under tanks. The canals constructed under Vamsadhara Stage I project are playing a major role in supplying water for irrigation. There are nearly 1056 small, medium and large tanks in this watershed. The major tanks are Asarla Sagaram near Temburu, Ranga Sagaram near Narayanapuram, Pedda tank near Kottakota village.

Unfortunately tanks in these three watersheds are facing serious siltation problem resulting in a lot of loss in ayacut. Very high amount of agriculture land, which can be brought into cultivation, is left fallow due to lack of sufficient water and improper maintenance of the tanks. The government's involvement to uplift the rural mass in these watersheds is very essential as the farmers are economically poor and cannot afford investment to create their own water sources. Besides this about 76% percent of the farmers are marginal farmers (Table. 1.2) with a maximum land holding of 2.46 acres. These farmers completely depend on the rainfall for cultivation. This scarcity of surface water is steadily leading to exploration of groundwater, for use in both domestic and agricultural sectors.

During preliminary reconnaissance survey in the three watersheds it is noticed that very good amount of groundwater is left untapped. Out of about 35153.85 ha-m. of groundwater available in these three watersheds only 7765.73 ha-m., i.e., only 22.1% of the total available groundwater is being utilized at present and remaining is left unutilized. In these three watersheds there is potential to construct nearly 34,700 wells which can bring about 72358.7 acres of land into irrigation (GWB report).

1.3. IRRIGATION SYSTEM IN SRIKAKULAM DISTRICT AND IN THREE WATERSHEDS

Agriculture is the most dominant sector in the district's economy. Development of irrigation sources (e.g. Vamsadhara Stage I project) to provide timely and adequate water supply in these watersheds is essential which effects positively on agriculture growth and this also ensures cultivation of land which is left un-irrigated or fallow. About 90% of the population depends on agriculture directly or indirectly. Cultivators and agricultural labor account for 74% of the total main workers (67.06% of the total workers) in the district. Among the total population of 2,321,126 (1991) of the district, 87.5% are living in rural areas. Other sources of livelihood are very limited in the district. The alluvial soils in the district are fertile and suitable for network of

Table 1.2. Size of operational holdings in mandals of Peddagedda, Nagavali and Vamsadhara watersheds

(Area in acres)

Mandal	Marginal farmers (1.0 to 2.46)	Small farmers (2.47 to 4.94)	Medium (4.95 to 24.7)	Large farmers (>24.7)	Total

	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area
Srikakulam District	321769 (76.18)	304302	60865 (14.41)	213850	38901 (9.21)	348667	840 (0.20)	30319	422375 (100.0)	878809
Seetampeta	7249	7625	1820	6210	1122	8887	17	516	10208	23238
Veeraghattam	7944	7990	1776	6286	1154	10117	19	647	10893	25041
Palakonda	5523	6555	1286	5189	958	8245	13	454	7780	20444
Vangara	5004	5090	1400	4896	1085	9364	16	523	7505	19881
R.A.Valasa	8446	8079	2163	7474	1352	11466	16	516	11977	27634
Rajam	7025	9104	1669	6017	1091	8808	12	400	9797	24329
Burja	6051	5965	1155	4011	760	6358	2	59	7968	16393
Kotabommali	9312	9020	1819	6175	1004	7901	5	136	12140	23233
Saravakota	7782	6775	1458	5081	906	8109	42	1509	10188	21474
Pathapatnam	8989	8781	1389	4809	846	7197	33	1198	11257	21985
Hiramandalam	6271	5501	1052	3905	798	7170	11	395	8132	16971
Jalumuru	7433	7514	1687	5992	2162	10502	10	719	10492	24344
S.Kaviti	8434	8588	1854	6239	1221	10219	28	911	11537	26063
N.Peta	8103	6923	1341	4649	1191	10413	27	1008	10662	22993
Polaki	9014	9280	1403	4804	1061	9460	43	1526	11152	25070
Srikakula	7145	10120	1477	6540	1117	9951	15	494	9754	27088
Gara	11686	10898	1423	5073	1119	10350	46	1776	14274	28104
A.valasa	8433	7795	1128	4019	600	4841	3	84	10164	16739
Sarubujjili	12434	10512	1848	6378	995	7575	24	753	15301	25668
Echcherla	11726	9999	2124	7348	1099	9059	56	2263	15005	28669
Gsigadam	8669	8260	2008	7153	1217	10033	11	585	11905	25718
Ponduru	11173	9603	1702	5950	853	6906	7	326	13735	22783
Laveru	7737	7872	1947	7489	1247	8761	46	1806	11199	27928

*Figures in parenthesis indicate percentage to total.
Source: Handbook of Statistics, Srikakulam district, 1994-1995.

irrigation canals. The very good quantities of water that is being brought by the rivers in the district, if tapped properly can be of immense benefit to the agriculture in the district. Table 1.3 shows the area sown and area irrigated from 1980 to 1998 in Srikakulam district. From Table 1.3, it is clear that there is lot of variation in net area sown and net area irrigated. On an average only about 56% of the net sown is being irrigated and remaining is left unirrigated. The area irrigated more than once also has a lot of fluctuations over a period of 19 years. This is attributable to the uneven rainfall and availability of stored water. With the extensive development of surface water resources and groundwater resources, the irrigation potential of the district at full development is estimated to be as much as 902497 acres in Kharif and Rabi seasons together.

1.3.1. Cropping Pattern

Cropping pattern is the proportion of area under various crops at a point of time (Mishra, 1990)[ix]. The economic development of a region depends on the cropping pattern. It includes identification of commercial crops of that region. The factors that influence the cropping pattern are suitability of soils, availability of water, pattern of rainfall, development of market, transport, and supply situations. At micro level, the important considerations are size of the land, irrigation facilities, and net returns of the crops. In Srikakulam district farmers are showing rigidity in changing cropping pattern due to non-availability of sufficient water. When assured irrigation facility is provided, a change in cropping pattern can be

Table 1.3. Sown and Irrigated area in Srikakulam District

(area in acres)

Year	GAS	NAS	ASMO	GAI	NAI	AIMO
1980	938472	778487	159985	NA	NA	NA
1981	962967	803503	159464	476797	444242	32555
1982	958056	805907	152149	485201	450881	34320
1983	933280	774292	158988	442011	434413	7598
1984	950672	786417	164255	449982	441465	8517
1985	933216	778407	154809	NA	434252	NA
1986	954225	785416	168809	444880	430013	14867
1987	992259	790461	201798	494395	476847	17548
1988	603578	517287	86291	183957	183957	-
1989	996283	776528	199755	500457	445769	54688
1990	1030280	815501	214779	502940	458893	44047
1991	1031354	812610	218744	506348	461095	45253
1992	1086258	803185	283073	512421	472524	39897
1993	1214210	825441	388769	526788	483814	42974
1994	1063988	770991	292997	461957	432126	29831
1995	1120315	803041	317368	488593	463421	25172
1996	1146985	844390	302595	518253	477992	40261
1997	1026885	762850	264035	446467	411976	34491
1998	993397	759751	233646	456479	435895	20584

Source: Chief Planning Office, Srikakulam district.

expected. The important crops grown in the district are paddy, jowar, bajra, ragi, sugarcane, mesta, groundnut and sesamum. Paddy is the major crops through out the district with an area of 485,303 acres followed by groundnut, mesta, and ragi. From the field survey it is clear that there is a clear discrimination in crop area under tanks and under groundwater. Paddy is extensively grown under tank irrigation and groundwater is used to irrigate groundnut, chillies etc. The areas under principal crops together in the kharif and rabi in the district and in mandals of the three watersheds are shown in Table 1.4.

1.3.2. Sources of Irrigation

Surface and groundwater irrigation are only the sources of irrigation in the district. Surface waters are from the rainfall, main rivers and water stored in the tanks and reservoirs. River water is diverted to agricultural fields through canals taking off from the rivers. Tanks, which are important sources of irrigation, are mostly rainfed. The water from the tanks is allowed to flow to the fields by gravity, making it less expensive. The entire agriculture in the district depends mostly on minor and medium irrigation projects. The minor irrigation sources are small tanks, tube well, lift irrigation, dug wells, and small streams. The minor irrigation schemes sanctioned during 1992-1993 are still in progress. Vamsadhara Project Stage I is only the major irrigation project in the district. Approximately 474 m long barrage has been constructed across the Vamsadhara river near Gotta village in Hiramandalam mandal. The left main canal is laid for about a length of 104 km with 68 distributory net works benefiting about 364 villages of 12 mandals. The total cost of the project is Rs. 109.0 crores with a registered ayacut of 148,175 acres. So far irrigation potential has been created to 127,882 acres and irrigation potential to 20,352 acres is yet to be created. However, except for Jalumuru, Polaki and Narasannapeta, the remaining mandals in the study area do not fall within the command area of this major irrigation project. Minor irrigation is very prominent in the remaining mandals.

Groundwater is tapped by openwells and tube wells. In Srikakulam district as a whole, canals are playing major role in irrigation followed by tanks. Tanks are only the source of irrigation in case of Laveru and G. Sigadam mandals. The source-wise gross area irrigated in Srikakulam district and mandals of the three watersheds are shown in Table 1.5 and Table 1.6 respectively.

Table 1.5. Source wise Gross Area Irrigated in Srikakulam District

(area in acres)

Year	Tank	Tube wells	Canals	Other wells	Other sources	Total Area
1986	221491	5381	209510	2917	5581	444880
1987	213546	9296	237415	25604	8834	494395
1988	51769	7476	97485	24016	3211	183957
1989	236067	11852	217663	27175	7700	500457
1990	200916	8666	250562	34324	8472	502940
1991	195731	15766	257612	28799	8440	506348
1992	193063	17339	264722	30144	7153	512421
1993	203827	19900	265355	29847	7859	526788
1994	175992	20242	232699	26412	6746	461959
1995	191467	24964	228379	25552	18231	488593
1996	210394	22743	238662	28607	17847	518253
1997	160687	20065	213558	31708	20439	446467
1998	180121	24130	207095	28612	16521	456479
Growth rate	-2.08%*	11.0%*	-0.21%	7.9%**	8.70%*	-0.22%

*Significant at 1% level, ** Significant at 5% level,

From Table 1.5, it may be observed that the area irrigated by tanks in Srikakulam district is decreasing rapidly and the area under other sources and tube wells is

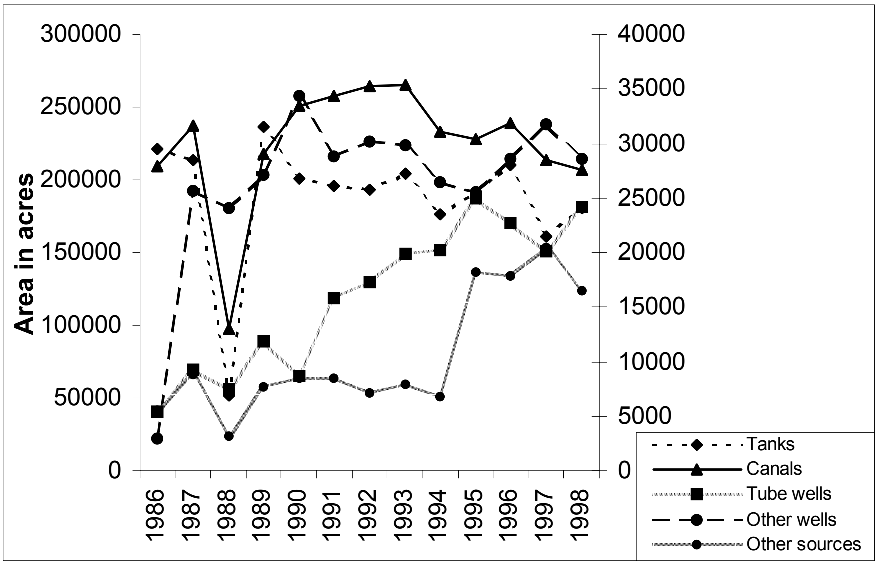


Figure 1.3. Variation in irrigated area under different sources

increasing. It may be observed from Table 1.5. that from the year 1986, the area under tanks is decreasing whereas the area under canals is steadily increasing. From 1994 onwards canal irrigated area remained almost constant, while area under tube wells and other sources is increasing.

This indicates that due to water problems the farmers are slowly changing the water source and also the cropping pattern from paddy to other crops, which require less water. This can be attributable to the decreased area under paddy (Table 1.4). In Srikakulam district as a whole the area under paddy decreased by about 35,768 acres during the period 1986-1999. In other mandals an average decrease of 15% is observed. The graphical representation of the variations in source-wise irrigated area is shown in Figure 1.3 .

The changes that occurred in the irrigated area from 1986 to 1998 under different sources have been analysed by studying the growth rates obtained from log-linear analysis. From the values of growth rates in Table 1.5 it may be observed that there is a significant negative growth in the area irrigated under tanks. A non-significant negative growth rate is observed in case of canals. On the other hand, there is a significant growth in other sources and wells. This indicates that the subsidiary sources of irrigation have developed significantly over a small period of time.

CHAPTER 2: WATER BALANCE

2.1. WATER BALANCE IN PEDDAGEDDA, NAGAVALI AND VAMSADHARA WATERSHEDS

The use of both surface and groundwater resources for irrigation, drinking and industries continues to increase day by day. During planning for the development and management of water resources, it is to be ensured that a balance between precipitation, recharge and discharge in a basin is maintained. Precipitation is the main constituent in the entire hydrological system. Precipitation can directly benefit agriculture. Though the surface and groundwater resources also receive their supplies entirely from precipitation, they cannot be used directly for domestic or industrial requirements. For that reason, estimation of annual volume of precipitation, its allocations, and surface water flows and groundwater stocks together are essential for planning and management of water resources.

Water balance technique is extensively used to make quantitative assessment of surface and groundwater resources, and influence of man's activity on the hydrological cycle. Water resource planning and development based on conjunctive use of surface and ground water is necessary to meet the future demand of water. The realistic assessment and planning of the surface water and groundwater resources to fulfill the needs of domestic, industrials and crop requirement with neither water logging nor excessive exploration of groundwater resources is a prerequisite for sustainable development.

Hydrological system is a complex system that maintains balance between precipitation, interception, evaporation, transpiration, run-off, infiltration, and other sub features like seepage, soil moisture, soil retention and stocks. Local geology, land use/land cover, soils and slope control this system. This system is further influenced by human and animal population for withdrawals to meet their demands for survival. The hydrological cycle can be classed into four sub-systems: i) atmosphere system containing rainfall, interception, evaporation; ii) surface water system maintaining surface run-off to streams, rivers and oceans, overland flow, sub-surface flow and groundwater out flow and iii) subsurface system, infiltration (groundwater recharge) and groundwater flow which occurs deeper in the soil and rock strata; and finally iv) water utilization shows the consumption of water for different purposes. Figure. 2.1 show the general Hydrological system.

The physical accounting of water and individual contributions of sources in Peddagedda, Nagavali and Vamsadhara watersheds has been carried out using water balance approach. The water balance can be demonstrated broadly by the following equation

Precipitation = Interception + Evapotranspiration +Surface water storage +Run-Off

+Groundwater Recharge

For proper assessment of potential, present use and additional exploitability at optimal level of both surface and ground water resources, it is acknowledged that a basin wise or catchment wise approach yields the best results. Hence, watershed is selected as a unit, having single drainage point, most suitable for hydrological studies. The relationships between inputs viz., rainfall, interception, evapotranspiration, run-off, groundwater recharge, and extractions and out flows are studied here in detail.

2.2. Data Collection

Secondary data regarding rainfall, temperature, irrigation pattern and other socioeconomic data were collected block-wise from different State and Central government organizations and this data has been converted into information for individual watershed. The average monthly rainfall of all the three watersheds for the year 1971 – 95 has been obtained from National Information Center (Srikakulam), and temperature, evapotranspiration, wind velocity were obtained from Indian Meteorological Department observatory at Calingapatnam, Srikakulam district, A.P. Intensive field surveys were conducted to study the tanks in the three watersheds and farmers under the tanks were interviewed using a pre-tested structure to under stand their perception on irrigation, water and other socioeconomic aspects.

2.3. DESCRIPTION OF PERAMETERS AND METHOLODOY OF ESTIMATION

Precipitation or rainfall, on which all the hydrological parameters depend is the main driver for the entire hydrological system. Immediately after precipitation takes place, it is intercepted by tree canopy cover and some of the rainfall is retained by the canopy while remaining falls on the ground. Some amount of surface water that touches the ground is stored in tanks and reservoirs and the remaining flows as run-off into the sea. The water percolated during this process is utilized partly in filling the soil moisture deficiency and part of it is percolated down which finally gets stored in the groundwater aquifer. This process of water reaching the water table is called recharge from rainfall to the aquifer and depends on various hydro-meteorological and topographic factors, viz., slope, land use/land cover, soil characteristics, temperature and depth to water table of the area. The obtained field data, secondary data and the norms given by Central Groundwater Board, Indian Agricultural Research Institute have been used for this study.

This study has been carried out for all the three watersheds in four stages starting from computation of rainfall to the total extractions for irrigation, drinking, domestic and livestock purposes. In the first phase, average annual rainfall for the years 1971 – 95 in the watersheds has been calculated, while the amount of run-off into rivers, water stored in tanks, water out flow through run-off has been calculated in the second phase. In the third phase soil penetration, seepage losses, soil retention and groundwater percolation has been calculated. Finally, in the fourth phase water extractions are calculated and water balance is arrived. The study has been carried out using the data till 1994-95 as the latest data on watershed basis from 1994-95 is not available.

2.3.1. Precipitation

The knowledge of the amount and character of precipitation is mandatory in hydrological study. The amount of rainfall is expressed as the depth of water in millimeters. The average precipitation data on monthly basis from 1971 to 1995 for the three rain gauge stations located in the Peddagedda watershed, seven stations in Nagavali watershed and five stations in Vamsadhara watershed have been collected from National Information Centre, Srikakulam. Total rainfall is estimated by adding the monsoon rain and non-monsoon rain.

2.3.2. Interception

Interception, the initial loss, is the portion of the total rainfall, that adheres to the canopy in the watershed. The amount of intercepted water is a function of the duration and intensity of rainfall, types of plant species present and density of vegetation in the watershed and season of the year. Out of this, most of the intercepted water would evaporate into the atmosphere and some amount will reach the ground due to wind action. The volume of water that is lost by evaporation from tree canopy is called interception loss. There are no studies on the estimation of interception in the study area, but depending upon the area of forest cover and type of species in the three watersheds. However, based on the data given by, Mutreja, 1986, it is estimated that about 10% of the total rain is intercepted and returned to the atmosphere. The actual amount of rainfall that touches the ground surface after the initial losses is termed in this study as rainfall available to soil.

2.3.3. Evapotranspiration

Evapotranspiration is the main hydrological loss from the earth surface. About 75 percent of total annual precipitation is lost due to evapotranspiration (Mutreja, 1986)[x]. The evapotranspiration is the amount of water transferred to the atmosphere as water vapor through evaporation from surface water bodies, irrigation fields and topsoil, and transpiration from tree leaves in a watershed. The intensity of evapotranspiration depends on the area covered by surface water bodies, temperature, velocity of wind, and vegetation cover. Most of the water lost through evapotranspiration is not available to use within the same basin. Hence, it is a loss to that watershed.

Thoranthwaite (1948)[xi] developed the concept of potential evapotranspiration (PET) i.e., the amount of water that would be evaporated from the surface and transpired by the vegetation if sufficient moisture is always available to completely meet the needs of vegetation fully covering the area. The relation between mean monthly temperature and potential evapotranspiration to a month of 30 days, each having 12 hours of possible sunshine is shown by the equation

$$e = 1.6(10/I)^a$$

e = monthly thermal efficiency in Cms.

t = mean monthly temperature

I = annual heat Index being equal to

$\Box i_n$

where i_n = mean heat index of the nth month , $i_n = (t_n/5)^{1.514}$

where, t_n, is the mean temperature of the nth month, and

$$a = 675 \times 10^{-9} I^3 - 771 \times 10^{-7} I^2 + 0.01792 I + 0.49239$$

Using the above equations, the potential evapotranspiration for Peddagedda, Nagavali and Vamsadhara watersheds have been calculated separately for 1971 - 86 and 1987 - 95. The actual evapotranspiration is estimated considering the data available at Calingapatnam Meteorological Observatory located at a distance of 30 to 50 km. from the study area. From this data it is observed that about 63.3 percent of potential evapotranspiration is the actual evapotranspiration in the three watersheds. This parameter has been used to estimate monthly actual evapotranspiration (AET) in all the three watersheds. Table 2.1 to 2.6 shows monthly rainfall, interception and evapotranspiration losses in Peddagedda, Nagavali and Vamsadhara watersheds for the years 1971-86 and 1984-1995. Maximum evapotranspiration is observed in the month of April, May and June in all the three watersheds. The evapotranspiration is more though there is less rainfall in the months of January, February, March and December. This indicates that in these two months the water is evaporated from the soil moisture retained in the topsoil from the previous rainfall months and also from surface water bodies. The actual average amount of water that is evaporated and transpired from Peddagedda, Nagavali and

Vamsadhara watersheds from 1971-1995 is estimated at as, 5529 ha-m., 16964 ha-m., 11318 ha-m per annum which is 13.5%, 12.5 % 12.9% of the rainfall

Table 2.1. Rainfall and other losses in Peddagedda watershed for the rainfall period 1971-86.

Month	Rainfall (in mm)	Interception (in mm)	R/f available to soil (in ha-m)	Evapotranspiration (in ha-m)	
				PET (PEt)	AET (AEt)
January	8.62	0.86	337.95	623.24	393.46
February	13.77	1.38	539.91	763.25	481.24
March	14.15	1.41	554.73	789.45	494.51
April	24.30	2.43	952.88	794.11	501.24
May	125.83	12.58	4934.24	791.20	500.89
June	104.18	10.42	4085.44	756.91	479.85
July	156.30	15.63	6129.35	751.55	469.25
August	175.12	17.51	6867.33	761.24	482.15
September	160.08	16.01	6277.51	765.00	483.21
October	159.88	15.99	6269.78	725.00	459.01
November	98.76	9.88	3873.01	641.24	405.32
December	1.64	0.16	64.16	608.53	386.41
	1042.62	104.26	40886.29	8770.72	5536.54

Table 2.2. Rainfall and other losses in Peddagedda watershed for the rainfall period 1987-95.

Month	Rainfall (in mm)	Interception (in mm)	R/f available to soil (ha-m)	Evapotranspiration (in ha-m)	
				PET (PEt)	AET (AEt)
Jan	7.12	0.71	279.21	611.31	386.96
Feb	81.27	8.13	3186.99	750.30	474.94
Mar	17.34	1.73	679.98	773.83	489.83
April	29.19	2.92	1144.68	785.16	497.01
May	7.23	0.72	283.52	790.40	500.32
June	110.34	11.03	4326.96	763.81	483.49
July	172.29	17.23	6756.32	743.77	470.81
August	123.21	12.32	4831.66	763.81	483.49
September	196.73	19.67	7714.73	767.30	485.70
October	272.12	27.21	10671.13	727.65	460.60
November	98.21	9.82	3851.29	640.07	405.16
December	2.11	0.21	82.74	607.82	384.75
Total	1117.16	111.72	43809.21	8725.23	5523.06

Table 2.3. Rainfall and other losses in Nagavali watershed for the rainfall period 1971-86.

Month	Rainfall (in mm)	Interception (in mm)	R/f available to soil (ha-m)	Evapotranspiration (in ha-m)	
				PET (PEt)	AET (AEt)
January	3.60	0.36	454.84	1728.58	1094.17
February	10.40	1.04	1314.02	1789.80	1132.94
March	5.10	0.51	644.37	2062.20	1305.37
April	20.20	2.02	2552.23	2220.90	1405.82
May	42.10	4.21	5319.26	2300.90	1456.46
June	88.00	8.80	11118.65	2336.00	1478.68
July	161.40	16.14	20392.61	2181.60	1380.95
August	190.30	19.03	24044.08	2201.20	1393.35
September	171.80	17.18	21706.63	2159.10	1366.71
October	189.90	18.99	23993.54	2003.32	1268.10
November	103.10	10.31	13026.50	1788.60	1132.18
December	1.10	0.11	138.98	1736.77	1099.37
Total	987.00	98.70	124705.71	24508.97	15514.10

Table 2.4. Rainfall and other losses in Nagavali watershed for the rainfall period 1987-95

Month	Rainfall (in mm)	Interception (in mm)	R/f available to soil (ha-m)	Evapotranspiration (in ha-m)	
				PET (PEt)	AET (AEt)
January	6.70	0.67	846.53	2168.90	1372.90
February	15.00	1.50	1895.22	2230.70	1412.03
March	12.40	1.24	1566.70	2472.20	1564.90
April	32.70	3.27	4131.59	2529.70	1401.30
May	67.20	6.72	8490.60	2557.80	1919.10
June	93.30	9.33	11788.30	2498.80	1582.31
July	179.10	17.91	22628.98	2410.64	1525.80
August	168.40	16.84	21277.05	2379.50	1506.22
September	207.30	20.73	26192.50	2424.40	1634.64
October	174.80	17.48	22085.68	2365.61	1497.36
November	127.30	12.73	16084.13	2108.60	1498.36
December	8.90	0.89	1124.49	2097.30	1499.36
Total	1093.10	109.31	138111.77	28244.15	18414.28

Table 2.5. Rainfall and other losses in Vamsadhara watershed for the rainfall period 1971-86

Month	Rainfall	Interception	R/f available to soil	Evapotranspiration	
				PET (PEt)	AET (AEt)
January	2.40	0.24	204.61	1190.70	753.71
February	11.30	1.13	963.35	1299.70	822.71
March	4.50	0.45	383.64	1391.50	880.81
April	16.00	1.60	1364.04	1498.50	948.55
May	36.40	3.64	3103.19	1552.50	982.73
June	68.60	6.86	5848.32	1576.20	997.73
July	152.50	15.25	13001.01	1472.00	931.77
August	180.70	18.07	15405.13	1485.20	940.13
September	156.20	15.62	13316.44	1456.80	922.10
October	213.30	21.33	18184.36	1351.70	855.60
November	120.80	12.08	10298.50	1252.23	792.66
December	1.40	0.14	119.35	1176.50	744.72
Total	964.10	96.41	82191.94	16703.53	10573.22

Table 2.6. Rainfall and other losses in Vamsadhara watershed for the rainfall period 1987-95

Month	Rainfall	Interception	R/f available to soil	Evapotranspiration	
				PET (PEt)	AET (AEt)
January	5.60	0.56	477.41	1463.50	926.39
February	24.50	2.45	2088.69	1505.10	952.72
March	18.50	1.85	1577.17	1668.10	1055.90
April	43.40	4.34	3699.96	1706.90	1080.46
May	120.80	12.08	10298.50	1725.80	1092.43
June	141.10	14.11	12029.13	1686.10	1067.30
July	211.00	21.10	17988.28	1626.40	1029.51
August	196.80	19.68	16777.69	1605.50	1016.28
September	211.90	21.19	18065.00	1635.90	1035.52
October	168.00	16.80	14322.42	1596.10	1010.33
November	78.10	7.81	6658.22	1422.70	900.56
December	5.00	0.50	426.26	1415.10	895.72
Total	1224.70	122.47	104408.73	19057.20	12063.12

available to soil respectively. The actual amount of water available for further processes after evapotranspiration is termed as net volume of water. The evapotranspiration has been estimated in terms of volume by multiplying with area of the watershed.

2.3.4. Run-Off

Run-off is the excess of precipitation that reaches the stringlets, streams, tributaries and join rivers and that ultimately leaves the watershed as outflow. Run-off has been calculated in the watershed after estimating the quantity of water used by intermediate processes like initial losses, evapotranspiration, and infiltration. The actual run-off is equal to the total rainfall minus absorption, percolation and losses due to evapotranspiration,

Several empirical models (Ragan et al.,1980[xii]; Bathurst,1986[xiii]) are in use to estimate the quantity of rainfall run-off in a hydrological unit. Information on climatic parameters, soils, land use/ land cover and terrain characteristics are basic inputs to estimate run-off. The run-off is affected by many factors like shape and size of the watershed, underlying geological formation, duration and intensity of rainfall, type of soil and storage characteristics. The more the rainfall the more will be the run-off. If the rainfall intensity is very less, and it rains as light showers, much of the water will be retained by the top soil and mostly lost by evaporation.

The monthly run-off from Peddagedda, Nagavali and Vamsadhara watersheds was computed by using empirical formula given by Lacey (Punmia and Pandey, 1990)[xiv]. The main reason to chose this formula is the fact that the influence of both terrain features and soil type in the watershed are considered in estimating the run-off. The formula is expressed as,

$$R= P/1+((304.8*F)/P*S))$$

where, R= Run-off in cms.

P= Annual precipitation in cms

S= watershed factor, varies with the watershed characteristics

F= Monsoon Duration factor, varies with the rainfall.

304.8 is the constant irrespective of the terrain features.

Corresponding to the five classes of the watershed, the following values are given for watershed factor (Table 2.7).

Table 2.7. Watershed Factor

Class of watershed	Description of the Watershed	Watershed Factor 'S'
1	Flat, cultivated and black cotton soils	0.25
2	Flat, partly cultivated various soils	0.60
3	Average	1.00
4	Hills and plains with cultivation	1.70
5	Very hilly and steep hardly any cultivation	3.45

Lacy categorized the monsoon into three classes depending upon the duration and gave the following values of monsoon factor (Table 2.8)

Table 2.8. Class of monsoon and duration factor

Sl.No.	Class of monsoon	Monsoon factor 'F'
1.	Very short	0.5
2	Standard length	1.08
3	Very long	1.50

Peddagedda watershed comprises plain and partly cultivated land with isolated hills. Hence it is considered as a Class 2 watershed with watershed factor 0.6 has been used. Whereas the Nagavali and Vamsadhrara watersheds comprise plains, hills and cultivated land. Hence, these two watersheds are considered as Class 3 watersheds and watershed factor 1 has been used. The monsoon factor 1.08 is used for all the three watersheds as the monsoon in the area is of standard length. Using the formula given by Lacey it is estimated that 32.95%, 25.70% and 27.25% of monthly rainfall is flowing in rivers and streams as run-off in the Peddagedda, Nagavali and Vamsadhrara watersheds respectively.

2.3.5. Storage of water in the tanks

The water flow in to the surface water tanks in the three watersheds is estimated as a fraction of run-off. As there are no studies to estimate the amount of water flowing into the tanks out of rainfall, a parameter has been arrived at to estimate the amount of water that flows into the tanks. The total number of tanks, their surface area and area of different crops irrigated under the tanks (command area) are considered to arrive at the parameter as a percentage of net volume of water. In all the three watersheds tank water is sufficient only for single irrigated paddy crop. There are nearly 746 small and medium tanks in the Peddagedda watershed and the total area irrigated under different crops is about 19142 acres. The total surface area of the tanks measured through topographic maps is about 8117 acres. In Peddagedda watershed the average area irrigated under tanks is about 7279 acres(1985 – 86), 7629 acres (1988-89) and 5895 acres in 1994 – 95. By taking the irrigated area under the tanks, the approximate volume of water stored in the tanks is arrived at as 32.17% of the net volume of water. In Nagavali watershed there are nearly 2014 water bodies with surface area of about 20772 acres. The average area irrigated by tanks under different crops is about 55713 acres (1985-86), 54962 acres (1988-89) and 44111 (1994 – 95) and the estimated volume of water in the tanks is about 28% of the net volume of water. In Vamsadhara watershed, there are about 1057 tanks with surface area of about 12214 acres. The average area irrigated by tanks under different crops is about 37037 acres (1985-86), 45186 acres (1988-89) and 29084 acres(1994-95) respectively. The estimated volume of water in the tanks is assumed as 26.80% of the net volume of rain.

2.3.6. Soil Retention

The next process of the hydrological cycle is soil retention. First the top soil is saturated and after the top soil reaches saturation stage, the remaining water that percolates into the earth surface seeps through the soil layers and reaches the groundwater to recharge the aquifer. The water retained by the topsoils is called soil retention and depends on the type and thickness of the soil. In the present study the soil retention in the three watersheds is calculated from the field capacity- “the amount of water that the soil can retain". The soils in the three watershed are alluvial, sandy silty clay, sandy silty loam and marine soils. The water holding capacity of these soils is 100 mm (Thoranthwaite, 1930)[xv]. Thus the average value of soil retention based on the field capacity is taken as 10% of the volume of water available for groundwater recharge.

2.3.7. Groundwater recharge

Recharge from rainfall is the most important parameter in the water balance studies. Recharge refers to water reaching the saturated zone of an aquifer where it is available for extraction. The increase in groundwater takes place mainly due to recharge of aquifers through deep percolation of rainwater. The rainfall after interception by vegetation canopy cover reaches the land surface and fills the surface depressions (tanks) while some amount infiltrates into the soil surface vertically and horizontally. The topsoil retain a portion of the infiltration water as soil retention and remaining reaches the groundwater storage and is called groundwater recharge. This recharge which is a fraction of total rainfall depends on several factors like land use/land cover, type of soil, underlying geological formation, and depth of water table. The recharge in Peddagedda, Nagavali and Vamsadhara watersheds is estimated after subtracting the water stored in tanks, run-off and soil retention from net volume of rain. The estimated run-off, water in tanks, run-off and groundwater recharge in all the three watersheds for the rainfall years 1971-86 and 1987-95 are presented in Tables 2.9 through 2.14.

2.3.8. Recharge from Irrigation Fields

A part of the irrigation water applied to the field crops is used in meeting the consumptive use of crops and the balance water infiltrates into the soil and recharges the groundwater aquifer. The recharge from applied irrigation water plays a major role in replenishing the groundwater in all watersheds as this area is mostly under paddy cultivation, which is a wet crop requiring submergence of soil with water for long duration. The recharge from surface water irrigation and groundwater irrigation has been calculated according to the norms given by Ground Water Estimation Committee , The following norms are recommended by the GWEC.

a) Irrigation by surface water resources

i) 35 percent of water applied in the field

ii) 40 percent of water applied to the field in case of paddy

b) Irrigation by groundwater resources

i) 35% of the applied irrigation water for paddy.

These figures include losses in field channels.

In the Peddagedda watershed about 2910 ha. of paddy, 507 ha. of other corps on an average, were irrigated by the surface water sources and 2304 ha. of paddy and 441 ha. of other crops are being irrigated by groundwater sources in 1985-86. In 1988-89, about 3051 ha. of paddy, and 560.32 ha. of other crops were irrigated by surface water sources and about 2350 ha. of paddy, and 445 ha of other crops were irrigated by groundwater sources. In 1994-95, about 2008 ha. of paddy, and 851 ha. of other crops were irrigated by surface water sources, and 1498 ha. of paddy and 715 ha. of other crops were irrigated by groundwater resources. Using the norms given by Groundwater Estimation Committee and the irrigated area, the estimated groundwater recharge from quantity of surface water and groundwater used to irrigate paddy and other crops together is 2440 ha-m., 2856 ha-m., 1887 ha-m. in 1985-86, 1988-89 and in 1994-95 respectively. Thus average recharge in Peddagedda watershed is 2394 ha-m.

In Nagavali watershed about 58360 ha-m. of surface water and 4348 ha-m. of groundwater was put to use to irrigate paddy, and 6461 ha-m of surface and groundwater to irrigate other crops like ragi, sugarcane, groundnut in 1985-86. In 1988-89, the surface water consumption and groundwater consumption to irrigate paddy is about 58637 ha-m and 5457 ha-m., respectively and the consumption for other crops was about 5094 ha-m. In 1994-95, the surface water consumption of paddy was reduced to 49694 ha-m. and groundwater consumption has increased to 7113 ha-m. and surface and groundwater consumption for other crops has also increased to about 7627 ha-m. The estimated groundwater recharge from surface and groundwater irrigated fields in this watershed is 27127 ha-m., 27147 ha-m., and 25036 ha-m. in 1985-86, 1988-89 and 1994-95 respectively. The average recharge from applied irrigation in this watershed is 26436 ha-m.

Table 2.9. Net volume of rain and its natural distribution in Peddagedda watershed for the rainfall period 1971-86

(in ha-m)

Net Volume of rain	Water Stored in tanks	Run-off in Rivers/ Streams	Soil Retention	Groundwater Recharge
0.00	47.31	0.00	0.00	0.00
58.67	75.59	19.30	5.87	0.00
60.22	77.66	19.81	6.02	0.00
451.64	133.40	148.59	45.16	124.48
4433.35	690.79	1458.57	443.34	1840.65
3605.59	571.96	1186.24	360.56	1486.83
5660.10	858.11	1862.17	566.01	2373.81
6385.18	961.43	2100.73	638.52	2684.51
5794.30	878.85	1906.32	579.43	2429.69
5810.77	877.77	1911.74	581.08	2440.18
3467.69	542.22	1140.87	346.77	1437.83
0.00	8.98	0.00	0.00	0.00
35727.51	5724.08	11754.35	3572.75	10682.53

Table 2.10. Net volume of rain and its natural distribution in Peddagedda watershed for the rainfall period 1987-95

(in ha-m)

Net Volume of rain	Water Stored in tanks	Run-off in Rivers/ Streams	Soil Retention	Groundwater Recharge
0.00	39.09	0.00	0.00	0.00
2712.05	446.18	892.26	271.20	1102.40
190.15	95.20	62.56	19.02	13.38
647.67	160.26	213.08	64.77	209.56
0.00	39.69	0.00	0.00	-39.69
3843.47	605.77	1264.50	384.35	1588.85
6285.51	945.88	2067.93	628.55	2643.14
4348.17	676.43	1430.55	434.82	1806.37
7229.03	1080.06	2378.35	722.90	3047.71
10210.53	1493.96	3359.26	1021.05	4336.26
3446.13	539.18	1133.78	344.61	1428.56
0.00	11.58	0.00	0.00	0.00
38912.70	6133.29	12802.28	3891.27	16136.54

Table 2.11. Net volume of rain and its natural distribution in Nagavali watershed for the rainfall period 1971-86

(in ha-m)

Net Volume of rain	Water Stored in tanks	Run-off in Rivers/ Streams	Soil Retention	Groundwater Recharge
0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00
1146.41	320.99	294.63	114.64	416.15
3862.80	1081.58	992.74	386.28	1402.20
9639.97	2699.19	2477.47	964.00	3499.31
19011.66	5323.26	4886.00	1901.17	6901.23
22650.73	6342.20	5821.24	2265.07	8222.21
20339.92	5695.18	5227.36	2033.99	7383.39
22725.44	6363.12	5840.44	2272.54	8249.33
11894.32	3330.41	3056.84	1189.43	4317.64
0.00	0.00	0.00	0.00	0.00
111271.25	31155.95	28596.71	11127.13	40391.46

Table 2.12. Net volume of rain and its natural distribution in Nagavali watershed for the rainfall period 1987-95

(in ha-m)

Net Volume of rain	Water Stored in tanks	Run-off in Rivers/ Streams	Soil Retention (1	Groundwater Recharge
0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00
1.80	0.50	0.46	0.18	0.65
2730.29	764.48	701.68	273.03	991.10
6571.50	1840.02	1688.88	657.15	2385.45
10205.99	2857.68	2622.94	1020.60	3704.77
21103.18	5908.89	5423.52	2110.32	7660.45
19770.83	5535.83	5081.10	1977.08	7176.81
24557.86	6876.20	6311.37	2455.79	8914.50
20588.32	5764.73	5291.20	2058.83	7473.56
14585.77	4084.02	3748.54	1458.58	5294.63
0.00	0.00	0.00	0.00	0.00
120115.54	33632.35	30869.69	12011.55	43601.94

Table 2.13. Net volume of rain and its natural distribution in Vamsadhara watershed for the rainfall period 1971-86

(in ha-m)

Net Volume of rain	Water Stored in tanks	Run-off in Rivers/ Streams	Soil Retention	Groundwater Recharge
0.00	0.00	0.00	0.00	0.00
140.64	37.69	38.33	14.06	50.56
0.00	0.00	0.00	0.00	0.00
415.49	111.35	113.22	41.55	149.37
2120.46	568.28	577.83	212.05	762.31
4850.59	1299.96	1321.79	485.06	1743.79
12069.24	3234.56	3288.87	1206.92	4338.89
14465.00	3876.62	3941.71	1446.50	5200.17
12394.34	3321.68	3377.46	1239.43	4455.77
17328.76	4644.11	4722.09	1732.88	6229.69
9505.84	2547.57	2590.34	950.58	3417.35
0.00	0.00	0.00	0.00	0.00
73290.37	19641.82	19971.62	7329.04	26347.89

Table 2.14. Net volume of rain and its natural distribution in Vamsadhara watershed for the rainfall period 1987-95

(in ha-m)

Net Volume of rain	Water Stored in tanks	Run-off in Rivers/ Streams	Soil Retention	Groundwater Recharge
0.00	0.00	0.00	0.00	0.00
1135.97	304.44	309.55	113.60	408.38
521.27	139.70	142.05	52.13	187.40
2619.50	702.03	713.81	261.95	941.71
9206.07	2467.23	2508.65	920.61	3309.58
10961.83	2937.77	2987.10	1096.18	3940.78
16958.77	4544.95	4621.26	1695.88	6096.68
15761.41	4224.06	4294.98	1576.14	5666.23
17029.48	4563.90	4640.53	1702.95	6122.10
13312.09	3567.64	3627.54	1331.21	4785.70
5757.66	1543.05	1568.96	575.77	2069.88
0.00	0.00	0.00	0.00	0.00
93264.05	24994.76	25414.45	9326.40	33528.42

In Vamsadhara watershed, surface water and groundwater consumption to irrigate paddy, in 1985-86, was about 53126 ha-m. and 4641 ha-m. respectively, where as the groundwater and surface water consumption to irrigate other crops was 4718 ha-m. In 1988-89, the surface and groundwater consumption for paddy was 57718 ha-m. and 5111 ha-m. and the consumption for other crops was 4796 ha-m. In 1994-

95, the surface water consumption for paddy was 50545 ha-m. and groundwater consumption for paddy was 5442 ha-m. The water consumption for other crops from surface and groundwater sources was 4192 ha-m. Thus the estimated groundwater recharge from surface and groundwater irrigation for the years 1985-86, 1988-89 and 1994-95 are 24526 ha-m, 26554 ha-m, and 23589 ha-m. respectively. The average recharge from irrigation fields is 24889 ha-m. From the above analysis is clear that surface water utilization is maximum in these three watersheds.

Considering the irrigated area under different crops and water consumption the total recharge to groundwater aquifer is estimated in the three watersheds as the residue of the water after all intermittent processes in the watershed. Thus the total groundwater recharge is estimated at as

Tot. GWR = Rain recharge + Recharge from Irrigation fields

Peddagedda Watershed

1985 – 86 = 10682 ha-m. + 2440 ha-m
= 13122 ha-m.
1994 – 95 = 16136.5 + 1887 ha-m
= 18023.5 ha-m.

Nagavali watershed

1985 – 86 = 40391 ha-m + 27127 ha-m.
= 67518 ha-m.
1994 – 95 = 43601 ha-m + 25036 ha-m
= 70748 ha-m.

Vamsadhara Watershed

1985 – 86 = 26347 ha-m + 24526 ha-m.
= 50873 ha-m.
1994 – 95 = 33528 ha-m +23589 ha-m
= 54117 ha-m.

From the above statistics it is evident the groundwater recharge is increased from 1985-86 to 1994-95. This is attributed to increase in rainfall and increase in irrigation return flow.

2.4. ESTIMATE OF WATER UTILIZATION

From the water balance studies the estimated total average annual surface water stored in tanks and that flowing in the rivers/streams are 5928 ha-m. and 12278.3 ha-m. in the Peddagedda watershed, 32393 ha-m. and 29732 ha-m. in the Nagavali watershed, and ha-m. 22317 ha-m. and 22692 ha-m. in the Vamsadhara watershed respectively. The estimated average groundwater excluding irrigation return flow is 13409 ha-m. in the Peddagedda, 41996 ha-m. in the Nagavali and 29937 ha-m in the Vamsadhara watershed. An attempt has been made to assess the annual withdrawls of water from tanks, rivers and groundwater for irrigation, domestic and livestock usage in all the three watersheds. Industries are not considered in this study, as there are hardly any significant industries. As reliable information regarding actual utilization of water for different crops, which varies from crop to crop and season to season is not available, an attempt has been made to provide a few approximate estimates of water utilization.

From the irrigation data available for the last 10 years (1985-86 to 1994-95) it has been observed that at an average of 14913 acres of land in Peddagedda watershed, 140720 acres in Nagavali watershed and 149375 acres in Vamsadhara watershed, which account to 3.5%, 30.51%, and 32.4% of the district total respectively are being used to irrigate paddy and other crops by different sources. The primary irrigation sources are tanks, followed by canals, tube wells and dug wells in Peddagedda and Nagavali while canals constitute are the primary irrigation source in Vamsadhara watershed.

2.4.1. Methodology for estimating water utilization

To understand the average annual water requirement in all the three watersheds to irrigate paddy, ragi, sugarcane, groundnut and other crops, an attempt has been made to estimate water utilized for the years 1985-86, 1988-89 and 1994-95 in all the three watersheds. Source-wise and crop-wise water requirement has been estimated in detail in this study. The data on irrigation potential and cropping pattern was collected from Chief Planning Officer, Srikakulam. As there is no exact estimate of water required by different crops for each season in the present study area, the crop water requirement norms (Table 2.15) given by Indian Agriculture Research Institute (IARI), New Delhi are taken into consideration to compute present water utilization.

Table 2.15. Crop water Requirement

Sl. No.	Type of Crop	Depth of water (mm)
1	Paddy	1300
2	Ragi	460
3	Sugarcane	1400
4	Bajra	340
5	Groundnut	650
6	Chillies	600
7	Jowar	400
8	Sesamum	500
9	Mesta	400

Source: IARI, New Delhi.

Using the above norms the amount of water consumed by different crops grown in the area and the percentage of water withdrawl from each source has been estimated. The consumption has been estimated for the irrigated crops only. The crop-wise and source-wise irrigated area and water consumption in all the three watersheds for 1985-86, 88-89, and 94-95 are shown in Table 2.16, 2.17 and 2.18 respectively.

In Peddagedda Watershed at an average of about 44 - 46% of irrigation water being utilized is from the tanks, 7 to 8% of water requirement is being met from the canals, and 41-43% is being met from groundwater sources. This shows that the irrigation requirements in Peddagedda watershed are completely dependent on tanks and groundwater for irrigation. In Nagavali watershed 32 to 38% of irrigation water is used from tanks and 45 to 49% is met from canal sources and only 8 to 10% of groundwater is used for irrigation. Whereas, in Vamsadhara watershed 20 to 28% of total water utilized for irrigation is met from tanks, 48 to 53% is met from canals and only 6 to 8% is tapped from groundwater sources.

The maximum amount of water is being used to irrigate paddy as it is economically feasible crop with high benefits. It is observed that on an average 1.3 ha-m. of surface water and 0.7 ha-m. of groundwater are used to irrigate one hectare of cropped area indicating that surface water consumption is almost double the groundwater consumption in the three watersheds.

It is observed that in Peddagedda the average water consumption from tanks per annum is 3241 ha-m. while the average storage in the tanks is 5928.6 ha-m. Almost 54% of the water stored in tanks is being utilized to irrigate paddy, and other crops. Remaining water can not be utilized due to technical problems like height of sluice, loss of gravitational flow and other reasons.

Therefore, the surface irrigation potentiality indicates the serious limits to the availability of tank water for irrigation in Peddagedda watershed. In the Nagavali watershed, out of 32393 ha-m. of average availability of water in tanks, from estimates of water utilization it is found that 27745 ha-m of water, which amounts to 86% is being used for agriculture for a single crop of paddy and other crops. This shows that the tanks in Nagavali watershed are not able to provide water for second crop and the tanks are almost getting dry after January and February, which is corroborated from the field check also. In Vamsadhara watershed, out of the estimated average volume of 22317 ha-m. water available in tanks, the average utilization is 18791 ha-m. i.e., 85% of the available water. During field surveys in the three watersheds it is found that due to reduction of water levels in the tanks after using the water to certain level the farmers of the tail end of the tank command area are not getting water even for first crop.

2.4.2. Demand of Water

On an average every year there is about 40413 acres in Peddagedda watershed, 238,712 acres in Nagavali and 87570 acres of land in Vamsadhara watershed left un-irrigated under different crops due to lack of surface water resources, and financial constraints to tap groundwater. An estimate of the demand of water required to bring this un-irrigated land into irrigated is estimated and presented in Tables 2.19 to 2.21. Thus it can be observed from this

Table 2.19. Average un-irrigated area in Peddagedda Watershed and Demand

Crop	Area Un-irrigated (acres)	Water Demand (ha-m.)
Paddy	716	378.17
Ragi	498	93.02
Sugarcane	338	192.41
Groundnut	28034	7377.5
Jowar	93	15.38
Bajra	2134	294.02
Sesamum	2062	417.81
Mesta	6538	1058.86
Total	**40413**	**9827.17**

Table 2.20. Average un-irrigated area in Nagavali Watershed and Demand

Crop	Area Un-irrigated (acres)	Water Demand (Ha-m)
Paddy	25547	14498
Ragi	15020	2797
Sugarcane	2410	1366
Groundnut	105772	27834
Jowar	8575	1388
Bajra	16949	2333
Sesamum	10537	2133
Mesta	53902	8729
Total	**238712**	**61078**

fact that about 9827 ha-m. in Peddagedda watershed, 61078 ha-m. in Nagavali and 27084 ha-m. of water in Vamsadhara watershed is further required to bring the un-irrigated land to irrigated land. From the water balance studies it is found that about 12278 ha-m. of water is leaving the Peddagedda watershed as run-off into the Bay of Bengal. It is interesting to note that the amount of water leaving the basin is almost equal to the amount of water required for irrigating the remaining un-irrigated land. This requires efficient water conservation measure in these watersheds.

Table 2.21. Average un-irrigated area in Vamsadhara Watershed and Demand

Crop	Area Un-irrigated (acres)	Water Demand (Ha-m)
Paddy	26592	13995
Ragi	7612	1417
Sugarcane	1138	654
Groundnut	24976	6572
Jowar	2151	348
Bajra	5199	715
Sesamum	3969	803
Mesta	15933	2580
Total	**87570**	**27084**

On an average, the land under different crops left un-irrigated every year is about 40413 acres in Peddagedda watershed, 238712 acres in Nagavali and 87570 acres in Vamsadhara watersheds. This could be attributed to reasons like lack of surface water resources and financial constraints to tap groundwater.

Narayanapuram left and right canals have been constructed in the upper reaches of Nagavali watershed, and Gotta Barrage is constructed near Gotta village in the upper reaches of Vamsadhara watershed. As the canals are constructed only in the upper reaches the run-off water of the lower reaches is going waste (except a small amount which is not possible to measure due to lack of data) into the sea in both the Nagavali and Vamsadhara watersheds. However, in Peddagedda watershed there are no canals and run-off water is entirely going to the sea. If the run-off water leaving the three watersheds as waste is conserved as per the norms, there will be an increase irrigation potential in these three watersheds. This conserved water can be used during drought period. Thus the average yearly run-off leaving the Peddagedda, Nagavali and Vamsadhara watersheds is 12278 ha-m., 29732 ha-m, 22692 ha-m. every year respectively.

Though the groundwater availability in these three watersheds is high with 13409 ha-m. in Peddagedda, 41996 ha-m. in Nagavali and 29937 ha-m in Vamsadhara watersheds, the consumption is comparatively high is only in Peddagedda watershed. The consumption of groundwater resources for irrigation in this watershed is 2970 ha-m. which is 22.16% of the available groundwater resources. In Nagavali watershed the average groundwater consumption for irrigation is 6580 ha-m. which is 12.5% of the total available, whereas Vamsadhara watershed the groundwater consumption for irrigation is 5424 ha-m. which is only 7.8% of the total available groundwater. The remaining groundwater in these two watersheds is not tapped showing under utilization of groundwater. The main reason for this is that all the farmers in the area are small farmers owning 0.5 to 1.0 acre of land. Hence, they cannot invest high capital expenditure to go for groundwater irrigation.

2.4.3. Water for Drinking

The main source of drinking water in all the three watersheds is groundwater. The groundwater is pumped directly to the overhead tanks and distributed through pipe lines in the village. This system is called *"Rakshita Manchineeti Sarafara Pathakamu"* (*Telugu*) or "Protected Drinking Water Supply Program". About 90% of drinking water supplies are only from open wells and hand pumps. The drinking water consumption depends on the size of population in an area. The greater the population residing in an area, the more will be the water consumption. In addition, it depends upon their ages, social status, habits, religious beliefs and climatic conditions. The demand of water in urban areas is more than that of villages.

There is not much variation for drinking water from season to season in the study area. According to Indian Standards Specification the per capita consumption of water per day is 135 litres (Birdie, 1991)[xvi] including flushing of water closets. But this value is higher than the actual requirement in villages. In the rural areas it is difficult to measure exact consumption of water per day because most of the water consuming activities in rural areas like washing clothes, bathing etc. are carried out near open wells, hand pumps or tanks. By virtue of these limitations, assessment of domestic water requirement in the present three watersheds can only be a rough estimate. However, from the household survey conducted in the study area it is observed that the average water consumption per capita/per day is 62 liters in the villages of these three watersheds. The average consumption of water obtained from household surveys is given in Table 2.22.

Table 2.22. Domestic water consumption

Purpose	Consumption in lts.
Drinking	5
Cooking	10
Washing Utensils	12
Washing Clothes	15
Bathing	20
Total	62

Source: Household Survey

Population data was obtained from the Census of India (1991)[xvii]. Population projections have been made based on the 1981 and 1991 census and population growth rate. Water consumption by population is estimated by considering the water usage pattern noted from the household survey. The figures of the present and future water consumption in Peddagedda, Nagavali and Vamsadhara watersheds are shown in Table 2.23.

From table 2.23, it is found that the consumption of water in 1981 was 212.85 ha-m. in Peddagedda, 305ha-m in Nagavali, 861 ha-m in Vamsadhara and the projected demand for drinking water by 2021 AD is estimated at as 492.64, 2780, 1642 ha-m in Peddagedda, Nagavali, Vamsadhara watersheds respectively. The rate of increase of is around 2.3% per annum in Peddagedda, 1.92% in Nagavali and 1.4% in Vamsadhara watershed.

Table 2.23. Present and projected annual water consumption

Watershed	Peddagedda		Nagavali		Vamsadhara	
Year	Population	Water Consumption (ha-m)	Population	Water Consumption (ha-m)	Population	Water Consumption (ha-m)
1981	94056	212.85	577072	1305.91	380579	861.25
1991	115870	262.21	694793	1572.32	446285	1009.94
2001	142871	323.32	838375	1897.24	524065	1185.96
2011	176300	398.97	1013866	2294.38	616270	1394.62
2021	217694	492.64	1228811	2780.80	725732	1642.33

This shows that there will be lot of pressure on groundwater resources in the three watersheds in the coming years.

2.4.4. Livestock

Livestock is a life long asset in agriculture and plays an important role in agricultural economy. In Peddagedda, Nagavali and Vamsadhara watersheds, human to animal ratio is 2:1. During the field visits, no villager was able to give the exact rate of consumption of water by cattle. The main reason is that, generally, animals drink water directly from tanks or pits located near their grazing sites. Hence, in the absence of figures on exact rate of consumption of water by livestock, the approximate consumption rates given by the cattle owners obtained through field surveys (Table. 2.24) were used to estimate animal consumption.

Table 2.24. Water consumption by livestock

Livestock	Water Consumption liters/animal/day
Cows	67
Buffaloes	70
Sheep	13
Goat	13
Pig	17
Poultry	0.09

Source: Field Survey

To arrive the water consumption for livestock, the livestock population was taken from district handbooks. Table 2.25 gives the cattle wise annual consumption of water in Peddagedda, Nagavali and Vamsadhara watersheds.

2.4.5. Total Water Consumption and Balance

From the waters balance studies the estimated annual total water stocks, consumption obtained by aggregating the usage for irrigation, domestic and livestock, the water balance in Peddagedda, Nagavali and Vamsadhara watersheds is given below.

Peddagedda Watershed:

Stocks

Surface Water

Tanks : 5928.5 ha-m.

Rivers/Streams : 12278.31 ha-m.

Ground water : 13409.5 ha-m. (excluding irrigation return flow)

Extractions

Surface Water

Tanks : 3241 ha-m.

Groundwater

Tubewells & Dugwells : 2970 ha-m.

Outflow : 12278.31 ha-m.

Balance

Surface water

Tanks : 2687.50 ha-m.

Rivers/Streams: 12278.31ha-m.

Groundwater

10439.5 ha-m. + 2563 ha-m. (recharge from irrigation fields)

Nagavali Watershed:

Stocks

Surface Water

Tanks : 32392 ha-m.

Rivers/streams : 29732 ha-m.

Ground water : 41996 ha-m. (excluding irrigation return flow)

Extractions:

Surface Water

Tanks : 27745 + 263* ha-m..

Groundwater

Tubewells & Dugwells: 6580 * ha-m.. + 263*

Outflow : 29732 ha-m.

Balance :

Surface water

Tanks : 4384 ha-m.

Groundwater : 35416 + 26436 ha-m. (recharge from irrigation fields)

Vamsadhara watershed:

Stocks

Surface Water
Tanks : 22317 ha-m.
Rivers/Streams : 22692 ha-m.

Ground water : 29937 ha-m. (excluding irrigation return flow)

Extractions
Surface Water
Tanks : 18791* ha-m. + 262 ha-m.
Groundwater
Tubewells & Dugwells : 5424 ha-m.+ 262 ha-m.

Outflow : 22692 ha-m.

Balance
Surface water
Tanks : 1931.87 ha-m.
Rivers/Streams: 0.00 ha-m.
Groundwater : 24251 ha-m. + 24889 ha-m. (recharge from irrigation fields)

It is assumed that 50% of livestock consumption is from groundwater sources and 50% from surface water sources.

Table 2.25. Total annual water consumption by livestock

Peddagedda												
Year	Cattle	Water Consumption (ha-m)	Buffaloes	Water Consumption (ha-m)	Sheep	Water Consumption (ha-m)	Goat	Water Consumption (ha-m)	Pigs	Water Consumption (ha-m)	Poultry	Water Consumption(ha-m)
1985-86	32053	78.385	10700	27.338	19561	9.281	6404	3.039	656	0.407	48972	0.161
1988-89	29825	72.937	9002	23.001	19561	9.281	6405	3.039	656	0.407	48972	0.161
1994-95	30968	75.731	8646	22.090	20318	9.641	5925	2.811	1240	0.769	49376	0.162
Nagavali												
Year	Cattle		Buffaloes		Sheep		Goat		Pigs		Poultry	
1985-86	162834	398.211	58868	150.408	45153	21.425	24973	11.850	8923	5.537	319137	1.048
1988-89	144453	353.259	58367	149.127	45153	21.425	25579	12.137	9923	6.157	319137	1.048
1994-95	146230	357.605	51160	130.713	51095	24.244	23051	10.938	9269	5.751	325203	1.068
Vamsadhara												
Year	Cattle		Buffaloes		Sheep		Goat		Pigs		Poultry	
1985-86	96560	236.139	96560	246.712	32432	15.389	21173	10.047	6005	3.726	272138	0.894
1988-89	100417	245.571	48444	123.775	39387	18.689	21108	10.016	6005	3.726	272137	0.894
1994-95	100045	244.659	42069	107.485	45815	21.739	21057	9.991	5521	3.425	249307	0.819

CHAPTER 3: WATER QUALITY

The awareness and concern for environment, and pollution and its affects on human health is increasing with active involvement of the general public, particularly, with regard to groundwater which is the major source of drinking water in many villages in India. Though efforts are being made from a long time by successive governments across the country to ensure adequate drinking water, enough exercise in checking the quality of water supplied is lacking. With the rapid growth and urbanization and industrialization, the possibilities of the contamination of both the surface and groundwater sources are rapidly increasing. The groundwater sources being considered as relatively free from contamination are gradually, becoming degraded as a result of transport of soluble chemicals via the rainwater percolating into the subsoil and ultimately meeting the groundwater. The major elements in groundwater for cause of concern to the human health have come to light only after their effects were visible, which is often only after irreparable damage has been done. Of many such cases, the glaring examples of parts of Prakasham, Anantapur and Nalgonda districts of Andhra Pradesh are worth mentioning with regard to the high levels of fluoride in groundwater and widespread fluorosis as a result. Such cases should serve as standing examples for the scientific community to sit up and realize their basic commitment to the society to primarily channelize their efforts towards preventive measures against such devastating phenomena. This requires concerted effort from experts from all relevant fields.

According to drinking water standards of the WHO (1984)[xviii] the water containing more than 45 mg of nitrate per liter is harmful for infants. In the USA and Europe, approximately 2000 cases of methaemogolobinaemia were reported during the period 1945-1960 and about 7-8% of the infants died (Handa, 1989)[xix]. In Colombia and Italy, high levels of nitrate in well waters were associated with an increased risk of gastric cancer (Cuello et al., 1976[xx]; Gilli et all., 1984[xxi]). In a cross-sectional study in an area with a high incidence of gastric cancer in northeastern China, an association was observed between high levels of nitrate in drinking water supplies and neoplastic changes in the stomach (Xu et al., 1992)[xxii]. Fluoride is an essential nutrient and prevents dental caries but excessive concentrations (>1.0 mg/l) cause dental fluorosis (Srinivasa Rao,1997)[xxiii] and even skeletal fluorosis may occur if the fluoride content in water is more than 3 mg/l.

3.1. Pollutants in Groundwater

About 40% of the precipitation that falls on the earth infiltrates the soil and recharges local aquifers, the sediments and rocks that store and transport the groundwater. In general shallow, permeable water table aquifers are the most susceptible to contamination, but susceptibility of all aquifers to contamination is determined largely by such site-specific characteristics like

a) distance from the contamination source to the aquifer and residence time of the water in the unsaturated zone

b) presence of clay and organic matter in the unsaturated zone material

c) potential of a particular contaminant to biodegrade and decompose

d) amount of precipitation, which effects recharge and the rate at which contaminants move to the aquifer

e) evapo-transpiration, which in recharge areas may decrease the amount of water that moves downward to the aquifer

Groundwater contamination can occur in many ways and from many sources, both natural and human induced.

Natural Sources:

Groundwater commonly contains one or more naturally occurring chemicals leached from soil or rocks by percolating water, in concentrations that exceed drinking water standards or otherwise impair its use. Dissolved solids and chloride are one of the most common water quality concerns which found in all the coastal aquifers and are quite common in aquifers at depths greater that a few hundred feet below the land surface. Iron and manganese which occur in manganese rich areas, though not much toxic, but can impair the taste of water, stain plumbing fixtures, glass ware and form encrustations on well screens, thereby reducing well pumping efficiency. Nitrate-nitrogen concentrations of less that 0.2 mg/L generally represent natural conditions where as valued greater than 3 mg/L may indicate the effects of human activities.

Human activities:

Contaminants can enter groundwater from more than 30 different generic sources related to human activities. These sources commonly are referred to as either point or non-point sources. Point sources are localized in areas of an acre or less, where as non-point sources are dispersed over broad areas.

Man made fertilizers became widely available after World War II and quickly spread into the use across India too. At present nitrogen fertilizers (commonly nitrate or ammonium compounds) are used in large quantity in most agriculture settings. Nitrogen fertilizers applied to agricultural fields are the primary sources of nitrate in shallow groundwater, as the nitrate is very water soluble, and so can be transported by water from the land surface into soil and consequently to the aquifer. Nitrogen fertilizers not used by crops can be carried to the underlying aquifer by water percolating through soil. In the Srikakulam district irrigation water carries nitrate into shallow groundwater. Irrigated agriculture is consequently associated with high nitrate concentrations and high frequency of contamination of groundwater in the study area. Some times recharge from precipitation and irrigation carry nitrogen compounds from soil into the aquifer, often resulting in elevated nitrate concentrations in shallow wells. Where irrigation has raised the water table and fertilizer application is particularly heavy, elevated nitrate concentrations can be expected. Nitrate is the form of nitrogen that plants assimilate, and nitrogen compounds naturally transform into nitrate.

The possible pollutants in groundwater are virtually limitless. They can be either organic or inorganic. Organic materials are composed primarily of carbon and hydrogen; they may also contain smaller amounts of chlorine, nitrogen, sulphur, and phosphorus. Inorganic pollutants are nitrate, which can come from fertilizers or decayed organic materials; chlorides. The quality of groundwater is mostly influenced by the human use of water. A complete and interrelated series of modifications to natural water quality is created by the diversity of human activities impinging on the hydrologic cycle. Contaminants can enter groundwater from more than 30 different generic sources related to human activities. These sources are commonly referred to as either point or non-point sources. Point sources are localized in areas of an acre or less, whereas non-point sources are dispersed over broad areas. The most common sources of human-induced groundwater contamination can be grouped into four categories: waste disposal practices, storage and handling of materials and wastes; agricultural activities; and saline water intrusion. Of these, most pollution of groundwater stems from the disposal of wastes on or into the ground. The present study has been carried out to analyze the concentrations of nitrate and fluoride in the drinking water sources of the study area and to assess their impact on human health. In the last three decades reports on occurrence of excess fluoride and nitrate in water resources in several states of India were reported by Chari, et al., 1971[xxiv]; Handa, 1975[xxv], Sharma and Swamy, 1983[xxvi]; Gaumat et al., 1992[xxvii]; Handa, 1983[xxviii]; Bulusu and Pandey, 1990[xxix].

3.2. Occurrence of Fluoride

Fluorine normally exists in the form of fluoride in natural water due to its high reactivity. Minerals like fluorite (fluorspar), fluoraptite, fluormica (pholgopite), cryolite epidote, topaz, phosphorite, tremolite, villuanite and certain varieties of mica contribute fluoride (Matthess, 1982[xxx]; Hem, 1986[xxxi]). Gaciri and Davies (1993)[xxxii] report the presence of fluoride from 30 to 21000ppm in amphiboles present in metamorphic rocks. However, though such high values have not been reported in Indian condition, Raju et al., (1979)[xxxiii] reported high concentrations of fluoride in the amphibole formations of the Anantapur distict of Andhra Pradesh. The occurrence of fluoride in both igneous and sedimentary rocks is reported to be similar (Deer et al., 1983)[xxxiv]. The occurrences of minerals pyroxene amphibolites, apatites and pegmatites in the form of veins were reported by Padmanabhayya (1958)[xxxv] in the present study area. The recent application of phosphatic fertilizer is also observed to have a recognizable contribution to the enrichment of fluoride in the soils and groundwater in the study area.

3.3. Effects of excess flouride intake in humans

Fluoride is an essential nutrient and prevents dental caries but excessive concentrations (>1.0 mg/L) cause dental fluorosis and even skeletal fluorosis (>3.0 mg/L).

3.3.1. Dental Fluorosis

Dental flourosis or “mottled enamel” is a disfigurement associated with the ingestion of toxic amounts of flourides during the period of calcification of the teeth in infancy and early childhood i.e., birth to 6 years old. The permanent teeth, mainly, are effected, although dental flourosis can sometimes appear in baby teeth. The degree of severity depends mainly on the level of fluoride consumption but children are more sensitive to fluoride and develop severe dental flourosis even with a low in take. Flouride can have adverse effects on people of all ages. Reversible adverse effects include eczema, dematitis, epigastric distress, headache, excessive thirst, chronic fatigue, muscular weakness, mouth ulcers, lower urinary tract infection and flare up of old allergies.

3.3.2. Skeletal Fluorosis

Skeletal flourosis is a chronic metabolic bone and joint disease caused by chronic exposure to high doses of flouride. Skeletal flourosis has several stages: two pre-clinical asymptotic stages characterized bya slight radiographically-detectable increase in bone mass; an early symptomatic stage characterized by sporadic pain and stiffness of joints and osteosclerosis of the pelvis and vertebral column; a second clinical phase associated with chronic joint pain, arthritic symptoms, slight calcification of ligaments, and increased osteosclerosis of cancellous bones, sometimes accompanied by osteoporosis of long bones; and crippling skeletal fluorosis characterized by marked limitation of joint movements, and considerable calcification of ligament.

There are many areas in India where skeletal flourosis (non-dental flouride poisoning) has been reported since 1937. In areas having as much as 9.5 ppm fluoride, the reports of skeletal flourosis are decribed in terms of crippling deformities, quadriplegic patient bent with markedly restricted movements of spine, contractures of hips and knees, and with vertebrae fused at many places.

3.3.3. Other health problems due to excess fluoride

In India, fluorosis due to excess fluoride ingestion is a major health problem, and 15 of the thirty states and union territories being endemic for fluorosis. Rao and Susheela (1979) [xxxvi] reported that flouride may affect testosterone synthesis. Teotia and Teotia (1984)[xxxvii] have reported skeletal flourosis and dental flourosis in residents of rural areas consuming water containing 0.6ppm flouride. Jolly et al. (1969)[xxxviii] have also reported skeletal flourosis in some villages in Punjab with mean drinking water flouride levels of 3.0 ppm.

The male reproductive system in animals is also known to be adversely affected by excess flouride. Fluoride adversely affects spermatogenesis decreases mobility and density of sperm (Kumar and Susheela, 1994[xxxix]). Only a few reports are available on the affect of flouride on human male sex hormone. Tokar and Savchenko (1977)[xl] reported a decrease in serum testosterone levels in the occupational skeletal flourosis patients.

Fluoride is also known to cause ageing in human body. During the ageing process, the body loses its ability to discriminate between which tissues should be mineralized and which tissues should not. Fibroplasts in the arterial cell walls produce larger amounts of an imperfect collagen or collagen-like protein, resulting in calcification of the arteries. This disorder is commonly called hardening of the arteries or arteriosclerosis.

As mentioned earlier, groundwater is extensively (about 90%) used for drinking purpose in Srikakulam district. Water used for drinking must be free from bacteria, viruses and toxic elements and must contain minimum unattractive tastes, odor or color. Hard water effects household appliances and also increases soap use. The drinking water quality requirements are primary to preserve human health.

There is a misconception among farmers, that excess usage of fertilizers would return more yields. Thus excessive use of fertilizers has become a common practice in some parts of Srikakulam district. Consumption of nitrogenous fertilizers (e.g. Urea, NPK etc.) in Srikakulam district is at the rate of 100 to 150 kg per acre cropped area. The consumption of nitrogenous fertilizers is one of the major sources for nitrate in the groundwater. Any fertilizer, containing nitrate, if applied to soils in any form is immediately converted by soil organisms into nitrate, which are highly soluble by water and slowly infiltrates and reaches groundwater.

In this session an attempt has been made to identify and demarcate the groundwater sources with nitrate and fluoride contamination in Peddagedda, Nagavali and Vamsadhara watersheds. As there is no secondary data available for this watershed, water samples from bore wells and open wells, which are maximum used by the villagers for drinking water, were collected during November, 1999. In this area groundwater is recharged during monsoon season and from irrigation fields also. Water levels in these wells are ranging from 5 m to 8 m in pre-monsoon period and 1 m to 3 m in post-monsoon period from the ground surface. The groundwater flow is towards the main river. The chemical analysis of water samples has been carried out for the above samples and results are presented in Tables 3.1, 3.2 and 3.3 for Peddageda, Nagavali and Vamsadhara watersheds respectively.

From the results, it is clear that the groundwater is containing high values of either nitrate or fluoride. The water in the well near Ranasthalam village contains high values of both nitrate and fluoride. From Table 3.1, the nitrate concentration in groundwater ranges between 25 and 145 mg/l, while the tolerable limit is 45 mg/l, according to World Health Organization (WHO, 1984)[xli] standards. This indicates that out of fifteen samples collected and analyzed, 10 wells excess nitrate concentration. The cattle barns, which act as point sources for nitrate, were reported as main sources for high nitrate concentrations in the groundwater of Vamsadhara watershed (Srinivasa Rao, 1998)[xlii]. The agricultural practices and soil conditions in Peddagedda watershed were found to be more or less similar to the Vamsadhara watershed, thus the higher concentrations of nitrate in Peddagedda are also derived from animal wastes near cattle barns.

The WHO has prescribed a drinking water standard of 1.5mg/l for fluoride. However, it depends on climatic conditions. For Indian conditions (average temperature – 27°C), the maximum limit can be taken as 0.8 mg/l. It is found that some of the villages in three watersheds contains excess fluoride. The high fluoride concentrations are attributed to the dissolution of fluoride from geological formations (eg. fluorite, fluorapatite minerals etc.). However, the phosphatic fertilisers are also contributing some fluoride to the region.

Table 3.1. Nitrate and Fluoride Concentration in the villages of Peddagedda Watershed

Sample No.	**Village Name**	**Nitrate (mg/l)**	**Fluoride (mg/l)**
		Tolerable limit 45 mg/lt	**Tolerable limit 1.5 mg/lt**
1	Uppalavalasa	65	0.55
2.	Patharlapalli	145	0.70
3.	Ranasthalam	80	2.00
4.	Bejjipuram	37	0.60
5.	Bondapalli	108	0.52
6.	Punnam	87	0.60
7	Batuva	110	0.15
8.	Nimmalavalasa	37	1.80
9.	Laveru	35	1.20
10	Adapaka	120	0.50
11.	Kottakunkam	115	0.85
12.	Kuppili	80	0.50
13.	Budumuru	135	0.60
14.	Rompivalasa	32	0.45
15.	Regapalem	25	1.00

Table 3.2. Nitrate and Fluoride Concentration in the villages of Nagavali watershed

Sample No.	Village Name	Nitrate (Mg/L)	Flouride (Mg/L)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
1	Amadalavalasa	193.00	1.30
2	Belamam	29.00	0.25
3	Kalivaram	37.00	BDL
4	Mandadi	112.00	0.66
5	Vanajangi	40.00	1.90
6	Mamidivalasa	65.00	0.70
7	Neeladevipuram	BDL	0.15
8	Niddam	80.00	1.20
9	Enduva	87.00	0.50
10	Ampolu	125.00	0.60
11	Tampatapalli	275.00	0.35
12	Bhasuru	3.00	0.10
13	Buridikancharam	55.00	0.85
14	Konchada	90.00	0.10
15	Ponnada	220.00	0.45
16	Adavaram	BDL	0.70
17	Mulagalavalasa	58.00	1.20
18	Tamaram	35.00	0.25
19	Kusimi	420.00	BDL
20	Gudem	130.00	0.15
21	Singupuram	15.00	1.56
22	Tandemvalasa	8.90	1.56
23	Neelayyavalasa	75.00	0.70
24	Vangara	220.00	0.70
25	Tudi	190.00	0.45

Table 3.3. Nitrate and Fluoride Concentration in the villages of Vamsadhara watershed

Sample No.	Village Name	Nitrate (Mg/L)	Flouride (Mg/L)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
1	Vykuntapuram	17.00	0.62
2	Chinabommidi	45.00	0.74
3	Tilaru	0.00	0.00
4	Akkivalasa	12.40	0.64
5	Chodasamudram	62.00	0.70
6	Bhairavanipeta	55.00	1.24
7	Naira	9.40	0.44
8	Ponnam	69.00	0.30
9	Buravalli	208.00	0.24
10	Chinavattavalasa	29.00	0.96
11	Korlam	0.00	0.35
12	Ramachandrapuram	50.00	0.95
13	Sativada	20.00	0.66

Sample No.	Village Name	Nitrate (Mg/L)	Flouride (Mg/L)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
14	Srimukhalingam	24.00	0.27
15	Thonangi	4.40	0.68
16	Allada	86.00	0.00
17	Chennayyavalasa	25.00	1.30
18	Chinadugam	52.00	0.55
19	Gotivada	19.00	0.86
20	Guggilli	5.50	1.56
21	Jalumuru	23.00	0.40
22	Jonanki	15.00	1.35
23	Karakavalasa	11.80	0.68
24	Kondapolavalasa	8.00	1.10
25	Lingalapadu	71.00	0.13
26	Marrivalasa	4.20	0.80
27	Rana	22.00	1.30
28	Subrahmanyapuram	2.00	0.44
29	Timadam	174.00	0.44
30	Borrampeta	15.60	0.72
31	Bottadasingi	97.00	0.16
32	Dappapadu	324.00	0.64
33	Jagannadhapuram	9.20	0.15
34	Kaviti	236.00	0.23
35	Mariapalli	-	0.28
36	Peddakota	22.00	0.10
37	Badam	75.00	0.16
38	Balaseema	163.00	0.30
39	Chellayyavalasa	8.20	0.68
40	Devadi	94.00	0.08
41	Gokayyavalasa	1.90	0.20
42	Gopalapenta	-	0.13
43	Gundivillipeta	12.00	1.30
44	Jammu	87.00	0.45
45	Kambakaya	199.00	0.30
46	Lukalam	14.00	0.22
47	Madpam	0.00	0.28
48	Makivalasa	10.50	0.34
49	Mamidivalasa	8.60	3.40
50	Narasannapeta	58.00	0.74
51	Paraselli	12.40	0.32
52	Peddabadam	2.20	0.00
53	Potayyavalasa	-	0.48
54	Deerghasi	5.00	0.60
55	Dola	0.00	0.06
56	Gollavalasa	21.00	0.25
57	Jillelavalasa	100.00	0.40
58	Kollivalasa	10.00	0.13
59	Kollivalasa	13.40	0.42
60	Kusumpolavalasa	8.00	0.90

Sample No.	Village Name	Nitrate (Mg/L)	Flouride (Mg/L)
		Tolerable limit 45 mg/lt	Tolerable limit 1.5 mg/lt
61	Mabagam	-	0.00
62	Priya	6.00	0.74
63	Rallagodayavalasa	0.80	1.80
64	Srikurmam	0.00	1.40
65	Agraharam	0.05	1.60
66	Buridivalasa	0.66	3.50
67	Chinasalantri	0.78	3.40
68	Dakaravalasa	0.68	4.00
69	Eragam	0.00	3.20
70	Lakshmipuram	1.50	6.90
71	Peddasowlapuram	0.00	1.80
72	Purushottapuram	0.27	2.60
73	Ravivalasa	0.85	
74	Sarubujjili	0.86	4.00
75	Shalantri	1.10	

3.5. COSTS INVOLVED IN REMOVAL OF FLOURIDE

Several methods were developed to remove fluoride from drinking water. Alum Coagulation, Lime Softening, Ion Exchange and Adsorption, Bone Char Method, Activated Alumina and Reverse Osmosis Process are some of the methods usually used to remove fluoride.

In villages, alum (Aluminum Sulphate) coagulation technique is normally used to remove turbidity and color of the water. The addition of alum during the coagulation process yields a flocculent precipitate of hydroxy-complexes of aluminium. For fluoride removal, the mechanism is believed to be the formation of an aluminium fluoride complex of the adsorption of the alum floc. The fluoride may be removed with the floc in the sedimentation or filtration step. Once floc has precipitated it will have no further fluoride removal capacity. The use of re-circulated sludge will therefore not achieve significant fluoride reduction (Culp and Stoltenberg, 1958).

Advantages:

1. Among many materials tested as coagulation or adsorbents for fluoride removal during the coagulation process, only alum has been found practical for full-scale plants.

2. Alum has relatively high fluoride removal capacity, in the absence of interferences and at favourable pH's

3. Alum coagulation can also reduce iron, manganese, colour and turbidity. Iron and manganese are removed in the process by addition of chlorine.

4. Soft water is ideally suited to fluoride reduction by alum coagulation.

5. Alum is readily available and relatively inexpensive.

6. Waste disposal is not a problem if alum sludge can be satisfactorily handled in an overflow lagoon.

7. Alum coagulation has been widely used in conventional water treatment. Therefore equipment, chemicals and operating procedures are comparable to those in conventional treatment plants and require little special training for local employees, making the defluoridation process within the reach of smaller communities.

8. A plant treating the existing water supply by alum coagulation may be easily adapted to treatment of water from other future sources.

Disadvantages:

1. Large doses of alum in excess of those required for turbidity and colour removal are often required, resulting in high chemical and sludge disposal costs.

2. A high alum dosage can also raise the sulphate content to an undesirable level.

3. The process requires sludge collection, dewatering and disposal, and long start-up and shut-down periods.

4. Highly mineralised ground waters with excessive fluorides will limit the effectiveness of alum in removing fluorides. Alkalinity will also interfere with fluoride removal.

5. Although one study showed that calcium actually improved fluoride removal slightly in alum coagulation, other reports generally suggested that hardness in water may interfere with fluloride removal.

6. Careful pH control is necessary to optimise treatment. Re-adjustment is also required before the treated water can be distributed.

7. Alum coagulation is not readily adaptable to very small water systems or individual wells operating on demand. This process is unreliable and impractical for home application.

However, all the processes mentioned above suffer from one or more drawbacks, such as high initial cost, lack of selectivity for fluorides, poor fluoride removal capacity and complicated or expensive regeneration of medium. In order to overcome this lacuna, alum coagulation method has been revived and a technology evolved in (National Environmental Engineering Research Institute (NEERI), Nagpur, which is popularly referred as Nalgonda Technique.

3.5.1. Fill-And-Draw Defluoridation Plant For Rural Water Supply

Removal of excess fluoride is a must to prevent the villagers from sufferings of fluorosis The technique developed by NEERI is a simple and cheap method for removal of fluoride from drinking water. This techniques can be easily implemented by the villagers. Domestic deflouridation can be performed using a steel drum with a tap in the bottom. The doses of alum, bleaching and lime are fixed by testing the water for fluoride and alkalinity. Table 3.4. shows the alum dose required to decrease the fluoride content in domestic level. After fixing the doses the villager has to be informed how much volume of 10% alum solution be used for deflouridation operation. Table 3.5. shows the volumes of alum solution required to be added in 40L of raw water to obtain permissible limit of fluoride.

Table 3.4. Alum Dose (mg/L) required to obtain permissible limit of fluoride

Test Water fluoride (mg F/L)	Test Water Alkalinity, mg CaCo3/L							
	120	200	300	400	500	600	800	1000
2	143	221	273	312	351	403	468	520
3	221	299	351	403	507	520	585	767
4	*	403	416	468	559	598	689	936
5	*	*	507	598	689	715	884	1010
6	*	*	611	715	780	936	1066	1209
8	*	*	*	*	988	1118	1300	1430
10	*	*	*	*	*	*	1508	1690

* To be treated after increasing the alkalinity with lime or sodium carbonate
Source: Nawlakhe and Bulusu, 1989[xliii].

Table 3.5. Volume of alum solution (ml.) required to be added in 40L test water

Test Water fluoride (mg F/L)	Test Water Alkalinity, mg CaCo3/L							
	125	200	300	400	500	600	800	1000
2	60	90	110	125	140	160	190	210
3	90	120	140	160	205	210	235	310
4		60	165	190	225	240	275	375
5			205	240	275	290	355	405
6			245	285	315	375	425	485
8					395	450	520	570
10							605	675

Source: Nawlakhe and Bulusu, 1989.

Solutions of bleaching powder and lime are added first and mixed well with water. Alum solution is then added and the water stirred slowly for 10 minutes continuously and allowed to settle for one hour. The supernatant water which contains treated water for fluoride is to be decanted into another container and can be used for drinking. The settled sludge is to be discarded. The same container can be used for another operation.

The fill-and-draw defluoridation plant for rural water supply comprises cylindrical tank of 10 m^3 capacity with a dished bottom, inlet, outlet and sludge drain. The cylindrical tank has the sturdy railings. Each tank is fitted with an agitator assembly consisting of (i) 5 HP drip proof electric motor : 3 phase, 50 Hz, 1440 RPM with 415 V $\pm$ 6% voltage fluctuation and (ii) gear box for 1440 output speed of 24 RPM, complete with downward shaft to hold the agitator paddles. The agitator is fixed to the bottom of the vessel by sturdy, suitable stain-less steel supporting bushings.

The defluoridation scheme comprises tanks of 10 m^3 capacity each, a sump well and an overhead reservoir. Raw water is pumped into the units and treated by Nalgonda Technique. The detention period for flocculation is 30 min and that for sedimentation is 2 hours. The treated water is collected into the sump and is pumped into the overhead reservoir form where it is supplied through stand posts. The entire operation is completed in 3 – 4 hours and the same tank can be reused for subsequent operations for a number of times. The number of tanks are decided depending upon the number of times each tank is reused and the water supply need of the village population. The scheme is recommended for up to 5000 population for rural water supply, based on Nalgonda Technique, six fill-and-draw defluoridation plants are already installed in Andhra Pradesh, two in Gujarat and one in Haryana under Water Technology Mission Programme. The plants are reportedly functioning satisfactorily and the villagers are supplied with defluoridated water for drinking and other domestic purposes.

3.6. COST ESTIMATES FOR FILL-AND-DRAW DEFLUORIDATION PLANT FOR RURAL WATER SUPPLY:

The running cost of the defluoridation varies between Rs: 1.00 and Rs. 5.00 per m^3 depending upon fluoride and alkalinity of the raw water. A typical example of cost estimates for 2000 population is given below:

Population	: 2000
Water consumption	: @40 liters/day
Total water need	: 80 M^3 per day
No. of operations of each tank per day	: Two
No. of tanks required	: Four
Capital cost of the plant	: 8,00,000.00

Water Quality

Fluoride Level upto	: 5.0 mg/L
Alkalinity level	: 400 mg /L

Requirement of chemical doses

Alum	:	600 mg / L
Lime	:	30 mg / L
Bleaching powder	:	5 mg / L

Total Cost per year

- Depreciation at 5% p.a : Rs. 40000
- Interest at 12% p.a : Rs. 96000
- Staff : Rs. 87600

Chemist 1 at Rs. 2500 p.m : Rs. 2500

Helpers 4 at Rs. 1200 p.m : Rs. 4800

Total : Rs. 7300

- Annual Maintenance Cost @5% Rs. 40000

Total Annual Cost Rs. 134,900

Cost per day Rs. 722.19

Chemical Cost :

-	Alum consumption, 48 kg/d at Rs 7/ kg	Rs.	336.00
-	Lime consumption, 2.4 kg/d at Re.2.00/kg	Rs.	4.80
-	Bleaching powder, 0.4 kg/d at Rs. 5.50/kg	Rs.	2.20
	Total Chemical Cost	Rs.	343.00

Electricity Charges:

Electricity consumption, 35 units per day & Rs.1.25 / unit Rs. 43.75

Total Operational and Maintenance Cost. = Rs. 722 + Rs. 343.00 + Rs. 43.75

= Rs. 1108.75

Operational Cost/M^3 = Rs. 13.85

Running Cost:

Total Running Cost	= Rs. 386.75 (Electricity + Chemical costs)
Running cost/m^3	= Rs. 4.83

Thus, the annual running cost of defluoridation per capita is estimated as Rs. 70.51

The costs shown above are subject to price change.

(Source: Nawlakhe, W.G. and Bulusu, K.R. , "Water Treatment Technology for Removal of Excess fluoride" International work shop on appropriate methodologies for development and management of groundwater resources n developing countries")

3.7. OCCURRENCE OF NITRATE

Nitrate is the end product of oxidation process of nitrogen and its high concentration in water is often an indicator of pollution from sewage or fertilizers (Sahgal et al., 1989)[xliv]. Nitrogen fertilizers applied to fields are the primary sources of nitrate in shallow groundwater. Nitrogen fertilizers not used by crops can be carried to the underlying aquifer by water percolating through the soil. Nitrate is in the form nitrogen that plants can assimilate and nitrogen compounds naturally transform into nitrate. Nitrate in surface and groundwater may be contributed by bacteria and algae, decomposition of organic matter in the soil, leaching of fertilizers and human and animal excreta. Nitrate is very water-soluble and so can be transported by water from the land surface into soil. Nitrate concentrations are generally lower at greater depths. Some nitrate may be transformed into other compounds as it is carried through the groundwater system. Mixing also decreases nitrate concentrations, as water with higher nitrate concentrations enters deep groundwater systems farther from agricultural or other influences. Nitrate concentrations at the water table may vary greatly. Groundwater moves along flow paths that vary from a few feet to hundreds of miles. Shallow flow paths tend to be influenced by land-use practices at the surface, while deeper flow paths are farther from human influences. Deeper flow paths also have much longer travel time, in most cases predating modern land use practices.

3.7.1. Effects of nitrate on human health:

Most groundwater not affected by human activity contains less than 10mg/L nitrate-nitrogen. Humans ingest nitrates from food and water. Once nitrate enters the body of the humans older than six months, it is steadily absorbed from the digestive tract and excreted in the urine. Healthy human adults can consume fairly large amounts of nitrate with little harmful effect. Infants under the age of six months, however, are susceptible to nitrate poisoning because their undeveloped digestive tracts possess bacteria that convert nitrate to nitrite, which is toxic. When nitrite enters bloodstream, it reacts with oxygen carrying hemoglobin and forms a compound called mathemoglobin. This compound reduces the blood's ability to carry oxygen. As oxygen levels decrease, infants may show signs of suffocation, a condition called methemoglobinemia.

The most conspicuous symptom of methemoglobinemia is bluish skin, most noticeably around he eyes and mouth. If detected rapidly, methemoglobinemia can be successfully treated with an injection of methylene blue, which changes methemoglobin back to hemoglobin. Untreated, the condition is extremely serious: death occurs when 70 percent of the body's hemoglobin has been converted to methemoglobin.

While rare, infant deaths from methemoglobinemia (or blue syndrome) have been linked to high levels of nitrate in well water. Doctors recommend using bottled water to make formula when nitrate levels exceed the drinking water standard set by the Public Health Service: 44 parts per million (ppm) of nitrate (NO_3). This level is equivalent to 10 ppm of nitrate – nitrogen (NO_3-N). With one possible exception, no breast-fed infants have developed methemogloninemia, probably because the mother excretes nitrate so rapidly.

3.7.2. Livestock Health Problems

Because bacteria in the rumen convert nitrite to oxygen-seeking nitrate, nitrate poisoning occurs most often in ruminant animals such as cattle and sheep. Mono-gastric animals such as swine and chickens have no rumen; thus they rapidly eliminate nitrate in their urine. Young monogastric animals, however, are similar to human infants in that they are highly susceptible to nitrate poisoning until their digestive systems develop.

Although relatively nontoxic, nitrate may be reduced to nitrite in the intestines of newborn infants and cause the disease mathemoglobinemia. Nitrate also can react with amines in the human body to form N-nitrosamines, carcinogenic chemicals known to induce tumors in laboratory animals and thought to be linked to human cancers.

3.8. Nitrate concentrations in the study area

sere an attempt is also made to understand the extent of nitrate concentrations in the three watersheds, sources of these nitrate concentrations and methods to control nitrate pollution in groundwater. From the analysis and secondary data it is observed that in the sample villages about 66.6% in Peddagedda, 64% in Nagavali and 28% of villages are suffering from excess nitrate content in the drinking water. However, no medical records are available on the affect of nitrate. The nitrate concentrations in groundwater in all the three watersheds are shown in Tables 3.1, 3.2 and 3.3 respectively.

In the study area, though fertilizers may be contributing nitrate to the groundwater, the overall contribution is not likely to be very significant. This is corroborated by the fact that though high nitrate concentrations have been observed in some well, a secondary analysis in wells very close to these high nitrate concentration wells showed the nitrate concentrations within the desirable limits. Thus, most of the nitrate concentration problem in all the three watersheds is mostly due to point sources. These point sources were observed to be mostly cattle barns. Animals such as cows, buffaloes etc. produce large amount of nitrogenous wastes. In the villages, as these animals are mostly confined to comparatively small places, the excreta gets accumulated which on leaching increases the nitrate content of groundwater. Morris(1966)[xlv] has reported that nitrogen content of animal manure slurries expressed as N varies from 0.13 to 0.42% for cattle, 0.3 to 0.9% for hogs and 0.41 to 1.7% for poultry. The nitrogen concentration of wastewater from cow-sheds and milking parlors has been found to be 4200mg/L (Loehr, 1970)[xlvi].

3.8.1. Measures to prevent Nitrate Pollution:

Water contaminated with nitrate can be treated so that it meets drinking standards. Treatments are expensive, however, and include processes such as reverse osmosis, deionization, and distillation. Boiling, softening, or disinfection will not reduce the water's nitrate content.

Hence, In the view of spreading of high concentrations of nitrate in Peddagedda, Nagavali and Vamsadhara watersheds, an immediate measures should be taken to control and stop the nitrate pollution in this area, as there are no established methods to treat nitrate polluted groundwater at cheaper rates.

However, the following measures can be implemented to prevent nitrate pollution:

5. The unlined sewage system from various houses in the villages should be lined to help in flow away the drainage water and to prevent seepage which slowly degrades the groundwater quality
6. Fertilizers should be used according to the optimal requirements to prevent percolation of fertilizers to groundwater.
7. Abandoned wells should be closed to stop dumping wastes
8. Finally, animals should be sheltered away from the place of source of groundwater to prevent pollution from animal waste.

Secondary data has been collected from various departments of the State government to estimate the extent of saline and waterlogged areas. From this data it has been observed that five mandals namely Santhakaviti, Srikakulam, Gara, Polaki and Sarubujjili are affected with this problem. More than 50% of the geographical area of village Fazulbegpeta in Srikakulam mandal is saline land. In village Purushottamapuram of Sarubujjili mandal, about 17% of the total geographic area of the village is water logged. A list of all the mandals/villages with saline and waterloged areas is given in table 3.6.

Table. 3.6: List of mandals/villages with saline and waterlogged areas.

(area in acres)

Mandal	Villages	Saline land	Water logged
Santhakaviti	K.Ramachandrapuram	-	80.0
	Podali	-	150.0
Sarubujjili	Purushottamapuram	-	650.0
	Pedakakitapalli	-	100.0
	Parvathalapeta	-	30.0
	Lakshimipuram	-	50.0
	Seetharampuram	5.0	40.0
	Turukapeta	61.0	-
Srikakulam	Fazulbegpeta	258.0	-
Gara	Gara	-	150.0
	Vomaravilli	40.0	40.0
	Kalingapatnam	70.0	71.0
	Tonangi	60.0	60.0
	Cormi	-	75.0
	Korlam	30.0	30.0
	Jalluvalasa	-	50.0
	Nizamabad	-	45.0
	Sativada	-	40.0
	Kothurusirigam	-	200.0
	Deepavali	8.0	-
	Gonti	6.0	10.0
Polaki	Koduru	21.0	69.0
		559.0	1940.0

However, from the field surveys in the saline areas it is observed that the reclamation of this limited saline/water logged is found to be economically not viable.

CHAPTER 4: TANK STUDIES

4.1. IRRIGATION PATTERN IN PEDDAGEDDA, NAGAVALI AND VAMSADHARA WATERSHEDS

Cropping pattern generally explains the nature of crops grown and the proportion of area under each crop in a region. An examination of the cropping pattern helps to understand whether the agricultural sector in a particular region has developed or not. Table 4.1, 4.2, 4.3 presents the details of area under principal crops between 1985-86 and 1994-95 in the three watersheds. It is observed in all the watersheds that paddy is the major crop in terms of area followed by groundnut and mesta. The percentage of area under paddy in the total principal cropped area lies between 35-40. On the other hand, the percentage of groundnut in the total principal cropped area is in the range of 24-40. The percentage of other cereals and millets such as bajra, jowar and ragi grown in these watersheds is very less. A meager percentage of area is under total pulses. The proportion of area under the remaining crops is negligible.

In Peddagedda watershed the area under paddy in total principal cropped area has generally declined over the years from 14758 acres in 1985-86 to 9454 acres in 1994-95 though some increase was observed in some years (Fig. 4.1). Similarly area under other cereals and pulses like jowar, bajra and ragi has declined gradually over the years. On the other hand, the area under groundnut has increased from 14365 acres in 1985-86 to 23003 acres in 1994-95. Also, area under sesamum, sugarcane and total pulses has increased during this period. However, the area under mesta is observed to fluctuate between 2700 to 7700 acres. This shows that due to water problem the farmers reduced paddy irrigated area and started growing groundnut which require less water.

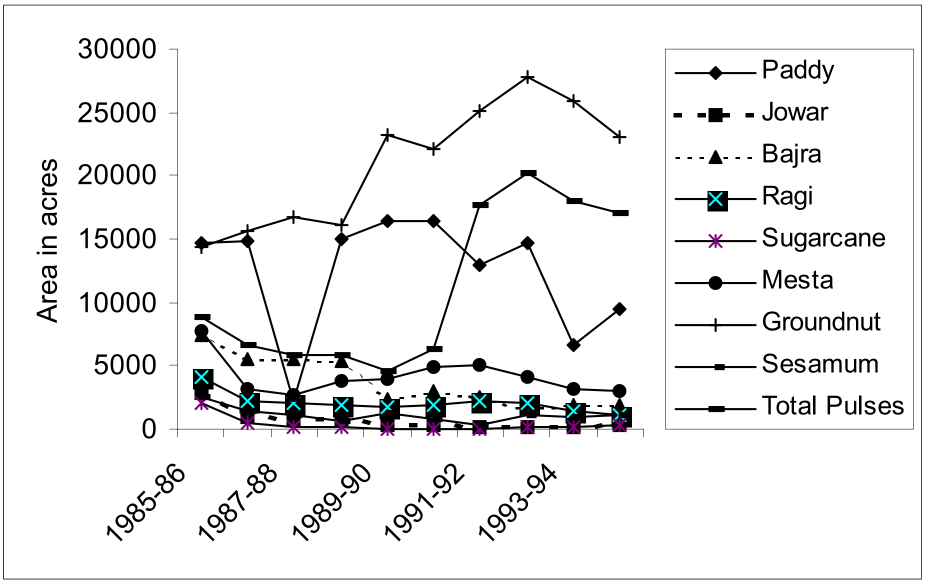


Figure 4.1. Variation in cropping pattern in Peddagedda Watershed

In Nagavali watershed, the area under paddy was observed to be declining very slowly while an increase in the area under sugarcane has been observed. The sugarcane which was 6996 acres in 1985-86 has increased to 14582 acres by 1994-95. Lot of fluctuation are observed in the area of other crops. In Vamsadhara watershed no much variation was observed in any crop from 1985-86 to 1994-95. This can be attributed to the assured water supply from the Vamsadhara project.

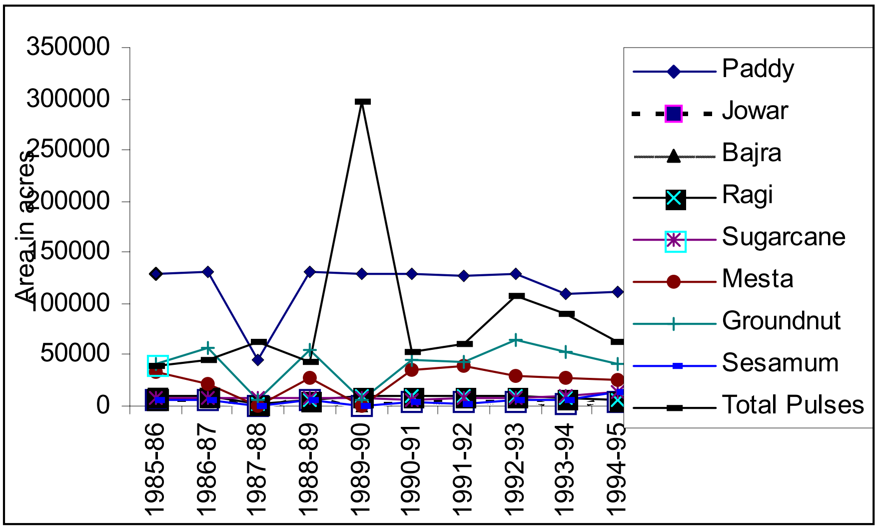


Figure 4.2. Variations in cropping pattern in Nagavali Watershed

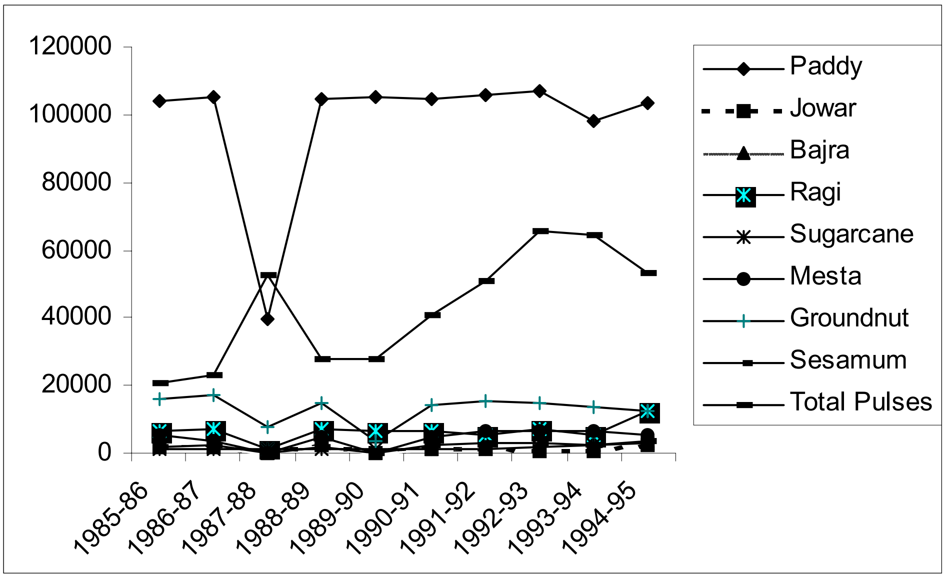


Figure 4.3. Variations in cropping pattern in Vamsadhara Watershed

The state of irrigation development in any area can be understood by examining the changes in the gross irrigated area (GIA), net irrigated area (NIA) and area irrigated more than once (AIMO). Paddy, jowar, bajra, ragi, sugarcane, mesta, sesamum are the major crops grown in all the three watersheds. As mentioned in earlier chapters, the main sources of irrigation are canals and tanks. Though the groundwater usage is low in the previous past, the usage at present has been increasing. The data available for the last 9 years on the gross and net irrigated area under canals, tanks, tube wells, other wells and other sources has been shown in Table 4.4 in all the three watersheds.

Considering the source wise irrigated area in Peddagedda, Nagavali and Vamsadhara watersheds, it may be observed that tanks irrigate a major part of Gross Irrigated Area (GIA) in Peddagedda watershed though it has declined from 86% in 1985-86 to 43.4% by 1994-1995. The share of canals has also come down from 11.5% in 1988-89 to 10.1% by 1994-95. During field surveys it was found that the decrease in the tank irrigated area is due to decrease in tanks bed area and lack of water due to silt and weed accumulation, foreshore encroachment, and irregular rainfall. The gross area irrigated by tube wells has increased from 1.7% in 1985-86 to 11.8% by 1994-95. Tremendous increase in the gross irrigated area by other wells has been observed in this watershed. The source wise Net Irrigated Area (NIA) presented in Table 4.5 also shows similar trends. Large variations were observed in the area irrigated more than once, because the availability of water for second crop (or to irrigate an area more than once) depends only on availability of water in tanks. This shows that the tanks are not giving assured irrigation for second crops in this watershed.

Table 4.4. Gross area irrigated under different sources in Peddagedda watershed

(Area in Acres)

Year	Canals	Tanks	Tube Wells	Other Wells	Other Sources	Total
1985-86	1536	11462	224	83	0.00	13300
1988-89	1542	11831	906	2240	0.00	16521
1991-92	1382	11044	1650	5180	0.00	19258
1994-95	1352	5922	1608	4230	1	13654

Table 4.5. Net Area Irrigated Under Different sources in Peddagedda watershed

(Area in Acres)

YEAR	CANALS		TANKS		TUBE WELLS		OTHER WELLS		OTHER SOURCES		TOTAL	
	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO
1985-86	1473	63	10668	794	178	46	83	0	0	0	12403	897
1988-89	1542	0	11831	0	252	654	839	1401	0	0	13532	2989
1991-92	1118	264	10159	885	1002	648	4601	579	0	0	16882	2376
1994-95	1352	0	5758	164	1608	0	3938	292	1	0	13078	576

In Nagavali watershed, the gross irrigated area under canals and tanks has decreased from 74211 acres to 66706 acres in case of tube wells and 54008 acres to 48314 acres in case of other wells and the percentage of decline was 10.1% and 10.5% respectively (Table 4.6 & 4.7). At the same time the area irrigated using groundwater has increased. It has been observed that the irrigated area under tube wells and other wells has increased tremendously from 1.64 to 18.1% and 0.68 to 7.4% respectively. This indicates that the performance of tanks is decreasing in the watershed, and groundwater exploration is increasing. Though the groundwater-irrigated area has increased from about 20 to 90 percent, the area irrigated by these sources is still far lower than the area irrigated by surface water sources. The main reason for this is the farmers in this area are small farmers owning 0.5 to 1 acres land and they can not afford investment to tap groundwater.

Table 4.6. Gross area irrigated under different sources in Nagavali watershed

(Area in Acres)

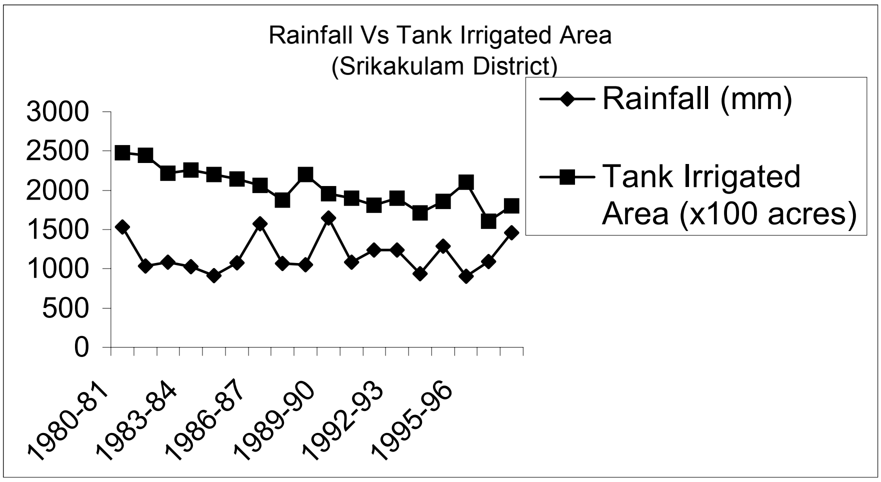
Year	Canals	Tanks	Tube Wells	Other Wells	Other Sources	Total
1985-86	74211	54008	2162	883	447	131711
1988-89	72398	55818	4055	8183	590	141044
1991-92	73718	53301	3712	11581	852	143164
1994-95	66706	48314	7496	10159	4439	137114

Table 4.7. Net Area Irrigated Under Different sources in Nagavali Watershed

(Area in Acres)

Year	Canals		Tanks		Tube Wells		Other Wells		Other Sources		Total	
	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO
1985-86	71057	3154	51373	2635	1688	474	883	0	447	0	125448	6263
1988-89	66442	5956	52648	3170	2082	1973	2361	5522	482	108	124015	17029
1991-92	66991	6727	51769	1532	2506	1206	8767	2814	837	15	130870	12194
1994-95	66824	118	40373	7941	5985	1511	10290	131	2528	1911	126000	11114

As shown in Tables 4.8 and 4.9, in Vamsadhara watershed, in spite of increase in the groundwater irrigated area under tube wells and other wells from 2557 acres in 1985-86 to 9665 acres under tube wells and from 906 acres to 3250 acres under other wells, it is observed that the canal irrigated area is also increasing. The Gross canal irrigated area which was 69795 acres in 1985-86 has increased to 73118 acres by 1994-95 which shows about 4.8% of increase. The area irrigated under tanks in this watershed has decreased by about 2885 acres. The main reason for increase in canal irrigated area is attributable to the irrigation projects being constructed in the watershed. The reasons for decrease in tank irrigated area may be reduced capacity of tanks due to silt, foreshore encroachment and irregular rainfall. The graphical representation of Rainfall vs tank and well irrigated areas for Srikakulam district as a whole, and for the three watersheds are shown in figures 4.4 through 4.10.



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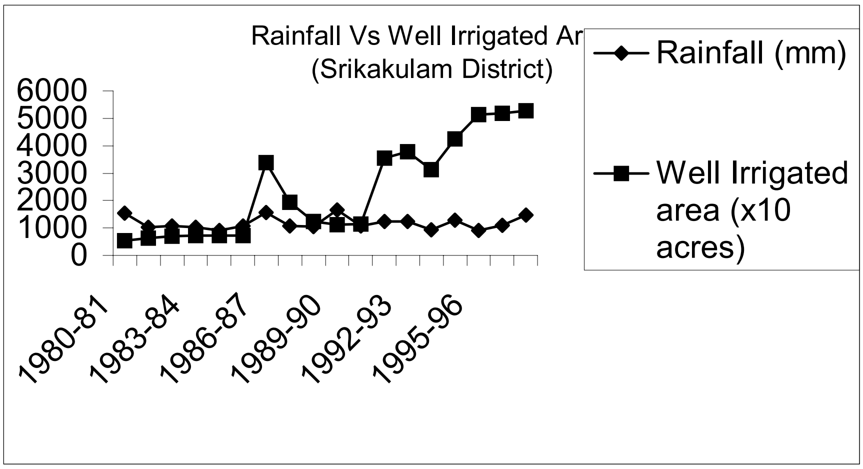
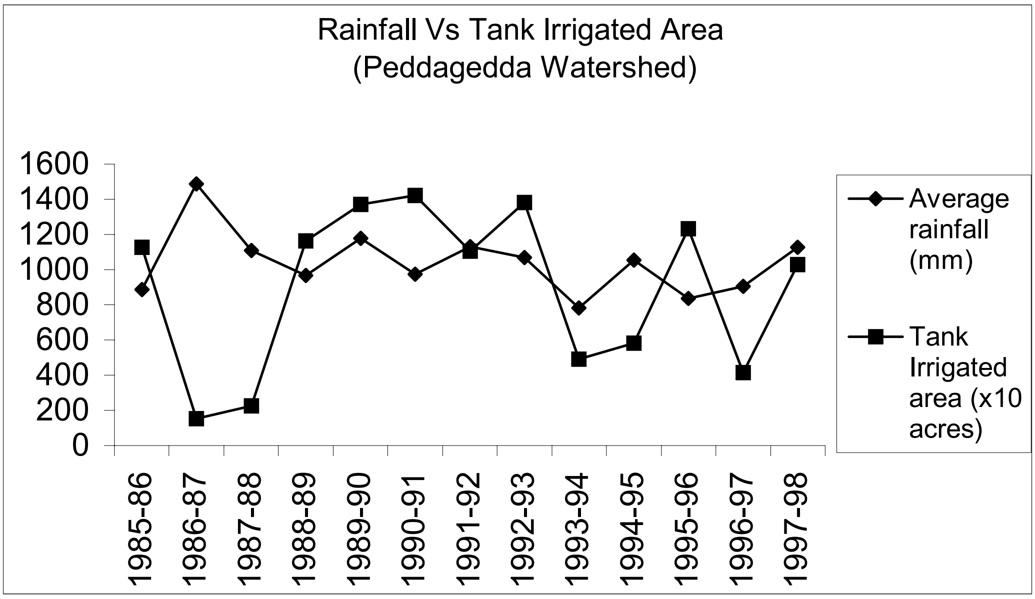


(b)

Figure 4.4. Behavior of (a) Tank and (b) well Irrigated area in Srikakulam District



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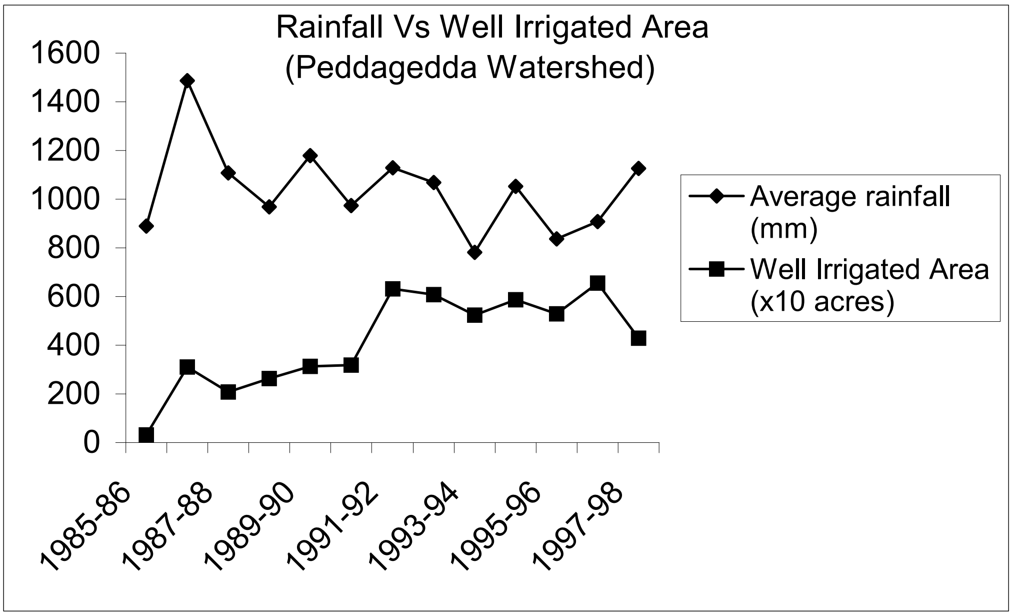
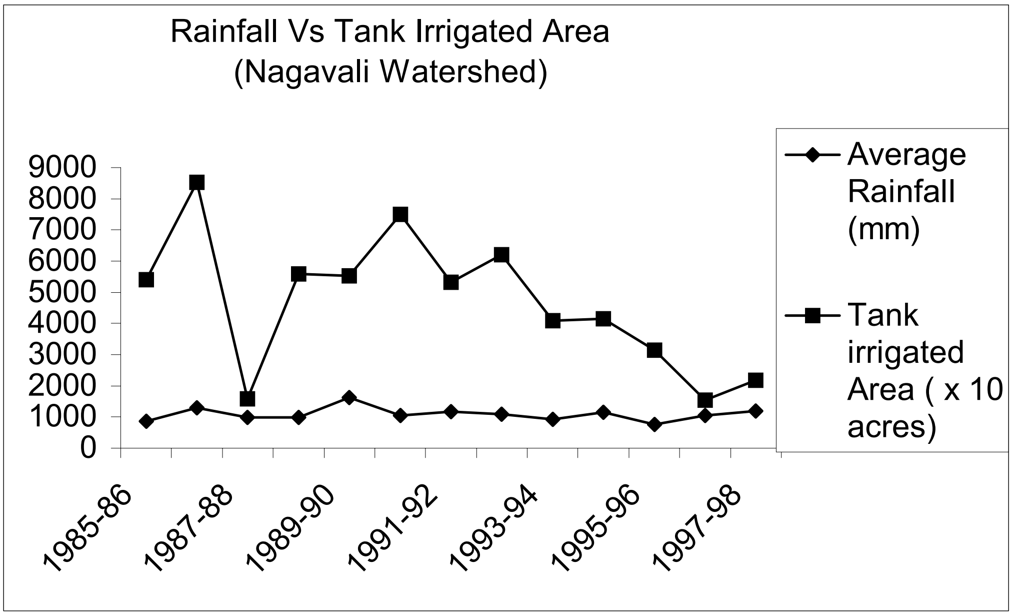


(b)

Figure 4.5. Behavior of (a) Tank and (b) well Irrigated area with rainfall in Peddagedda watershed



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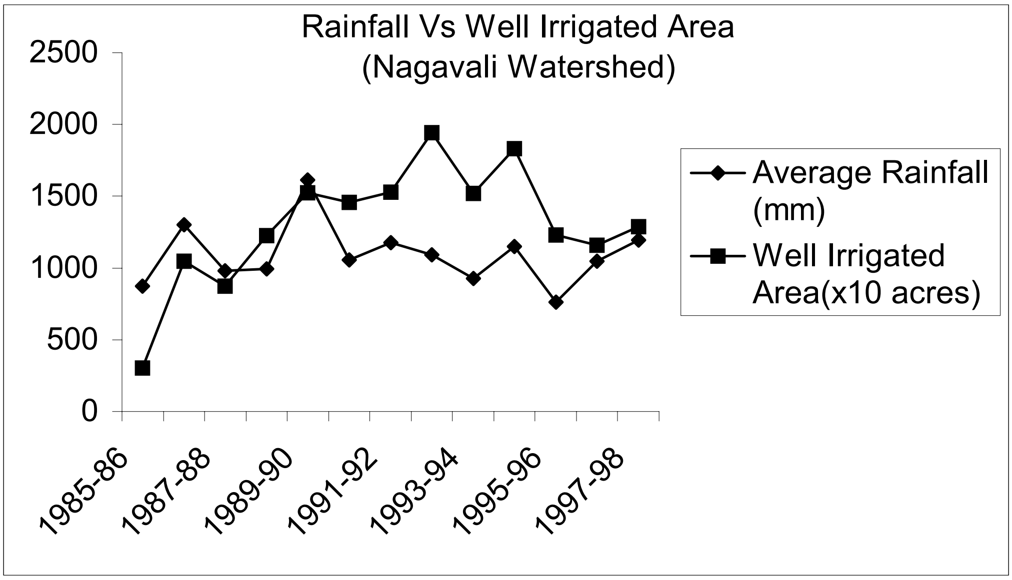
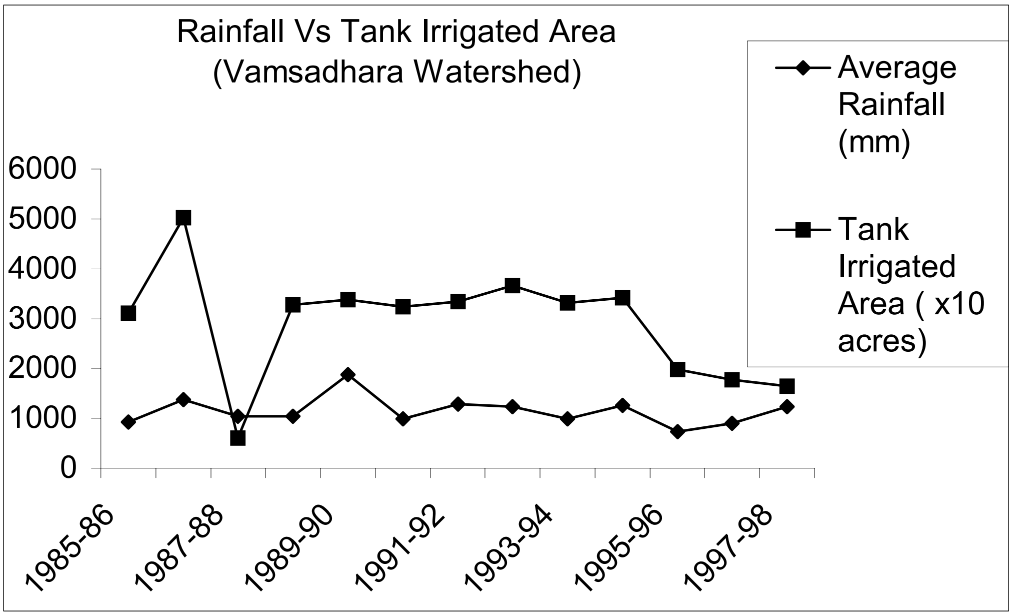


(b)

Figure 4.6. Behavior of (a) Tank and (b) well Irrigated area with rainfall in Nagavali watershed



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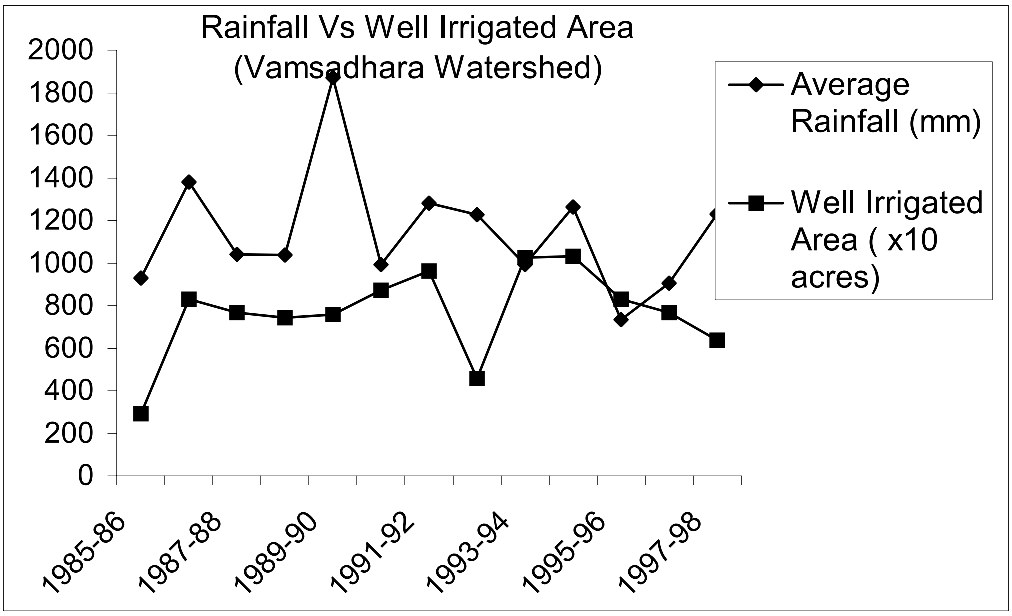

(b)

Figure 4.7. Behavior of (a) Tank and (b) well Irrigated area with rainfall in Vamsadhara watershed

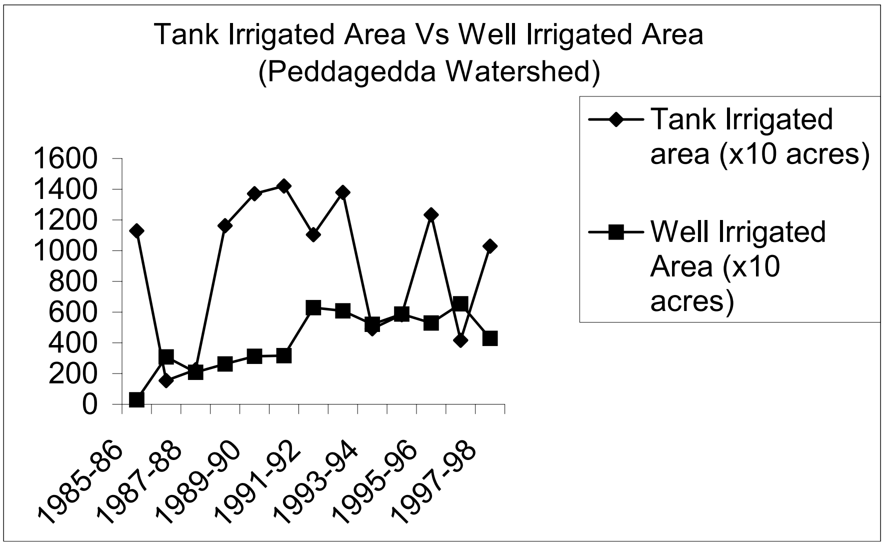

Figure 4.8. Behavior of Tank and well Irrigated area in Peddagedda watershed

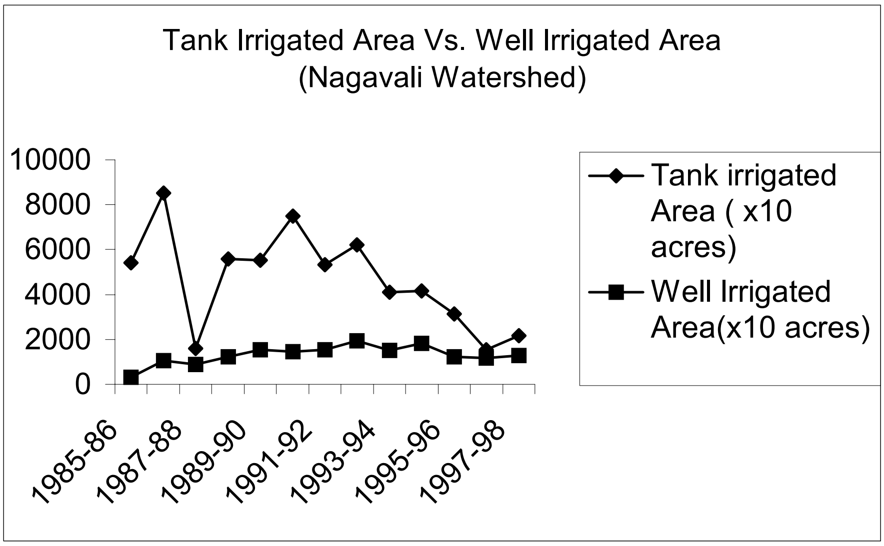

Figure 4.9. Behavior of Tank and well Irrigated area in Nagavali watershed

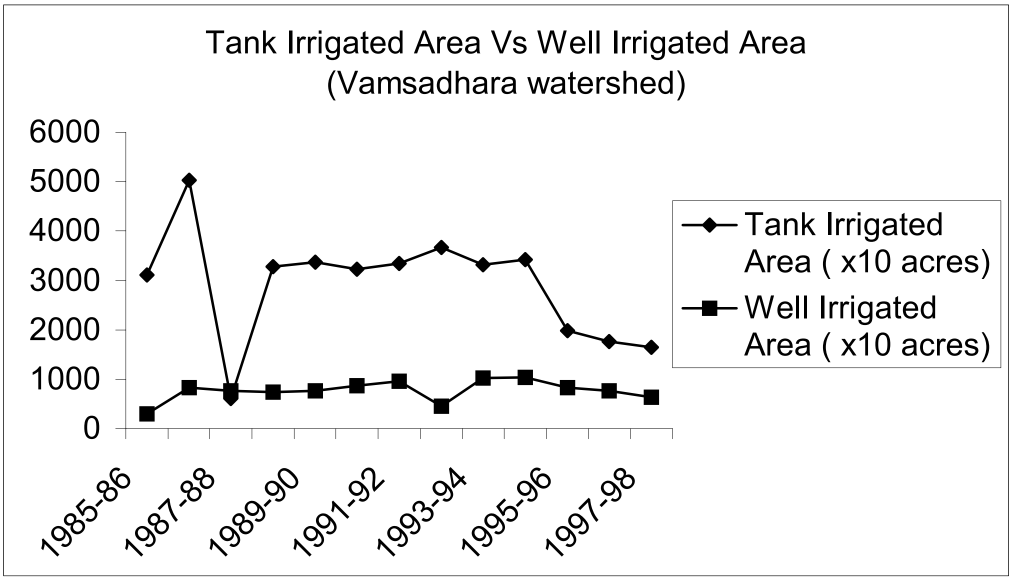

Figure 4.10. Behavior of Tank and well Irrigated area in Vamsadhara watershed

Table 4.8. Gross area irrigated under different sources in Vamsadhara watershed

(Area in Acres)

Year	Canals	Tanks	Tube Wells	Other Wells	Other Sources	Total
1985-86	69795	39696	2557	906	277	113231
1988-89	72401	41744	5691	5366	877	126079
1991-92	78097	34907	7160	4216	521	124901
1994-95	73118	36811	9665	3250	1428	124272

Table 4.9. Net Area Irrigated Under Different sources in Vamsadhara Watershed

(Area in acres)

Year	Canals		Tanks		Tube Wells		Other Wells		Other Sources		Total	
	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO	NIA	AIMO
1985-86	67802	1993	37991	1705	2049	508	906	0	277	0	109025	4206
1988-89	70400	2001	38713	3031	2321	3370	1349	4017	769	108	113552	12527
1991-92	73710	4387	33034	1873	4351	2809	3301	915	506	15	114902	9999
1994-95	71578	1540	35681	1193	5400	4265	2590	660	1148	280	116397	7875

Fluctuations are observed in area sown and area irrigated in all the three watersheds. This fluctuation in the irrigated area and decline in Gross Irrigated area will have effects on the sown/cropped area that is served by irrigation and sown area will affect the ratios of NIA/NSA, GIA/GSA and AIMO/ASMO. It is observed that even Gross Sown Area (GSA) has increased from 1985-86 to 1994-95 in all the three watersheds, the irrigation indicators show that Gross irrigated area is decreasing over the time. The irrigation indicator of Gross Area fall from 0.35 to 0.22 in Peddagedda watershed, and from 0.47 to 0.42 in Nagavali watershed, and from 0.68 to 0.52 in Vamsadhara watershed in 1985-86 and 1994-95 respectively. The GSA seems to have fluctuated as expected reflecting a decline in cropping intensity.

The cropping intensity is progressively increasing from 1985-86 to 1994-95 in all the three watersheds. Details of gross and net area irrigated, sown and cropping intensity of all the three watersheds are shown in Tables 4.10, 4.11 and 4.12 respectively.

Table 4.10. Irrigated area and sown area in Peddagedda watershed

(Area in acres)

Category	Years			
	1985-86	1988-89	1991-92	1994-1995
Irrigated Area				
Gross Irrigated (GIA)	13300	16521	19258	13654
Net Irrigated (NIA)	12403	13532	16882	13078
Irrigated More than Once(AIMO)	897	2989	2376	576
Sown Area				
Gross Sown(GSA)	52005	53143	70422	61080
Net Sown(NSA)	41957	42771	46045	42498
Sown More than Once(ASMO)	10048	10372	24377	18582
Irrigation Indicators				
GIA/GSA	0.25	0.31	0.27	0.22
NIA/NSA	0.29	0.31	0.36	0.30
AIMO/ASMO	0.08	0.28	0.09	0.03
Cropping Intensity*	123.95	124.25	152.94	143.72

Source: Chief Planning Officer, Srikakulam District

* GSA/NSA x 100

Table 4.11. Irrigated area and sown area in Nagavali watershed (Area in acres)

Category	Years			
	1985-86	1988-89	1991-92	1994-1995
Irrigated Area				
Gross Irrigated (GIA)	131711	141044	143164	137114
Net Irrigated (NIA)	125448	124015	130870	126000
Irrigated More than Once(AIMO)	6263	17029	12194	11114
Sown Area				
Gross Sown(GSA)	286659	297976	313583	319410
Net Sown(NSA)	224504	226892	226564	218407
Sown More than Once(ASMO)	62156	72084	87019	101003
Irrigation Indicators				
GIA/GSA	0.45	0.47	0.45	0.42
NIA/NSA	0.55	0.54	0.57	0.57
AIMO/ASMO	0.10	0.23	0.14	0.11
Cropping Intensity*	127.68	131.32	138.40	146.24

Source: Chief Planning Officer, Srikakulam District

* GSA/NSA x 100

Table 4.12. Irrigated area and sown area in Vamsadhara watershed

(Area in acres)

Category	Years			
	1985-86	1988-89	1991-92	1994-1995
Irrigated Area				
Gross Irrigated (GIA)	133231	126079	124901	124272
Net Irrigated (NIA)	109025	113552	114902	116397
Irrigated More than Once(AIMO)	4206	12527	9999	7875
Sown Area				
Gross Sown(GSA)	195538	202448	230473	242708
Net Sown(NSA)	152275	154068	155111	155994
Sown More than Once(ASMO)	43263	48418	75362	86715
Irrigation Indicators				
GIA/GSA	0.68	0.62	0.54	0.51
NIA/NSA	0.71	0.73	0.74	0.74
AIMO/ASMO	0.09	0.25	0.13	0.09
Cropping Intensity*	128.41	131.40	148.58	155.58

Source: Chief Planning Officer, Srikakulam District

* GSA/NSA x 100

These changes indicate that there are lot of fluctuations in the availability of water, which could be attributed to untimely rainfall and subsequent non-availability of water in the tanks. The wide fluctuations in these areas and their subsequent decline in some years are due to inadequate irrigation facilities available in the all the three watersheds.

The prime problem in the study area for reduction in irrigation area is reducing capacity of the tanks. The economic forces for reduction in rate of irrigation is in the present situation maintenance of irrigation infrastructure in the study area is poor. The provisions made to preserve the irrigation systems for long time is not adequate and in some areas the provision are not being utilized properly. Due to general shortage of funds from the government, the operation and maintenance activities like special repairs, replacement of equipment if any is being neglected. Hence, during heavy rainfall good amount of water is overflowing from tanks as the tank capacities were reduced. The water control systems like sluices which are in almost ruined stage, and in majority of tanks water level could not reach the sluice outlet due to accumulation of silt and weed growth near the sluice. There is no water control system in any of the tanks area. Water control system will be very useful in proper management of tank water. The simple methods for controlling the water system are

1) reducing the outflow at night, since crop water requirement will be less at that time, this can be possible by repairing the sluices and gates, 2) Keeping the sluices closed on rainy days. The economic constraint is that controlling water is not cost-free. Government or an organization has to employ a supervisor with a monthly salary. To maintain the irrigation system demanding rates for irrigation water is very important in crop production, and pricing is one of the first and important step which help in the efficient use of water. The under pricing of water tax will lead to resources constraint to maintain the irrigation infrastructure and at the same time it will lead to misuse of precious water resources. However, the farmers in the area cannot invest capital for exploration of groundwater.

It may be observed from the above analysis that though paddy is the main and important crop among all the principal crops, the area under it has gradually declined. This decline in the area of paddy may be attributed to inadequate irrigation sources in the watershed. Thus an attempt has been made to study the performance of tanks that constitute the primary source of irrigation in the watershed.

An analysis of the role of tanks and wells in the irrigation has also been carried out. Table 4.13 presents a comparative statement of tank and well-irrigated area from 1985-86 to 1997-98. Tank irrigated area as a percentage of total cropped area is fluctuating over the years. Tank irrigated area as a percentage of net irrigated area is declining except for the year 1997-98 while the well-irrigated area as a percentage of net irrigated area is steadily increasing.

Table 4.13. Comparison of Tank and Well Irrigation

(Area in acres)

Area	Year				
	1985-86	**1988-89**	**1991-92**	**1994-95**	**1997-98**
Total cropped(TCA)	119736	124574	138510	138499	133439
Net Irrigated(NIA)	36371	39479	42007	35729	42335
Well Irrigated(WIA)	1328	3361	9175	11008	10016
Tank Irrigated(TIA)	19975	21284	20997	11201	21474
TIA/TCA (%)	16.68	17.09	15.16	8.09	16.09
TIA/NIA (%)	54.92	53.91	49.98	34.35	50.72
WIA/NIA (%)	3.65	8.51	21.84	30.87	23.65

Source: Chief planning Officer, Srikakulam District

4.2. Perspective of Tank Irrigation in Peddagedda, Nagavali and Vamsadhara watersheds

The small earthen dams are called tanks (Sharma, 1981)[xlvii]. Tanks are primary sources for irrigation, but many villagers use tank water for drinking purpose also. Irrigation from tanks, which are small reservoirs usually fed by run-off water, is a common technique in geologically and climatically suitable regions of India (Von Oppen et al, 1980)[xlviii]. Tank irrigation, the oldest source of irrigation, and a major practice in south India, accounts for above one third of rice irrigated area (Palanisami, 1998)[xlix]. Tanks are built in different sizes providing irrigation potential to varying areas depending upon the size of the tank, terrain conditions and rainfall. Tank irrigation is an old tradition while canal and tube well irrigation with electric pump sets and diesel pumps are recent technology.

The north coastal districts -Srikakulam, Vizianagaram and Visakhapatnam are surfaced with enormous number of tanks. In Andhra Pradesh, Vizianagaram district occupies a record place with 9895 tanks followed by Srikakulam district with 7004 tanks. Tanks in Srikakulam district are constructed by digging hollow places across the streams in the watershed for storage of rainwater. These tanks are constructed in series, so that, the surplus water escaping the upper tank feeds the next lower tank and so on. Tanks are given much importance as a source of irrigation as the rivers in this area are rainfed and the rainfall is irregular. The water from the irregular rainfall is stored in tanks and this water is used for irrigation. There are a number of streams, which become torrential during rainy season and dry up immediately. The tanks constructed in the past are playing major role in irrigating 180121 acres (1998) of land in this district.

In southern India tanks are used mainly for paddy cultivation as they assure provision of continuos flow of water with low mineral content. Unfortunately the tank irrigation in India is decreasing over past two decades and has become unreliable in many areas including the present study area. In India, tank irrigated area was 4.8 million hectares in 1958-59, which fell to 4.0 million hectares in 1975-76. In Srikakulam district tank irrigated area which was 221491 acres has come down to 180121 acres by 1998. Hence an attempt has been made to study the factors contributing to the fall of tank-irrigated area under tanks and the measures that should be taken to improve the tanks in the study area.

4.3. Administration of Tank Irrigation

For administrative reasons irrigation systems in India are classified into three categories as 1) Major irrigation 2) Medium irrigation 3) Minor irrigation schemes. These irrigation schemes are categorized on the basis of command area under that particular source. All irrigation sources with less than 5000 acres of cultivable command area are considered as minor irrigation works, between 5000 acres to 25,000 acres as medium irrigation schemes and the cultivable command area more than 25,000 acres are called major irrigation system. Major irrigation projects are constructed on major perennial rivers, with large dams, and canals irrigating very large command area. Medium irrigation works are constructed for storing run-off water constituting reservoirs or large tanks that irrigate large areas. Minor irrigation projects include small surface tanks and groundwater.

In Srikakulam, Irrigation department and Panchayat Raj department maintain district tanks. Tanks are divided in to two classes on the basis of their command area under the each tank. Tanks with an ayacut area of less than 100 acres are under the administration of Panchayat Raj and those with command area above 100 acres are under the jurisdiction of irrigation department.

4.4. Status of the Tanks

A large number of tanks which used to irrigate high amount of land in the past are now facing serious silting problem and very good number of potential tanks are now abandoned either leaving the agriculture land under that tank as fallow or decreasing the agriculture yield. It is estimated that in Srikakulam district there were about 12,374 tanks during 1963-64 which have declined to 8,273 in 1985-1986 and further reduced to 7000 in 1999 (Figure. 4.11). This shows the reducing trend of tanks due to encroachment, siltation and other reasons. It is estimated that 37668 acres

(30.3% of district total of 124301 acres) of land is left fallow, which can be developed into irrigated land with good yields if the tanks can be replenished by taking up proper desiltation measures. Table 7 shows the decrease in gross area irrigated under tanks over a period of 23 years.

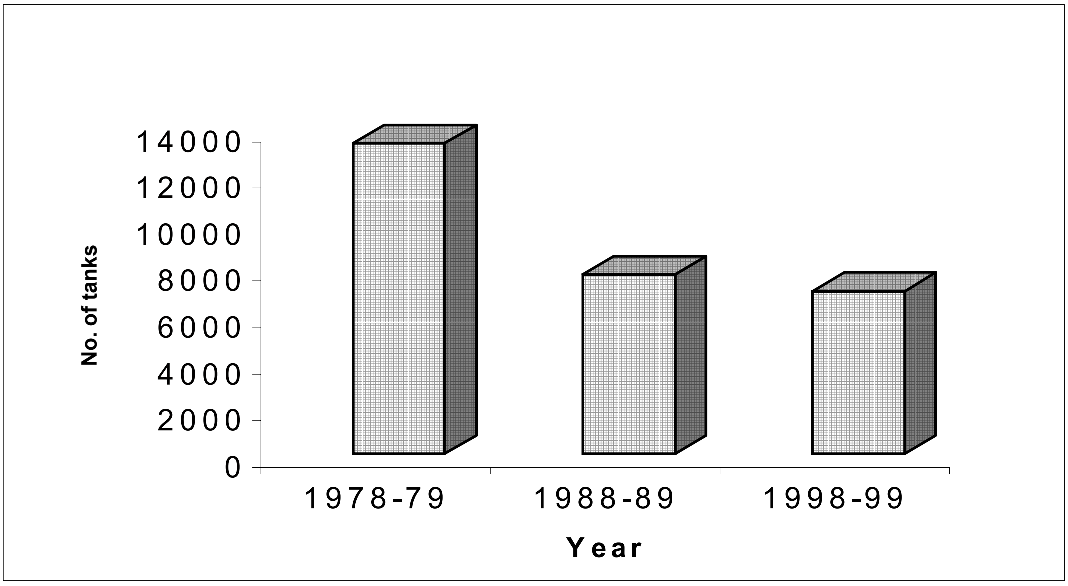

Figure 4.11. Decreasing trend of number tanks in Srikakulam district

From Table 4.14, it is clearly understood that the area under tanks has decreased from 1975 to 1997 (Figure 4.12). In the year 1975, tanks used to provide water for about 60% of the gross irrigated area under all sources. But this has come down to 49% in 1995 and further fell to 35% by 1997. This is corroborated by the significant negative growth rate observed in table. This shows that the farmers are opting for either alternate sources of irrigation or leaving the land fallow. The main cause for this situation may be improper maintenance of tanks, accumulation of silt in the tanks bed, and construction of new canals and tapping of groundwater.

Table 4.14. Decrease in gross area irrigated under tanks in Srikakulam District.

(Area in acres)

	All sources		Tanks		
Year	Area	Gr. Rate	Area	Gr. rate	% to all sources
1974-75*	543756	-	332230	-	61.10
1979-80	463708	-14.72	245483	-26.11	52.902
1984-85	468302	0.99	228690	-6.84	48.83
1989-90	502940	7.4	200916	-12.14	39.95
1994-95	488593	-2.85	191467	-4.70	39.19
1996-97	446467	-8.62	160697	-16.07	35.99

Source: Season & Crop Report(s), Government of Andhra Pradesh.
* includes parts of Vizianagaram district.

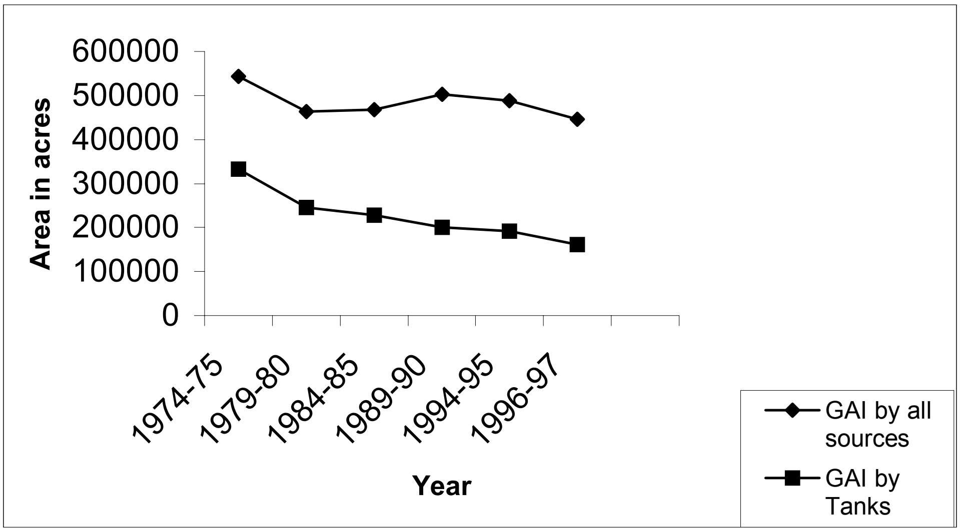

Figure 4.12. Decreasing trend of Gross area irrigated under tanks

Table 4.15 shows the gross irrigated area under tanks in mandals of three watersheds of Srikakulam district. In Jalumuru mandal the area under tank irrigation in 1985-86 was 8035 acres which has drastically gone down to 2630 acres in 1998. In Narasannapeta and Polaki mandals also though the gross area irrigated has increased, the area under tanks decreased from 1985 to 1998. The percentage decline in these two mandals is as much as 85% and 97% respectively.

Table 4.15. Gross Area Irrigated under tanks in three Watersheds in Srikakulam District.

(Area in acres)

Name of the mandal	1985-86	1988-89	1991-92	1994-95	1997-98	1985-86	1988-89	1991-92	1994-95	1997-98
	Area under all Sources					**Area under Tanks**				
Seetampeta	3237	4113	3445	3376	NA	1000	1162	760	0	NA
Veeraghattam	19722	21501	19313	18513	NA	1480	2023	625	689	NA
Palakonda	18934	18278	18633	18275	NA	1862	2133	327	667	NA
Vangara	8528	8877	9519	11730	NA	2730	3202	4843	3710	NA
R.A.Valasa	16643	16525	18142	15559	NA	9493	9457	10204	8045	NA
Rajam	9969	10164	10497	10243	NA	9589	9166	9357	8344	NA
Burja	13552	13773	15519	16937	NA	2870	3812	1902	4848	NA
Kotabommali	12946	16220	16184	16643	NA	8176	8651	1266	7541	NA
Saravakota	14913	16387	14397	13333	NA	9569	9254	11062	10085	NA
Pathapatnam	15028	16168	13250	12908	NA	8951	9256	6899	10952	NA
Hiramandalam	8359	8804	10141	10660	NA	9204	6305	8206	7998	NA
Jalumuru	16100	17756	17970	17742	17467	8035	8150	1051	2280	2630
Santhakaviti	14309	15033	15573	10344	13299	8605	8402	9048	3362	6752
Narasannapeta	18104	20408	20365	21388	21041	1780	2182	463	324	254
Polaki	20273	23889	24306	24120	23208	2080	2405	369	NA	53
Srikakulam	16191	17930	19390	18169	14010	4450	4404	3959	3164	2439
Gara	16856	18847	20347	18997	18486	2200	2745	1683	1838	1496
Amadalavalasa	11589	12037	12260	14067	11002	6310	5875	5702	6135	2427
Sarubujjili	19792	21233	19883	20121	18613	9025	9649	13869	13587	12510
Echcherla	10996	13678	12082	14375	12054	2955	3701	1756	3058	1990
G.Sigadam	8712	11039	12057	6869	10295	8214	9122	10078	4779	8935
Ponduru	11572	12824	12832	11478	11149	2905	2803	3379	1806	2654
Laveru	7056	8550	9955	6434	11135	6996	6990	6865	2558	7895

Source: Chief Planning Officer, Srikakulam District.

This indicates that in these two mandals, the situation of tanks is reaching an alarming stage. Similar situation can be seen in the remaining mandals also except for Sarubujjili, Laveru, and G. sigadam. In these mandals the irrigated area under tanks has almost remained constant.

Keeping these problems of tanks in view, an attempt has been made to study the existing conditions of tanks, identify the tanks facing silt problem and the amount of command area lost due to siltation and the costs and benefits involved in improving them are being studied for the three watersheds Peddagedda, Nagavali and Vamsadhara.

4.5. Tanks in three watersheds

As discussed in the previous chapters tanks are the important source of irrigation in all the three watersheds. As per survey of India topographic maps, there are nearly 746 small, medium and major tanks in Peddagedda watershed. These tanks occupy about 7% of the total geographic area of the watershed. In Nagavali watershed there area about 2013 tanks with a surface area of about 20772 acres occupying 6% of the total watershed area. In Vamsadhara watershed about 1056 tanks with a surface area of about 12214 acres showing 5.3% coverage of the total watershed area. Most of these tanks are entirely rainfed. From the field surveys it is observed that the development of tank irrigation was neglected for the last 5 decades after construction of projects to supply water through canals to some areas and after the availability of diesel and electrical motor pumps for tapping of ground water through tube wells and dug wells. All the tanks in this watershed have either huge silt deposits or enormous weed growth. The silted foreshore areas of these tanks are continually encroached by the farmers and in some cases the government is allotting these lands to the socially and economically backward communities. Hence there is a lot of decrease in capacities of the tanks resulting in the fall of irrigated area under tanks.

Though there is good amount of ground water in the watershed, it is not being utilized. The main reason for this is lack of capital investment with farmers as discussed elsewhere. Unfortunately the area under tank irrigation is declining due to lack of maintenance, repairs and efficient water management. Tanks still play a dominant role in these watersheds. The general causes for the decrease in tank irrigation in these watersheds are:

1. Silting of tank bed,
2. Improper maintenance of bunds
3. Lack of timely repair of sluices
4. Siltation of irrigation channels, feeder channels
5. Foreshore encroachment and casuarina cultivation in the tankbund and weed growth in the tank
6. Failure of rainfall

Hence, it is obligatory to study the condition of tank irrigation in this watershed. In this study a detailed investigation has been carried out to identify the tanks facing siltation problem and loss of income due to ayacut loss. An attempt has also been made to study the socioeconomic and financial benefits expected after desiltation.

4.6. Selection of Tanks

For the present study big tanks in all the three watersheds have been considered. The technical information about each tank was obtained from PWD and Zillaparishad departments. The basic data like size of the tanks, registered ayacut, crops grown under the each tank were obtained from concerned Village Administrative Officer (VAO). For the present study, the 23 largest tanks each ten from Peddagedda and Nagavali watersheds and three from Vamsadhara watershed with command area above 100 acres have been considered for detailed analysis. From the personnel interaction with the farmers it was learnt that properly organized desiltation works were not carried out in any of the tanks in the watershed for the last five decades. As a result the tank bed areas and consequently their capacities have gone down drastically. The silted parts of the tanks are being continually encroached by the farmers. In some cases, the tanks were receiving water to only 1/3 or ½ of their capacities due to improper maintenance of the tanks and almost completely neglected feeder channels of a few large tanks. It was observed that the water available in these tanks is not sufficient to irrigate the entire registered ayacut. The actual ayacut area of each tank was found to vary from 50-70% of the registered ayacut area.

4.6.1. Remote Sensing Studies

Remotely sensed data is an excellent tool for carrying out the temporal studies or change detection studies for any feature of interest. For the present study, tanks have been taken up. A good number of studies have been carried out in the recent past on tanks using remote sensing data (Sagar et al.,1995[l]; Sagar etal. 1998[li]; Sagar & Srinivas, 1999[lii]). Most of these studies concentrated on the spatial distribution of tanks and their dimensional analysis. But the present study is being taken up with the specific objective of estimating the feasibility of desiltation of the tanks and the costs incurred and the benefits obtained thereupon. The change detection studies on tanks basically involve the monitoring of tank size, extent of water spread and subsequently the extent of silt accumulated in the tank.

In view of the absence of reliable recorded data on these tanks, it was felt essential to carry out a comparative analysis of the tanks on the basis of the satellite data obtained for two seasons of two different years i.e. 1989 (dry and wet season) and 1998(dry and wet seasons). Remote sensing analysis gives up to date and reliable information about the condition of the tank. Indian Remote Sensing Satellite 1A, LISS II digital data for the years 1989 for the seasons dry and wet and IRS 1C LISS I data of 1998 were obtained from National Remote Sensing Agency Hyderabad. This data was used to demarcate the variations in areal extent of water spreads in the tanks over a decade.

Since some of the largest tanks irrigating areas more than 400 acres are reported to have almost completely gone dry in summer, a season-wise analysis was thought to be more useful.

4.7. Silt Area Demarcation

The accumulation of silt in tanks over years results in a decrease in the capacity of tanks, which in turn results in a reduction in the tank area filled with water. This variation in the extent of water spread can be clearly established from remotely sensed satellite data. Remote sensing technology can be used in a variety of ways to help in monitoring the quantity, geographic distribution and quality of surface water. The basic property of sunlight, when interact with the clear water, most of the sunlight that enters the clear water body is absorbed within about two meters of the surface. The degree of absorption is highly dependent on wavelength. Reflected infrared wavelengths are absorbed in only few tenths of a meter of water, resulting in very dark image pixel tones in the image. The transparency of the tank water changes with seasons. During monsoon season generally the tank water will be full of turbid (suspended sediment). In this condition most of the visible light will be reflected by the turbid water and hence in the digital image this portion will be in light blue shade. During post monsoon season the turbid will slowly settle down and water will be clear and maximum light will be absorbed by the clear water and hence the water body in the digital image will be in dark blue or black colour. When there is completely no water in the tank the entire sunlight obviously will be reflected by the bare sand in the tank bed and this will be in some other colour depending upon the type of soil like sand, alluvium, clay etc. in the tank bed. This change can be view clearly in plate, Tank No. PW1 Narayanasagaram tank during post monsoon season in 1989, the water body is in light blue shade, as the water has still turbidity. But during 1998 post monsoon season the water is completely settled and we can see the water in black shade, except in some portions where the water is not yet settled or depth of the water is shallow. In the same principle, the water bodies with shallow depth will be in light blue shade in the digital image, and it will be dark blue and black tone in the case of deep water bodies. This will help us to demarcate the silt accumulation, or encroachment of the tank beds in the study area. The still water promote aquatic plant life such as algae and water weeds. In remote sensing digital image this weed will represent light red tone in the tank beds. In plate NW2 TamaraTank in Nagavali watershed you can see the weed growth in the tank bed and the same is reflected in red tone in the Post Monsoon 1998 digital image. This change in the reflectance values of the incident energy in the tank bed helped in estimating and demarcation of the silt areas by counting the pixels in all the 23 tanks in the present studies. Pixel density counting has been done in the present analysis to estimate the area of water spread, area silted and encroachment if any. Pixel is a unit in the digital image which depends on the resolution of the satellite image. In the present study two digital images of IRS 1A and IRS 1D of different years were analyzed. The resolution of the IRS 1A, LISS II is 36.2 m while the resolution of IRS 1D LISS III is 23.5 m. This represents that in IRS 1A a pixel covers an area of 36.2 m x 36.2 m, and in IRS 1D a pixel covers an area of 23.5 m x 23.5 m. And a digital image is formed by a group of pixels. Each pixel in the digital image will have different or same reflectance value called digital number , depending upon the type of feature which reflected or absorbed the incident energy. In the present study Using the image processing techniques like the number of pixels with the same digital numbers were counted and the features in the digital image were identified. Thus, the different pixel values in the each and every tank bed of 23 tanks represent different type of units such as clear water body, reflected by shallow water, silted portion and deep water. Then these digital numbers/pixel values were identified and segregated to estimate silt accumulated area.

The monitoring of tanks or the change detection studies on tanks basically involves the monitoring of tank size, extent of water spread and subsequently the extent of silt accumulated in the tank. The techniques of image processing, which include thresholding, pixel density, and supervised, and unsupervised classification have been used for analyzing each of the individual selected tanks. The selected tanks were first traced from the Survey of India (SOI) topographic maps. These were later digitized and used in the overlay technique using the GIS package- ERDAS IMAGINE (Ver. 8.2). The water spread of each tank in the satellite data was extracted using the digital image processing techniques. The change in this area was determined by overlaying the original tank data digitized from SOI toposheets on the satellite data of the watershed. The pixel values within the water body vary with depth of the water. These pixel value variations have been used to identify the silted areas within the water body.

4.8. Performance Indicators of the tanks

The effectiveness of tank can be analyzed taking into consideration factors like tank area, Settled Command Area (SCA) and present command area. Tank Effectiveness Ratio (TER) is one such ratio determined as

$$TER = \frac{\text{Area irrigated by the tank}}{\text{Area of the tank}}$$

This ratio indicates the area that is irrigated by one unit of the tank area reflecting the effectiveness of the tank.

Deviation Factor (DF) is another indicator that gives the productivity of the tank. The deviation factor is calculated as

$$DF = \frac{\text{Present Command Area} - \text{Settled Command Area}}{\text{Settled Command Area}} \times 100$$

The positive DF value indicates that the tank is overused and if this value is negative it indicates under use of the tank. The TER and DF values calculated for the selected are shown in Tables 4.16, 4.17 and 4.18, 4.19.

4.9. Profile of the selected tanks in Peddagedda Watershed

1. Location: Village Budumuru

Name	:	Narayana Sagaram
Command area	:	697.94 acres
Source	:	Canal from Peddagedda
Crops	:	Paddy, sugarcane and ragi

This is the largest tank in this watershed. The bed area of the tank as per the records of the VAO is 300.19 acres whereas the Survey of India toposheets published more than three decades back show that the tank extent is only 160.55 acres. The remaining area is filled with silt and

Table 4.18. Deviation Factors (D.F.) for irrigation tanks

in Peddagedda watershed

(in acres)

Tank No	Regd. Bed Area	SCA	Present Command Area	D. F.
PW1	300.19	697.94	225.60	-67.68
PW2	160.55	500	427.64	-14.47
PW3	30	500	150.00	-70.00
PW4	50	400	206.00	-48.50
PW5	112.91	200	73.61	-63.20
PW6	72	162	75.31	-53.51
PW7	49.4	150	63.87	-57.42
PW8	43.2	140	57.23	-59.12
PW9	33.96	135	73.29	-45.71
PW10	40.14	133	92.80	-30.23

Table 4.19. Deviation Factors (D.F.) for irrigation tanks in Nagavali and Vamsadhara watersheds

(in acres)

Tank No.	Regd. Bed Area	SCA	Present Command Area	D. F.
NW1	160	312	153.04	-50.95
NW2	625	784	344.84	-56.02
NW3	300	1600	673.08	-57.93
NW4	58	247	165.56	-32.97
NW5	66.66	300	121.13	-59.62
N W6	92.74	204.7	164.15	-19.81
NW7	82.69	307	251.13	-18.20
NW8	67	251	208.88	-16.78
NW9	113	500	309.69	-38.06
NW10	125.8	670	412.69	-38.40
VW1	368.26	5400	3479.98	-35.56
VW2	326.86	1921	1429.06	-25.60
VW3	175	478	319.58	-33.14

encroached by the farmers. The satellite data of October 1989 shows water spread of 87.51 acres and 103.72 acres in October 1998. During the dry season (April/May) the water spread in the tank is around 5 acres. A walk along the entire 6.5 km of the feeder channel revealed several choked points all along its length as a result of huge silting and thick bushes. This is one of the main reasons for the tank not being filled to at least its present capacity.

The present tank effective ratio (TER) of this tank is 0.66. Its original Tank Effective Ratio (TER) calculated by taking the registered ayacut is 2.32. Thus one acre of the tank area was originally irrigating 2.32 acres whereas now it is irrigating only 0.66 acres. The Deviation Factor (DF) is –71.77, which indicates abnormal under use of the tank.

Under this tank paddy and sugarcane are grown in kharif season in 687 acres and 10 acres respectively. Ragi is grown in rabi season in around 20 acres. The remaining ayacut area under tank is left as fallow during the rabi season.

2. Location: Village Bejjipuram

Name	: Devala Cheruvu
Command area	: 500 acres
Source	: Rainfed
Crops	: Paddy, sugarcane and green gram

This is the second largest tank in the Peddagedda watershed with a registered ayacut of 500 acres. The original bed area of the tank is 160.55 acres. The present ayacut is 400 acres. The present TER is 2.49 while its original TER is 3.11. This indicates a loss of 0.66 acres in the irrigated area per acre of the tank area. The DF is –20.00 suggesting under use of the tank.

In kharif season, paddy is grown in 450 acres and sugarcane in 25 acres. During rabi season green gram is grown in 350 acres and other crops are grown in the remaining area.

3. Location: Village : Punnam

Name : Raju Tank

Command area : 500 acres

Source : Rainfed

Crops : Paddy, sugarcane, green gram and ragi

The tank bed area is 30 acres, and the command area is 500 acres. The present command area is around 206 acres. The present TER of this tank is 0.18. The high original TER compared to the bed area indicates that this is a deep tank. The DF is –58.80 indicating under use of the tank. During kharif season around 190 acres is under paddy, 16 acres under sugarcane, and in rabi season 30 acres is under greengram, 140 acres under blackgram and 30 acres under ragi.

4. Location: Village Patharlapalli

Name : Lanka Tank

Command area : 400 acres

Source : Rainfed

Crops : Paddy and sugar cane

The bed area of the tank is 50 acres. The present command area of this tank is around 150 acres. The present TER of this tank is 0.45 while its original TER is 8.00. This high value of TER when compared to the tank area suggests that this is a deep irrigation tank. One of the main reasons for the present TER to be extremely low is siltation. The DF of this tank is –62.50, which suggests under use of the tank. In Kharif season paddy is grown in 140 acres and sugarcane is grown in 10 acres.

5. Location: Village Chinna Murapaka

Name	:	Daba Tank
Command area	:	200 acres
Source	:	Canal from Narayanasagaram, Rainfed
Crops	:	Paddy, Sugarcane.

This tank has a bed area of 112.91 acres with a command area of 200 acres. But the present ayacut is around 78 acres. This decline in command area is due to siltation and thickly grown weed. The present TER of this tank is 0.31 and its original TER is 1.78. Since the bed area is relatively large it may be inferred that this is a shallow tank. Excessive weed growth was observed in the satellite data. Thus the decline in TER can be attributed to this weed growth. The DF value is –61.00 indicating under use. Under this tank 133.5 acres of paddy and 40 acres of Sugarcane is grown in kharif season.

6. Location: Village Adapaka

Name	:	Nidigandlam tank
Command area	:	162 acres
Source	:	Canal from Peddagedda.
Crops	:	Paddy, Sugarcane and Greengram.

This tank has a bed area of 72 acres with a command area of 162 acres. The present ayacut of this tank is 100 acres. The present TER is 0.72 while the original TER is 2.25. The original TER value when compared to the bed area suggests that this is a shallow tank. The DF value is –38.27 indicating under use of the tank.

Paddy is grown in 90 acres and sugarcane is grown in 10 acres in kharif season. In rabi season only greengram is grown in 90 acres. Weed growth is observed in this tank.

7. Location: Village Budatavalasa

Name	:	Pedda Tank
Command area	:	150 acres
Source	:	Rainfed
Crops	:	Paddy, Sugarcane, Greengram and Blackgram

The bed area of this tank is 49.4 acres and its present command area is 60 acres only. The decline in command area may be attributed to thick weed growth and siltation. The present TER is 1.21 and the original TER is 3.04. The DF value is –60.00 indicating that this tank is also under used. Paddy is grown in 65.0 acres and sugarcane in 5.0 acres in kharif season. Greengram and blackgram are grown in small areas in the rabi season.

8. Location: Village Pedda Rompivalasa

Name	:	Tamminaidu Tank
Command area	:	140 acres
Source	:	Rainfed
Crops	:	Paddy, Sugarcane and Ragi

This tank has a bed area of 43.20 acres and command area of 140 acres. The present ayacut of this tank is 50 acres. The present TER is 1.16 and the original TER is 3.24. The DF value is –64.29 indicating under use of the tank. Paddy is grown in 100 acres and Sugarcane in 40 acres during the kharif season. In rabi season, ragi is grown in 25 acres and remaining area is left fallow due to lack of irrigation water.

9. Location: Village Batuva

Name	:	Borrapathuvani Tank
Command area	:	135 acres
Source	:	Rainfed
Crops	:	Paddy, Greengram and Blackgram

The bed area of this tank is 33.96 acres and its present ayacut is 88 acres. The present TER is 2.59 while the original TER is 3.97. The DF value is –34.81 indicating under use. Paddy is grown in all the 135 acres of this tank's command area. Whereas in rabi season Greengram is grown in 30 acres and Black gram is raised in 20 acres. The remaining command area is left fallow till the onset of SW monsoon.

10. Location: Village Batuva

Name	:	Pedda Tank
Command area	:	133 acres
Source	:	Rainfed
Crops	:	Paddy, Greengram and Blackgram

The bed area of the tank is 40.14 acres and the present command area is 100 acres. The present TER is 2.49 and the original TER is 3.31 while the DF is –24.81 indicating under use of the tank. Paddy is grown in 103 acres in kharif season. During rabi season black gram and green gram are grown in 30 acres and 20 acres respectively.

4.10. Profile of the selected tanks in Nagavali Watershed:

1. Location: Village : Shermohammadpuram

   Tank Name : Pedda Tank

   Command Area : 312.00

   Source : Rainfed

   Major Crops : Paddy, Grams

This tank has the registered bed area of 160.00 acres. The Present tank effective ratio for this tank is 0.96. The original tank effective ratio is 1.95. It indicates that one acre of the tank area was irrigating 1.95 aces whereas now it is irrigating only 0.96 acres. The deviation factor –50.95 indicates under use of the tank.

2. Location: Village : Siripuram

   Tank Name : Tamara Tank

   Command Area : 784.00

   Source : Canal

   Major Crops : Paddy, Sugarcane, Mesta, Grams

This is the largest tank in this watershed. The registered bed area of this tank is 625.00 acres. The original tank effective ratio of this tank is 1.25 and the present tank effective ratio is 0.55. The deviation factor of this tank is –56.02 indicating under use of tank. The crops irrigated under this tank are paddy, mesta and less amount of Sugarcane.

3. Location: Village : Mandavakuriti

Tank Name : Mandavakuriti Tank

Command Area : 1600.00

Source : Rainfed

Major Crops : Paddy, Sugarcane, Grams

This is the fourth largest tank in the watershed and also in Srikakulkam District. The original bed area of this tank is 300.00 acres. The original tank effective ratio is 5.33, the present tank effectiveness ratio is 2.24. The deviation factor for this tank is –57.93 indicates under use of tank. The wet crops under this tank are paddy, sugarcane. In in rabi grams are grown.

4. Location: Village : Sitampeta

Tank Name : Salavani Tank

Command Area : 400.00

Source : Rainfed

Major Crops : Paddy, Sugarcane, Grams

This tank bed area is 58.0 acres. The original tank effectiveness ratio for this tank is 4.26, the present effectiveness ratio is 2.85. The deviation factor –32.97, indicates under use of tank. Paddy and sugarcane are the major crops grown under this tank in during kharif, and grams are grown in rabi.

5. Location:

Village: Boddavalasa

Tank Name : Medurikrishnamma Tank

Command Area : 300.00

Source : Rainfed

Major Crops : Paddy, Grams

The registered bed area of this tank is 66.66 acres. The original tank effectiveness ratio for this tank is 4.50 whereas the present tank effectiveness ratio is 1.82.

6. Location:

Village : Unukuru

Tank Name : C. R. Raju Tank

Command Area : 204.7

Source : Rainfed

Major Crops : Paddy, Gropundnut, Sugarcane, Grams

This is a tank with a bed area of 92.74 acres. Amount of Siltation and weed growth in this tank are more than a limit. The present tank effectiveness ratio is 1.77 and the original tank effectiveness ratio is 2.21. The deviation factor for this tank is –19.91. It is directly indicating the under use of tank.

7. Location: Village : Arasada

Tank Name : Subbi Tank

Command Area : 307.00

Source : Rainfed

Major Crops : Paddy, Sugarcane, Grams

The bed area of this tank is 60.47 acres. The original tank effectiveness ratio for this tank is 3.71 while the present one is 3.04. The deviation factor for this tank is –18.20, which indicates under use of tank.

8. Location: Village : Ungarada

Tank Name : Tamara Tank

Command Area : 251.00

Source : Rainfed

Major Crops : Paddy, Grams

The bed are of this tank is 67.0 acres. Water spread area in October, 1989 is only acres. Whereas in October 1998 it is acres. The present tank effectiveness ratio for this tank is 3.12, while the original tank effectiveness ratio is 3.75. The deviation factor for this tank is –16.78 showing that the tank under utilized. Major crop which grow under this tank in kharif is Paddy only. Grams are grown in some pockets in rabi season.

9. Location: Village : Lumburu

Tank Name : Gudivada Tank

Command Area : 500.00

Source : Rainfed

Major Crops : Paddy, Sugarcane, Groundnut, Grams

This is a tank with a bed area of 113.0 acres. The present tank effective ratio is 2.74 while the original tank effectiveness ratio is 4.42. The deviation factor is –38.06. This indicates under use of tank. Paddy and Sugarcane are irrigated under this tank in kharif. In rabi season, groundnut and grams are irrigated.

10. Location: Village : Wadada

Tank Name : Yebbaji Tank

Command Area : 670.32 Acres

Source : Channel fed, Rainfed

Major Crops : Paddy, Sugarcane, Grams

The registered bed area of the tank as per the records is 125.75 acres. The present tank effective ratio (TER) of this tank is 3.28. Its original Tank Effective Ratio calculated by taking the registered command area is 5.33. Thus one acre of the tank area was originally irrigating 5.33 acres whereas now it is found to irrigate only 3.28 acres. The deviation factor (DF) is –38.40, which indicates under use of the tank. Under this tank Paddy, Sugarcane are grown in kharif season. Groundnut, Grams and Mesta are grown in rabi season.

4.10. Profile of the selected tanks in Vamsadhara Watershed:

1. Location: Village : Temburu

Tank Name : Asarla Sagaram

Command Area : 5400 acres

Source : Rainfed, Canal

Major Crops : Paddy, Groundnut, Sugarcane, Grams

The registered bed area of this tank is 368.26 acres. The original tank effectiveness ratio for this tank is 14.66 largest among the studied tanks. The present tank effectiveness ratio for this tank is 9.45 is also largest among the studied tanks. But the area irrigated by one acre of tank bed is fallen drastically from 14.66 acres original to 9.45 acres present. Deviation factor for this tank -35.56 is also indicating under use of tank. Among the crops irrigated under this tank paddy, sugarcane are main and groundnut and grams are grown in rabi.

2. Location: Village : Kottakota

Tank Name : Pedda Tank

Command Area : 477.95.00

Source : Rainfed

Major Crops : Paddy, Sugarcane, Grams

The registered bed area of this tank is 175.0 acres. The present tank effectiveness ratio for this tank is 1.83 whereas the original tank effectiveness ratio is 2.73. The deviation factor for this tank is –33.14. It is indicating clear under use of tank.

3. Location: Village : Saravakota

Tank Name : Ranga Sagaram

Command Area : 1920.68

Source : Rainfed

Major Crops : Paddy, Sugarcane, Groundnut, Grams

The registered bed area of this tank is 326.86 acres. The original tank effectiveness ratio for this tank is 5.88 while the present one is 4.37. The deviation factor –25.60 is indicating the under use of tank.

4.11. ECONOMIC ANALYSIS OF EXISTING TANKS

Most of the major tanks in the study area are found to be in a state of total neglect. It is, therefore, necessary to first analyze their performance in their present condition. A significant observation made from the remotely sensed satellite data has been a general reduction in the tank bed areas. Hence, the under performance of these existing tanks is a forgone conclusion. Quantification of this conclusion primarily requires information on their registered bed areas and their settled command areas. The 23 plates from PW1 to VW3 shows the subset of the digital image acquired from IRS 1A and IRS 1B in two different season i.e. pre and post monsoon of two different years of 1989 and 1998. The light blue color in the images represent shallow water, deep blue or black color represents deep water bodies. The surrounding part in red colour represent cropping under command area of that tank. The rend tone in the tank bed represent weed growth or grass in the tank water. The other light colour in the tank bed represent no water zone and silt accumulation. The line drawings on the tracing film on the each plate shows the original tank boundary and area at the time of construction of the tank obtained from survey of India the topographic maps of 1973. This area obtained from the SOI toposheets is compared with the areas available with the village head and found exactly matching. Thus, we can observe variation in the tank beds when the boundary of the tank demarcated from the SOI topographic map is overlaid on the digital image of 1989 and 1998. Hence there will not be any change in the line drawings as they are original boundaries of the tank, and one can observe the changes in the digital images due to variation in rainfall from season to season.

The performance of these tanks can then be ascertained on the basis of their present bed areas and the present command areas. The estimation of actual benefits of tank irrigation requires data on the productivity of tank irrigated land vis-à-vis un-irrigated land. The cost involved to restore the tank is another major input in the benefit-cost analysis.

4.11.1. Tanks and Farmer Selection

A total of 23 tanks with settled command areas of more than 100 acres have been selected from all the three watersheds. Information on the registered bed areas, settled command areas and the list of beneficiaries along with their respective land holding was collected from the Village Administrative Officers. In order to estimate the benefits of tank irrigation over rainfed irrigation, it was ensured that the sample drawn had farmers who own both irrigated as well as rainfed land. The land holding of a majority of the beneficiaries was found to vary between 1 to 3 acres. Hence, farmers with irrigated land of 1.5 acres and above were included in the sample. Ten farmers were selected at random from the list of beneficiaries to carry out the detailed farm analysis. Data on actual input-output, cropping pattern, present command area, water availability etc., were collected through personal interviews with the farmers using pretested structured schedule. The data obtained from secondary sources include monthly rainfall for the mandals falling in the three watersheds.

4.11.2. Technical features of Irrigation Tanks

Tank bed area constitutes the submerged area that is the area covered with water when the tank is full. The bed area is a major factor that determines the command area of a tank. An attempt to establish a relationship between bed area and command area (Figure 4.13 (a) & (b)) taking into consideration all the tanks for which this data was available did not yield any good result. A close examination of this data has revealed that the command area for tanks with almost same bed areas vary widely. This is because of the differences in the bed slope and consequently the depths. However, classification of the tanks on the basis their effectiveness led to much better relationships as the effectiveness of a tank inherently takes into consideration the slope and depth factors. Based on these relations, the present command areas were estimated for some tanks for which this data was not available.

Table 4.16. Tank Effectiveness Ratio's (TER) for irrigation tanks

(area in acres)

Tank No.	Tank Name	Village	Mandal	Regd. Bed Area	Present bed area (IRS Data)	Loss in bed area	Silted area in present bed area	SCA	TER
PW1	Narayana Sagaram	Budumuru	Laveru	300.19	103.72	196.47	115.2	697.94	2.32
PW2	Devala Tank	Bejjipuram	Laveru	160.55	132.92	27.63	32.11	500	3.11
PW3	Raju Tank	Punnam	G. Sigadam	30	19.42	10.58	17.64	500	16.67
PW4	Lanka Tank	Patarlapalli	Ranasthalam	50	47.49	2.51	31.25	400	8.00
PW5	Daba Tank	Chinna Murapaka	Laveru	112.91	22.65	90.26	48.94	200	1.77
PW6	Nidigandlam Tank	Adapaka	Laveru	72	15.04	56.96	14.18	162	2.25
PW7	Pedda Tank	Budatavalasa	Laveru	49.4	19.49	29.91	29.64	150	3.04
PW8	Tammi Naidu Tank	Peda Rompivalasa	Laveru	43.2	18.53	24.67	28.99	140	3.24
PW9	Borra Patuvani Tank	Batuva	G. Sigadam	33.96	16.81	17.15	11.82	135	3.98
PW10	Pedda Tank	Batuva	G. Sigadam	40.14	24.72	15.42	6.79	133	3.31

Table 4.17. Tank Effectiveness Ratio's (TER) for irrigation tanks in Nagavali and Vamsadhara watersheds

(area in acres)

Tank No.	Tank Name	Village	Mandal	Regd. Bed Area	Present bed area (IRS Data)	Loss in bed area	Silted area in present bed area	SCA	TER
NW1	Pedda Tank	Shermohamadpuram	Etcherla	160	96.1	63.9	9.5	312	1.95
NW2	Tamara Tank	Siripuram	Santakaviti	625	311.67	313.33	75.61	784	1.25
NW3	Mandavakuriti Tank	Mandavakuriti	Santakaviti	300	161.9	138.1	92.26	1600	5.33
NW4	Salavani Tank	Seetampeta	Ponduru	58	48.83	9.17	11.91	247	4.26
NW5	M. Krishnamma Tank	Boddavalasa	Rajam	66.66	38.31	28.35	1.76	300	4.50
NW6	C. R. Raju Tank	Unukuru	Vangara	92.74	79.1	13.64	13.69	204.7	2.21
NW7	Subbi Tank	Arasada	Vangara	82.69	78.46	4.23	5.48	307	3.71
NW8	Tamara Tank	Ungarada	R. Amadalavalasa	67	67	0	13.21	251	3.75
NW9	Gudivada Tank	Lumburu	Palakonda	113	86.01	26.99	15.64	500	4.42
NW10	Yebbaji Tank	Vadada	Gara	125.8	106.78	19.02	24.8	670	5.33
VW1	Asarla Sagaram	Temburu	Saravakota	368.28	359.3	8.98	167.1	5400	9.45
VW2	Ranga Sagaram	Poppangi	Saravakota	326.86	302.33	24.53	72.18	1920.68	5.88
VW3	Pedda Tank	Kottakota	Sarubujjili	175	153.69	21.31	53.71	477.95	2.73

From Table 4.16, it may be observed that the effectiveness ratios for tanks in Peddagedda watershed vary from 1.77 to 16.67. The effectiveness ratios for tanks

PW3 and PW4 are relatively very high. This suggests that the general bed slope and depth of these tanks is much higher than the remaining tanks in this watershed. For the tanks in Nagavali and Vamsadhara watersheds effectiveness ratio varies from a minimum of 1.25 to a maximum of 5.88 (Table 4.17). It may be observed that, tank no VW1 has the highest bed area and the lowest effectiveness ratio. The average effectiveness ratio for tanks in Nagavali watershed is 3.67 while that in Peddagedda watershed is 4.77 and that in Vamsadhara watershed is 4.30.

The DF values (Table 4.18 and 4.19) suggest that six tanks in the Peddagedda watershed and four tanks in the Nagavali watershed are underutilized by more than 50%. Tank PW4 i.e., Lanka Tank in Punnam Village in Ganguvari Sigadam Mandal has the highest DF of –70.00 suggesting very bad state of the tank. In other words, the effectiveness of the tank has gone down by 70%.

4.11.3. Economics of Minor Irrigation Tanks

The input output data collected during farm surveys have been used to carry out the benefit cost analysis at the farmer level and project authority level. The gross returns per acre have been computed taking into consideration the value of the main product as well as the by-product, which is mainly fodder. The costs incurred per acre have been computed by taking into consideration the expenses incurred at every stage of farming starting from ploughing to harvesting. On the basis of land holding of individual farmers included in the sample, the weighted gross returns were calculated. Similarly, the weighted net returns were also calculated. These computations were carried out for tank irrigated land and rainfed land at village prices. The net benefit to farmers from tank irrigated land is the difference between the net income from tank irrigated land and that from rainfed land. To compute the benefit-cost ratio, the cost incurred to the farmer for tank irrigated land is taken as the water tax prevalent in the study area. The water tax structure in vogue in Srikakulam district (the Andhra Pradesh water tax act 1997) is given in Table 4.20.

Table 4.20. Water tax structure in Srikakulam District

S. No	Nature Of Crop	Rates Of Water Tax Per Acre In Respect Of Water Sources Under	
		Category I Rs.	Category II Rs.
1	First or single wet crop	200.00	100.00
2	Second and third wet crop	150.00	100.00
3	First crop irrigated dry	100.00	60.00
4	Second and third crop irrigated dry	100.00	60.00
5	Duffusal crop in Fasli year	350.00	350.00
6	Aqua-culture per year	500.00	500.00
		1400	1170

Category I : the command areas of Major and Medium projects.

Category II : the command area of Minor irrigation tanks which supply water for a period of not less than 4 months.

Based on this tax structure, the average water tax in all the three watersheds comes out to be Rs.160 .00. The results of the cost benefit calculations at farmers level are presented in Tables 4.21 and 4.22. It is seen that the average net benefit from tank irrigation in Nagavali watershed is Rs. 4095.34 per acre, Rs. 3822.69 per acre in Peddagedda and Rs.4631.15 per acre in Vamsadhara watershed. Since most of the area in Vamsadhara watershed comes under canal system of the Vamsadhara major irrigation project, large tanks from only those regions in the upper reaches of the watershed where there is no canal system have been considered. Even in the Nagavali watershed there exists a canal system but not as efficient and widespread as that in Vamsadhara watershed. Therefore, a comparison of net benefits from the tank irrigation between Peddagedda and Nagavali watersheds suggests that the net benefits are more in Nagavali than in Peddagedda watershed.

4.11.4. Increase in Land Value

The increase in land value due to irrigaton was measured by averaging the reported values for irrigated and non irrigated land. The increase in land value in tank irrigated land varies from a minimum of 1.68 times that of rainfed land to a maximum of 2.49 in Nagavali watershed with an average of 2.07. In the Peddagedda watershed, this varies from 1.85 to 2.66 with an average of 2.02. Thus, on the whole, the increase in land value in tank irrigated land is almost double that of rainfed land. However, the lowest ratio of irrigated land value over non irrigated was reported four in Nagavali watershed, one in Vamsadhara watershed and four in Peddagedda watershed. A correlation analysis did not show any relationship when the ratios of irrigated over nonirrigted land value with net benefits.

Table 4.21. Increase in Land value Peddagedda watershed

(in rupees)

Tank No.	Increase in land value (per acre)		Ratio
	(1)	(2)	(1)/(2)
	Tank	Rainfed	
PW1	72243.02	37344.47	1.93
PW2	80271.54	41301.69	1.94
PW3	78317.89	39073.98	2.00
PW4	89680.39	48535.00	1.85
PW5	79536.02	38153.97	2.08
PW6	82608.99	39615.02	2.09
PW7	91642.30	42337.49	2.16
PW8	88581.86	43350.29	2.04
PW9	98271.69	49524.79	1.98
PW10	76984.06	35950.76	2.14

Table 4.22. Increase in Land value in Nagavali and Vamsadhara Watersheds

(in rupees)

Tank No.	Increase in land Value (per acre)		Ratio
	(1)	(2)	(1)/(2)
	Tank Irrigated	Rainfed	
NWS1	92706.12	46930.59	1.89
NWS2	93071.18	40304.17	2.34
NWS3	91450.32	49707.99	1.83
NWS4	98982.74	52474.35	1.87
NWS5	92783.14	41098.58	2.22
NWS6	91618.34	44747.53	2.04
NWS7	74886.31	37158.27	2.03
NWS8	64470.33	25524.72	2.49
NWS9	79986.27	46653.83	1.68
NWS10	56522.23	23900.71	2.28
VWS1	122723.74	57802.19	2.17
VWS2	69687.00	34936.11	2.00
VWS3	90378.90	49751.46	1.83

4.11.5. Additional Employment

Another major social benefit from tank irrigation is the employment it generates. For small and marginal farmers irrigation means more productive work and increased intensity means productive work on more days of the year. Some who will go out or works before irrigation, may cease to be so after introduction of irrigation and may hire labor at peak time. For landless laborer irrigation gives more days work in the year especially where there is second and third irrigation season. An attempt has been made to analyze impact of irrigation on additional employment in the three watersheds. The present employment pattern in both irrigated and

Table 4.23. Farmers' benefit-cost ratio in Peddagedda watershed

(all costs and benefits in rupees)

Tank No.	Net Benefits (per acre)		Ratio	Benefits Due To Tank Irrigation	Cost (per acre)	BCR
	(1)	(2)	(1)/(2)	(3)	(4)	(3)/(4)
	Tank Irrigated	Rainfed				
PW1	3862.32	1970.13	1.96	1892.19	160.00	11.83
PW2	4509.61	1537.68	2.93	2971.93	160.00	18.57
PW3	4347.72	1325.49	3.28	3022.23	160.00	18.89
PW4	4208.39	753.92	5.58	3454.47	160.00	21.59
PW5	4788.61	1482.71	3.23	3305.90	160.00	20.66
PW6	5565.52	1746.92	3.19	3818.60	160.00	23.87
PW7	4210.77	1134.79	3.71	3075.98	160.00	19.22
PW8	4326.98	1157.03	3.74	3169.95	160.00	19.81
PW9	4193.63	1759.50	2.38	2434.13	160.00	15.21
PW10	5025.31	1488.72	3.38	3536.59	160.00	22.10

Table 4.24. Farmers' benefit-cost ratio in Nagavali and Vamsadhara Watersheds

Tank No.	Net Benefits (per acre)		Ratio	Benefits Due To Tank Irrigation	Cost	BCR
	(1)	(2)	(1)/(2)	(3)	(4)	(3)/(4)
	Tank Irrigated	Rainfed				
NWS1	5128.35	1952.85	2.63	3175.50	160.00	15.88
NWS2	3785.02	761.89	4.96	3023.13	160.00	15.11
NWS3	5498.75	1465.92	3.75	4032.83	160.00	18.09
NWS4	5002.23	1384.88	3.61	3617.35	160.00	18.09
NWS5	5097.36	1765.67	2.88	3331.69	160.00	16.65
NWS6	4901.45	1667.53	2.94	3233.92	160.00	20.21
NWS7	5926.42	1753.85	3.38	4172.57	160.00	26.08
NWS8	3680.53	1222.01	3.01	2458.52	160.00	15.37
NWS9	3054.39	1902.13	1.61	1152.26	160.00	7.20
NWS10	3502.82	1548.21	2.26	1954.61	160.00	12.22
VWS1	5616.37	2326.95	2.41	3289.42	160.00	16.45
VWS2	5074.49	1253.38	4.05	3821.11	160.00	19.11
VWS3	4814.89	1759.82	2.73	3055.07	160.00	15.26

un-irrigated land has been taken into consideration to arrive at the additional employment likely to be generated if irrigation facility is extended to the unirrigated or rainfed lands. The additional employment generated will also help curtail the large scale migration observed in many villages in the study area due to lack of irrigation.

Table 4.23, 4.24 and 4.25 present a comparison of number of employment hours for tank-irrigated land and rainfed land in all the three watersheds.

Table 4.25. Employment Generation in Peddagedda watershed

Tank No.	Tank Irrigated (in hours)	Rainfed (in hours)	Additional Employment Due To Tank Irrigation (in hours)	Proportion Of Tank Irrigated Over Rainfed
PWS1	456	254	202	1.80
PWS2	481	246	235	1.96
PWS3	439	216	223	2.03
PWS4	502	247	255	2.03
PWS5	487	234	253	2.08
PWS6	469	221	248	2.12
PWS7	512	304	208	1.68
PWS8	475	231	244	2.06
PWS9	465	260	205	1.79
PWS10	448	222	226	2.02

Table 4.26. Employment Generation in Nagavali Watershed

Tank No.	Tank Irrigated (in hours)	Rainfed (in hours)	Additional Employment Due To Tank Irrigation (in hours)	Proportion Of Tank Irrigated Over Rainfed
NWS1	394	214	180	1.84
NWS2	412	230	182	1.79
NWS3	402	195	207	2.06
NWS4	426	225	201	1.89
NWS5	392	188	204	2.09
NWS6	430	242	188	1.78
NWS7	438	216	222	2.03
NWS8	422	220	202	1.92
NWS9	395	189	206	2.09
NWS10	441	231	210	1.91

Table 4.27. Employment Generation in Vamsadhara Watershed

Tank No.	Tank Irrigated (in hours)	Rainfed (in hours)	Additional Employment Due To Tank Irrigation (in hours)	Proportion Of Tank Irrigated Over Rainfed
VWS1	481	235	246	2.05
VWS2	506	268	238	1.89
VWS3	446	218	228	2.05

4.11.6. Benefits to the Project Authority Level

With the establishment of an irrigation scheme, those who own land within the prospective command area can be charged a betterment levy, a one-time tax collected on the presumed increase in land value. Since the cost of improvement of tanks, which fall under the category of minor irrigation, would certainly not be as expensive as large irrigation projects, the betterment levy would help reduce the burden on the project authority and at the same time instills a sense of responsibility in the farmers. However, no data on the betterment levy charged for any irrigation scheme was found in the study area. Nevertheless, as the contingent valuation studies indicate, the concept of betterment levy was well received by the respondent farmers. In addition to the betterment levy, the project authorities would also be benefited from the additional revenue collected as a result of assured water supply to additional crops. This betterment levy can be accounted against the cost of construction before discounting it to its present value. Assuming a 22 year life period (t) and a 5.75% interest rate (i) on capital investment, the present value (P) of the cost per acre of tank irrigated land (C) is computed as follows.

$$P = C/(1+i)^t$$

The longer periods would generally decrease P only marginally, hence, a life period of 22 years is chosen. An interest rate of 5.75% is chosen as it represents the average rate at which capital might be invested elsewhere. If an amount P was deposited in the bank at interest rate i it will grow to the value of C after t years. To this annual cost the maintenance cost of Rs.117 was added. In the present three watersheds under study, from the preliminary surveys, with the government officials, it is observed that there are no regular release funds for maintaining the minor irrigation tanks. The government releases some amount every year per acre command area. Hence, the average maintenance cost released by the government which has been obtained from the officials in the irrigation department of the district, for the last five years is estimated to be Rs. 117/- per acre and this value has been used in the present study.

The ratio of irrigation fee over present value of tank costs plus maintenance cost per acre is the benefit cost ratio which the project authority faces (Table 4.26). In spite of the low BCRs for the tanks, the major benefit from tank irrigation, as from any irrigation project, is the additional production of food grain it generates. The computation of farmers net benefits (Tables 4.21 & 4.22) reflect this benefit. For the present investigation it has been observed that an acre under tank irrigation produced 1.5 to 2 times (in terms of value), more than a un-irrigated acre. Another important social benefit from tank irrigation is the additional employment it generates. As can be observed from Tables 4.23, 4.24 and 4.25, tank irrigation leads to an additional employment which varies from 1.5 to 2 times more than un-irrigated land. In addition to these economic and social benefits, tank irrigation also leads to beneficial environmental effects. In the present context where the concern for groundwater depletion and its consequent adverse environmental effects are increasing, tanks serve as excellent recharge zones. The soil retention and accumulation in tank beds makes it possible to reclaim the eroded topsoil. Thus on the whole tanks in the present study area have been found to be certainly beneficial to the farmers and the state, which can substantially improve the economy and help reduce the number of people below the poverty line.

CHAPTER 5: WILLINGNESS TO PAY FOR IRRIGATION

The people in all the three watersheds complained about irrigation and drinking water problems. Drinking water problem is high especially in summer season. During field visits and interaction with the villagers it is observed that the villagers are eagerly waiting for some body who can manage the irrigation and drinking water resources. Hence, an attempt has been in this chapter to assess the level of service required by the villagers in this area to meet their water demands and the extent of their participation in terms of willingness to pay for the services. Before the carrying out the study, a thorough analysis of the availability of water resources, usage pattern were dealt in the previous chapters. Village wise household surveys were conducted in all the three watersheds to understand the i) social background, ii) socio-economic status, iii) the availability of irrigation and drinking water and the perception of the villagers on current availability, and iv) finally to assess the willingness of the villagers to pay for irrigation and drinking water supply in case of deficit or to undertake repairs of the existing water sources or look for alternate sources.

Applying the contingent valuation method is generally a complicated, lengthy, and expensive process. In order to collect useful data and provide meaningful results, the contingent valuation survey must be properly designed, pre-tested, and implemented. Contingent valuation survey questions must focus on specific issue, irrigation water in the present context, that is clearly defined and understood by survey respondents. The results of contingent valuation surveys are often highly sensitive to what people believe they are being asked to value, as well as the context that is described in the survey. Thus, it is essential for CV researchers to clearly define the services and the context, and to demonstrate that respondents are actually stating their values for these services when they answer the valuation questions.

There is an increasing agreement that the contingent valuation method is a good method of measuring and understand the WTP of the households for better water supply of irrigation and drinking. However successful implementation of this method requires utmost cares because survey based (primary data) results are very sensitive to the secondary data results. Large amount of errors are possible if the survey instrument, like household survey with the questionnaire, is misunderstood or not honored by the respondents, and if the questions asked by the investigators are not clear and improperly influence the respondents. Hence, designing the questionnaire is the most important key in contingent valuation studies. In the present studies the questionnaire is prepared after giving intense care, research and rehearsals. Pilot surveys were conducted for pre-testing in about 300 households to test the responses of the respondents for biased answers. This led to further modification of the questionnaire to make more comprehensible to the respondents. In the present study respondents selected were in the age group of only above 45 years and below 50 years with a literacy rate of above 55%. The main reason for the selection of this age group is keeping in view that below the age 45 years of a respondent may not recall or know the past events, as most of them are not farmers and they are engaged in some other occupation, and they never show anxiety about the change in rainfall, crop yields, agriculture labour price etc as they have nothing to do with those facts. The reasons for not selecting the respondents above the age group of 50 years, due to the fear that they may forget the past events, because of their age constraint. Another important care that has been taken in asking the willingness to pay questionnaire is that as the respondents cannot recall the past events exactly, the respondent has given the scale to get the accurate result. For example in the questionnaire when posing the questions about the watershed awareness, a question has been asked " Is there any change in rainfall during the last 5 years". For this questions we asked whether the answer is YES/NO. If the answer is YES, then he has been asked to show it on scale starting from decreased to moderately increased. This type of scale will help in getting the good results from the respondents. The crop yields, labor charges and time obtained from the farmers voice are cross checked with the available government records and data collected in that village during data collection.

The following steps have been implemented to get reliable information from the farmers during the household surveys.

Step 1:

The first step is to define the problem. This would include determining exactly what services are being given to the farmers, and who the relevant population is. Because it is owned public land in that village, care has been taken that the respondents belong to that village where the survey is being carried out.

Step 2:

The second step is to make preliminary decisions about the survey itself, whether it will be conducted in person, how large the sample size will be, who will be surveyed, and other related questions. In-person interviews are generally the most effective because for complex questions, it is easier to explain the required background information to respondents in person, so that they can understand clearly.

Step 3:

The next step is the actual survey design. The survey design process started with initial interviews with the farmers during pilot surveys, who will be receiving the final survey. The investigators first asked general questions, including questions about peoples' understanding of the present study, whether they are familiar with the village amenities with regard to irrigation water.

Step 4:

The final step is to compile, analyse and report the results. The data must be entered and analysed using statistical techniques appropriate for the type of question. In the data analysis, the researchers also attempt to identify any responses that may not express the respondent's value for the services of the site. In addition, they can deal with possible non-response bias in a number of ways. The most conservative way is to assume that those who did not respond have zero value.

5.1. SELECTION OF THE VILLAGES AND HOUSE HOLDS

Villages from Peddagedda, Nagavali and Vamsadhara watersheds were selected based on the statistical and GIS analysis. The cluster analysis technique was used considering all the relevant village parameters. The villages from different clusters were then selected based on their geographic location to ensure proper geographic distribution of the villages in the entire watershed. All the three watersheds fall almost in the same climatic and topographic region. From all the three watersheds fifty villages have been selected on the basis of number of households, size of the farmers, water facilities available and other socioeconomic characteristics.

The survey has been conducted at the household level with the detailed questionnaire covering the questions on the social background, economic background, land ownership and water availability. The salient features of the three watersheds are shown in Table 5.1 and 5.2 respectively.

5.2. QUESTIONNAIRE

In order to collect the detailed information from the villagers a detailed household level questionnaire has been prepared after conducting pilot surveys in selected villages (Annexure I). Before designing the survey questionnaire, the factors like how people think about familiarity of the farmers about the good services, importance of the supply of irrigation water in good quality, quantity, accessibility and benefits thereof are considered.

Questions have been asked in a variety of ways, using closed-ended formats. The closed-ended format, also referred to as discrete choice, respondents are asked whether or not they would be willing to pay a particular amount, or whether they would vote yes or no for a specific policy at a given cost. The discrete choice format is generally accepted as the preferred method, hence in the present studies closed ended format with discrete format has been used.

The methodology involved in collecting information is ‘participatory rural appraisal’[liii]. The information has been collected from the villagers by interacting with them and explaining clearly the purpose of the survey while taking enough care to see that that they do not get the impression that the investigator is promising any immediate improvements in water situation. The questionnaire covers totally 59 questions covering the following aspects

1) Particulars on Household Identification, Members and working force

2) Land particulars and cropping pattern and agricultural income

3) Awareness of watershed

4) Irrigation water expenditure and drinking water consumption

5) Community participation

6) Willingness to pay

7) Food consumption pattern and indebtedness particular

The household identification particulars contains questions relating to the name of the head of the household and the name of the respondent, caste and particulars of the household members and information on age, education and present activity of the members of the house holds. These questions help to develop the interaction with the respondents to derive reliable information from them and to have an idea of the their background and social status.

Working force particulars like main occupation of the individual members, number of working days per annum, income, subsidiary occupation if any have been asked. This is intended to know the income and economic background of the family. Migration particulars have also been asked particularly due to problems in agriculture to have an idea of the agriculture situation in the village.

In the second part of the questionnaire, the land related data like ownership and value of the land, present irrigation facility and particulars of land-leased in/out have been covered. Information on farm assets like bullock cart, tractor, ploughs, cattle etc. and household assets like TV, Radio, Fridge, Fan etc. has also been gathered.

Information on the season wise cropping pattern, output and revenue, cost of cultivation and net incomes have been collected. This is helpful to know the extent of land under cultivation, variation in cropping patter from farmer to farmer, if any, and difference in output from farmer to farmer and reasons thereof, and variations in market price from village to village.

Since the main objective of the study is on availability of water for irrigation, detailed questions on awareness of watershed i.e. change in rainfall, change in water levels in various sources during summer, winter and rainy season, irrigation source to the respondents land, change in irrigated area and yield etc. has been asked. This is important to understand the performance of the tanks, canals and wells for irrigation in different seasons. To know the difficulty of the villagers in fetching the drinking water some questions are posed on availability and quality of drinking water, distance traveled to fetch water and alternative methods they follow in case of deficit. Some questions on community participation for drinking and irrigation have been asked to understand the unity and interest to participate and degree of interest by the respondent.

After creating an idea to the villagers by asking the above questions, the questions on willingness to pay are asked. When asking the questions about their willingness to pay the survey respondents were reminded to consider their budget constraints. This question is asked after explaining the statement, which gives a clear picture of the benefit they are going to get for their contribution. The statement is as follows:

"Suppose, some agency manages the water system in you village, so that you get sufficient water for irrigation/drinking throughout the year and your dry land becomes wet and also your crop productivity increases. This is an agency elected by the village people and responsible to it. To maintain the water system (canals, tanks, wells etc.) and extraction, the agency needs some capital expenditure for repair of tanks, installation of equipment, monthly maintenance and running expenditure (labor cost, electricity etc.)

Would you be willing to Pay ?

By posing the above statement a first question is asked whether the respondent is willing to pay to the agency. If the answer is 'yes' then he was asked how much he was willing to pay for capital investment as one time payment and annual maintenance separately. It is observed that most of the villagers are looking for government agency to maintain the water system in their villages. They are willing to pay good amount depending on their land ownership, situation of land from the source, water availability and number of family members. The households who are not willing to pay due to income constraint have been further asked by explaining the realistic situation by the statement:

"If there is an increase in crop productivity and income increases by Rs. 1500/- per acre due to sufficient and timely water supply, how much would you be willing to pay for getting water out of this increased amount"

To give an idea to the villagers from what minimum amount they have to start a bidding is given starting from Rs. 50/- as minimum to more than Rs. 500/- per year. After posing this statement some villagers who were reluctant to pay when the previous question was posed, have showed interest to pay. In this way, keeping in view the problems of the villagers, information on willingness to pay has been collected from them. The results show that 85% percent of the villagers really want some agency to come and maintain the water resources and have expressed their readiness to contribute in terms of money and labor.

5.3. DEMOGRAPHIC AND WORKNG FORCE INDICATORS

Only male farmer respondents were questioned in the present study as a majority of the females are generally involve in household works. The average age of the respondent is 49.33, 46.71 and 45.86 in Peddagedda, Nagavali and Vamsadhara watersheds. The average size of the household in all the three watersheds is almost same 5.33, 5.26, and 5.49 respectively. It was observed that most of the people in all the three watersheds fall in the backward communities BC (87.15%, 87.68%, 97.68%), 3 to 8% belongs to OC and remaining belongs to SC & ST. The average respondent age is 45 to 49 years. The three watersheds are well up in literacy rate and education levels. In Peddagedda watershed 33.02% respondents completed primary education,

Table 5.1. Details of Social Indicators

SOCIAL INDICATORS	PWS	NWS	VWS
No. Households studied	109	342	172
Caste living	OC-9, BC-97 SC-3	OC-13, BC-300 SC- 8, ST-21	OC- 3, BC- 168 SC- 1
Average age of the respondent	49.33	46.71	45.86
Literacy rate (%)	56.53	63.15	63.58
Marital Status	2.72	3.81	4.04
Average size of the family	5.33	5.26	5.49
Average Female/male ratio	1.02	1.02	1.01
Average days worked for main occupation	187	190	167
Average days worked for subsidiary occupation	123	20	36
Outside annual Income per HH in rupees	7848	2906	2245

6.42% have completed middle school, 10% completed secondary education and about 6.42% completed higher education. In Nagavali watershed 27.27% did primary education, 10.26% passed middle school, 12.02% completed secondary education and 10.26% completed higher education. In Vamsadhara watershed, percentage of primary education is 18.02, middle school education is 11.62, secondary school education is 15.7, and higher education is 12.79. Literacy is found to be maximum in Vamsadhara watershed followed by Nagavali and Peddagedda. The average outside income in Peddagedda watershed is (Rs. 7848) almost three times higher than Nagavali (Rs. 2906) and Vamsadhara (Rs. 2245) watersheds. It is clearly observed that the outside income, which is earned through daily labor work, the money sent by relatives who were migrated for employment etc., is inversely proportional to the average land owned. For example, in Peddagedda watershed the average land owned is 4.65 acres and the outside annual income is Rs. 7848 where in Vamsadhara watershed 5.94 acres and the average annual income is Rs. 2245. The outside income in Peddagedda watershed is due to lack of irrigation facilities, people are opting for other employment. The Peddagedda watershed doesn't have irrigation projects. Hence, people in this watershed are keen to migrate as daily labor.

Table 5.2. Details of Agricultural Indicators

AGRICULTURAL INDICATORS	PWS	NWS	VWS
Average Rainfall (mm)	1090.5	1082.34	1194.4
Availability of water in summer	Yes – 16.44% No – 82.56%	Yes – 37.06% No – 61.94%	Yes - 44.94% No – 52.64%
Average land owned (acres) per HH	4.65	6.78	5.94
Average irrigated land	2.13	6.66	4.06
Major crops	Paddy, Ragi, Sugarcane, Groundnut	Paddy, Ragi, Sugarcane, Groundnut	Paddy, Ragi, Sugarcane, Groundnut
Main source of water	Tanks	Tanks, Canals	Canals, Tanks

The average land owned per head in Peddagedda, Nagavali and Vamsadhara watershed is observed as 0.87, 1.28 and 1.08 acres respectively. Land ownership is high in Nagavali watershed followed by Vamsadhara and Peddagedda.

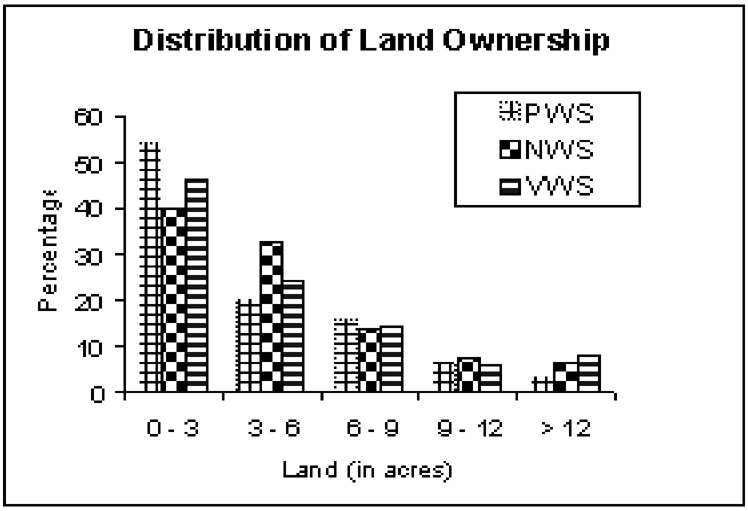

Figure 5.1. Distribution of Landownership in the three watersheds

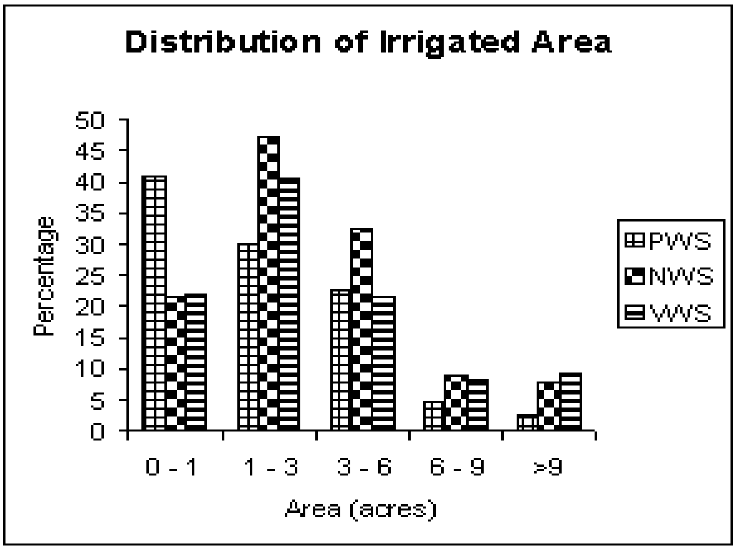

Figure 5.2. Distribution of Irrigated Area in three watersheds

Most of the farmers are having the land below 3 acres (Figure 5.1) in all the watersheds. Only 5 to 10% of farmers own more than 12 acres of land.

Figure 5.2. shows the graphical representation of distribution of irrigated land in three watersheds. Out of the total land owned in Peddagedda watershed only 45.95% is being irrigated. In Nagavali and Vamsadhara watersheds 47.27% and 68.56% of land respectively, is getting water for irrigation. The higher percentage in Vamsadhara basin is attributable to the Vamsadhara project in the watershed.

5.4. CROP YIELDS AND AGRICULTURAL INCOME

Income from agriculture depends upon the availability of water, use of fertilizers, the agricultural practicing methods, and total cost of cultivation. The yield per acre and market price plays a major role in estimating the agricultural income. The extent of agricultural development of an area can be analyzed through crop yields. The yield from different crops has been obtained through the questionnaire survey and analyzed. The average per acre yields of paddy in Peddagedda, Nagavali and Vamsadhara watersheds is estimated as 16.33, 19.16, 21.86 bags (One bag = 80 kgs) respectively. However, there is considerable variation among the yields of the lands under tanks and canals in the three watersheds. The yield is comparatively low in Peddagedda Watershed and high yields are observed in Vamsadhara watershed. The reason for high yield in Vamsadhara watershed is clearly due to availability of sufficient water through out the crop period from the Vamsadhara project. The poor yield rates are attributed to lack of sufficient water and irregular rainfall. From the tank studies it is noticed that the yields are high in head reach location and low near the tail end. The market price in the watersheds varies from place to place. Generally, the production will be sold within the village to local contractors. The observed average village price of different crops obtained from questionnaire survey shows (Table 5.3.) that the rates are almost same in all the watersheds. However, a variation of 20 to 80 rupees is observed.

Table 5.3. Average Market price of different crops

	Crop	PWS	NWS	VWS
1	Paddy (80 kg)	402.4	380	388.85
2	Sugarcane (qtl)	500	706.42	755.55
3	Green gram, Black gram, Red gram (100 kg)	1250	1163.7	1167.56
4	Groundnut (100 kg)	765.59	743.26	739.48

The average cost of cultivation in three watersheds together is estimated at as Rs. 3282.35 per acre in case of paddy, Rs. 8142.85 for sugarcane, Rs. 561.77 for grams and Rs. 1500 for groundnut.

5.5. WHO SHOULD MANAGE WATER? VILLAGERS PERCEPTION:

There are number of government bodies operating in the area to manage water extraction and distribution systems. These are Public Works Department for Minor Irrigation, Andhra Pradesh Irrigation Development Corporation (APIDC), Panchayat Raj, Groundwater department. In all the villages there are Water Users Associations to take care of water distribution and to attend the repairs of the water systems. It is felt to seek the view of the villagers about the performance of the irrigation systems in the area to assess the views of the farmers regarding water resources management. For this the villagers were asked a question "In case of Irrigation and Drinking water shortage, whom do you prefer to manage". The given options were Panchayat/ Community/ Private/Government/NGO.

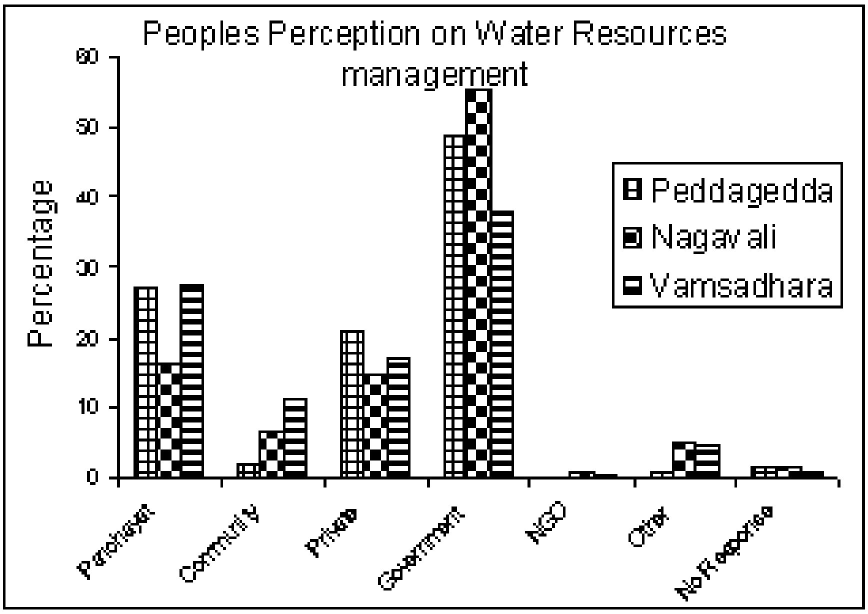

Figure 5.3. Perception of peoples participation for water resources management

From the analysis it is observed that 40 to 50% (Figure 5.3.) of the people prefer government to maintain the water distribution system. Next to government they are preferromg Panchayat followed by private organizations. Very few (5 to 10%) have preferred community to lead the agency to manage water. It is observed that many villagers are not aware of NGO's. Though there is community participation in most of the villages, the participation rate only 20%. Though there are many reasons for this poor participation, some consider it as waste of time, many other have no faith on this community participation, and some people complained about non-unity within the villagers.

5.6. ANALYSIS ON WILLINGNESS TO PAY

The contingent valuation method (Bidding Technique) has been used to elicit preference functions for public supplies such as water, and willingness to pay for the services (water supply in the present context). However, there remains considerable skepticism about the validity of the CVM approach due to response bias. The respondent's answers sometimes may be meaningless and too far from the expected answers. For example for the question 17 in the questionnaire stating, "Is there any decrease in the crop yield due to insufficient water during the last year", the respondent some times may give high figure thinking that the investigator will pay for the loss. In some cases respondents may give answers, which are influenced by their desire to please the investigator. Hence the investigator should be cautious about this "Compliance-bias". To avoid this bias thorough training on the questionnaire has been given to the investigators before starting the survey. The respondents were first explained about the use of water, conservation, sustainability and equitability. Even though the villagers might not have experienced or visualized about this type of agency and the water system, they were asked to express their preference in ordinal as well as in cardinal scales and values. To give an idea to start with they were given cardinal scales. As discussed earlier the questions on willingness to pay for water are

1. one time payment towards the capital investment for the project for extracting water
2. monthly maintenance cost for minor repairs and for watchmen salary to control the water release system for irrigation purpose

The responses obtained are quite interesting. Though most of the villagers willing to pay some of them are not interested to pay due to income constraint. For the villagers who felt that their low income may not permit to contribute, the willingness to pay has been obtained by putting the question in another way by giving a clear picture and assuring that their crop productivity and income increase after sufficient and timely supply of water. And they were clearly explained that due to sufficient water supply there will be possible increase in value of their land, increase in monthly income. The responses by the household after putting the above questions provided positive results. Table 5.4.shows the summary of these various indicators of willingness to pay at the watershed level in all the three watersheds.

On an average about 83.98% and 80.62% households expressed their willingness to pay for capital and maintenance cost in Peddagedda, Nagavali and Vamsadhara watersheds respectively. About 92.66% of households in Peddagedda watershed, 83.28% of house holds in Nagavali watershed and 76.02% of house holds Vamsadhara watershed were willing to pay towards capital expenditure. It was observed that the average willingness to pay among all (payers and non payers)

Table 5.4. Willingness to pay among all and only payers

		% of willingness to Pay positive sum	Willingness to Pay per HH (Rupees)	
			Among All	Among only Payers
Peddagedda	Capital Cost	92.66	669.72	737.37
	Maintenance	88.99	94.31	100.78
Nagavali	Capital Cost	83.28	491.58	611.78
	Maintenance	82.11	83.44	102.35
Vamsadhara	Capital Cost	76.02	708.72	991.0
	Maintenance	70.76	96.80	136.47

* Capital Cost per HH/only once and Maintenance cost is per HH/year.

in Peddagedda water shed is Rs. 669.72 /- and among payers is Rs.737.37/-, in Nagavali watershed Rs. 491.58/- and Rs. 611.78/-, and in Vamsadhara watershed Rs. 708.72 and Rs. 991 respectively. The gap between the values expressed among all (payer and non payers) and only payers is less in Peddagedda watershed and 120.2 in Nagavali watershed and Rs. 282.28 in Vamsadhara watershed. This is found to be statistically significant. In order to arrive at a representative value of willingness to pay, for the households who are not willing to pay due to income constraint alternate questions are posed. About 18.4% of households are observed in all the three watersheds together who responded as income is the constraint. The Table 5.5. shows measure of willingness to pay after posing alternative questions (backing up with additional income incentive based questions Q. No. 46).

Table 5.5. Willingness to Pay backing up with additional income incentive based question

Watershed	For Capital Cost	For Maintenance
Peddagedda	693.45	89.23
Nagavali	577.44	86.72
Vamsadhara	888.26	101.25

As far as the capital cost is concerned it was observed from the analysis that some respondents are willing to pay quite high of even Rs. 10,000/- towards one time capital investment. This indicates that the expected increase due to sufficient and timely water supply is reflecting on the payments. It is noticed that the willingness to pay is high in Vamsadhara watershed followed by Peddagedda and Nagavali. The high WTP in Vamsadhara watershed may be attributed to the existence of Vamsadhara major irrigation project. Though some of the respondents are not benefited by the project, they seem to be fully aware of the benefits of such well planned projects which ensure sufficient water supply. Keeping that in mind the respondents offered high willingness to pay. Where as in Peddagedda watershed, the situation is quite different. In this watershed there are no schemes, or projects and people are eagerly waiting for some body to manage water. Hence, the high WTP is observed in this watershed. However, the WTP for maintenance is almost same in all the three watersheds. The average potential land considered by the respondents that can be irrigated after sufficient and timely water supply stands at 4.65, 6.78, 5.94 acres per household, and the average willingness to pay per acre of irrigated area works out to be Rs. 150.12, Rs. 130.4 and Rs. 157.76 respectively in Peddagedda, Nagavali and Vamsadhara watersheds.

Based on the data obtained from the field survey of 109 households from Peddagedda watershed, 341 households in Nagavali watershed and 172 house holds from Vamsadhara watershed, an statistical analysis for willingness to pay for irrigation (WTPICAP) has been carried out. The dependent variables and explanatory variables used in this study are shown in Table 5.6. The independent variables/explanatory variables have been categorized as five groups as,

1. DIMENSION VARIABLES
2. KNOWLEDGE AND INCOME VARAIBLES
3. WATERSHED AWARENESS AND PERCEPTION VARIABLES
4. EXPENDITURE VARIABLES
5. HARDSHIP AND QUALITY VARIABLES
6. ECONOMIC VARIABLES

Table 5.6. Explanatory variables along with the units, mean, standard deviations

	EXPLANATORY VARIABLES	DESCRIPTION OF THE VARIABLES	Units	Mean	Std.
	DIMENSION VARIABLES				
1	HH_SIZE	Size of the household	No.	5.34	1.95
2	MAIN_OCC	Main occupation of the respondent	-		
3	NO_DAYS	No. of days working as main occupation	Days	182.94	58.78
4	SUB_OCC	Subsidiary occupation	-	0.84	1.63
5	S_NO_DAYS	No. of days working as subsidiary occupation	Days	40.2	69.42
6	OWN_LA_TOT	Total Land owned	Acres	5.23	6.36
7	PC_LA_OWN	Percapita land owned	Acre	1.15	---
8	OWN_IRR_TOT	Total irrigated land owned	Acres	3.00	10.96
9	AGRI_OUTPUT*	Output from the irrigated land (only paddy)	Bags 1 bag = 80Kg.	18.47	5.08
	KNOWLEDGE AND INCOME VARIABLES				
10	RESP_AGE	Age of the respondent	Years	46.94	12.11
11	EDUCA	Education level of the respondent 1. Primary 2. Middle 3. secondary 4. Higher Sec. 5. Higher edu	Codes	0.59	2.10
12	MAR_STA	Marital Status	Code	1.08	0.48
13	COMM_PARTI	Community participation (Yes = 1: No = 2	1,2	---	---
	WATERSHED AWARENESS AND PERCEPTION VARIABLES				
14	RAIN_CHANGE	Change in rainfall 1. Decreased 2. Mod. Dec. 3. Increased 4. Mod. Inc 5. No. change	Codes	1.36	0.84
15	WAT_LVL_CHNG	Change in Water level	1,2	--	---
16	DEC_TANKS	Decrease in tanks 1 = v. little 5 = v. high	Scale	2.10	1.89
17	DEC_CAN	Decrease in canals 1 = v. little 5 = v. high	Scale	1.13	1.56
18	DEC_WELL	Decrease in wells 1 = v. little 5 = v. high	Scale	1.56	1.79
19	DEC_IRR_AREA	Decrease in irrigated area due to insufficient water	Acres	1.57	.57
20	DEC_YIELD	Decrease in crop yield due to insufficient water, how much ?	Kgs.	17.43	5.41
	EXPENDITURE VARIABLES				
21	IRR_NET_COC	Net cost of cultivation in case of irrigated land	Rs./acre	2906.61	1500.05
22	DRY_NET_COC	Net cost of cultivation in case of dry land	Rs./acre	408.68	1279.83
23	TOT_TAX	Water or land tax	Rs./acre	152.19	110.15
	HARDSHP AND QUALITY VARIABLES				
24	WAT_AVAIL	Water availability round the year	1,2	---	----
25	DIST_TRAVEL	Distance traveled by woman, men and children to fetch water	Km	1.63	1.96
26	WAT_QUA	State of water quality Yes – 1, No- 2.	1,2	---	----
	ECONOMIC VARIABLES				
27	ANNU_YIELD	Average annual yield per acre (Paddy)	Bags 1 bag = 80Kg.	18.47	5.08
28	AVE_INCOME	Average annual income paddy	Rs.	15761.5	26623.38
29	S_ANN_INC	Average annual income from subsidiary occupation	Rs.	3589.82	15718.42
	DEPENDENT VARIABLES				

30	WTP	Willingness to Pay Yes = 1, No. 2	1,2	---	---
31	WTPICAP	Willingness to pay towards capital cost	Rs./acre/ HH	582.85	1377.5 8
32	WTPIMAIN	WTP towards maintenance/year	Rs./acre/ HH	49.51	107.96
33	TOTWTP	Total willingness to pay (36+37)	Rs./ Acre	632.36	1479.2

The dimension variables shown include size of the household (HH_SIZE), property owned in terms of lnd owned and total irrigated land (OWN_LA_TOT, OWN_IRR_TOT), agricultural out put from irrigated land for which only paddy is considered, as paddy is the major crop in the area. The subsidiary occupation (SUB_OCC), main occupation (MAIN_OCC), and number of working days in main occupation (NO_DAYS) and no of working days in the subsidiary occupation (S_NO_DAYS) are also included in the dimension variables. These dimension variables may influence the value of willingness to pay due to their sizes. The land owned and consequently the output from it may have significant influence on the willingness to pay. The watershed awareness and perception variables include the ecological changes like changes in rainfall (RAIN_CHANGE), changes in water levels in tanks (DEC_TANKS), canals (DEC_CAN), and wells (DEC_WELL), and decrease in irrigated area and yield. The knowledge variables include education (EDUCA), respondents' age (RESP_AGE), marital status (NAR_STA) and community participation (COMM_PART). The expenditure and economic variables include agricultural expenditure includes cost of cultivation for dry crop (DRY_NET_COC) and irrigated crop(IRR_NET_COC), tax (TOT_TAX) paid towards land/water. The economic variables include economic benefits and incomes, income from subsidiary occupation, income form main occupation and other incomes. The two dependent variables used in the study are willingness to pay for Irrigation towards capital cost (WITPICAP) and willingness to pay for maintenance (WTPIMAINT). These two variables give the amount that a farmer is willing to pay for getting assured water supply for his land.

Table 5.7 Distribution of Sample Households by social Background

Social Background	Peddagedda	Nagavali	Vamsadhara	All
OC	9 (8.25)	13 (3.81)	3 (1.75)	26 (4.07)
BC	97 (88.99)	299 (87.68)	168 (97.67)	564 (90.52)
SC	3 (2.75)	8 (2.34)	1 (0.58)	12 (1.92)
ST	-	21(6.15)	-	21(3.37)
All	109 (100)	341(100)	172 (100)	623 (100)

* Figures in parenthesis indicates percentage to watershed total

From Table 5.7., it can be observed that the majority of farmers in all the three watersheds belong to backward community. Most of the peoples of OC are engaged in small business in the villages it self. Scheduled caste and scheduled tribes are engaged in daily labour or agricultural labour.

Table 5.8. Distribution of Sample households by Age-group

Age	Peddagedda	Nagavali	Vamsadhara
25 – 35	12 (11.00)	77 (22.58)	38 (22.09)
35 – 45	34 (31.19)	90 (26.39)	59 (34.20)
45 – 55	28 (25.68)	101(29.61)	40 (23.25)
55 – 65	25 (22.93)	53 (15.54)	32 (18.60)
> 65	10 (9.17)	20 (5.86)	3 (1.74)

* Figures in parenthesis indicates percentage to watershed total

Most of the respondents with agriculture is the main occupation is within the age limit of 45-55 years, and 35-45 years (Table 5.8). Very few farmers are observed above 65 years. Farmers, below 25 years are not interviewed as they are only assisting to their parents or brothers in agricultural works, hence they do not have much idea about the irrigation situation in the watershed. Table 5.9, shows that illiterates are more in Peddagedda followed by Nagavali and Vamsadhara.

Table 5.9. Distribution of sample households by Education level

Education Level	Peddagedda	Nagavali	Vamsadhara	All
Primary	36 (33.02)	103 (30.20))	40 (23.25)	179 (28.77)
Middle	7 (6.4)	35 (10.26)	20 (11.62)	62 (9.96)
Secondary	11 (10.09)	42 (13.04)	27 (15.69)	80 (12.86)
Higher	7 (6.4)	35 (10.26)	22 (12.79)	64 (10.28)
Illiterate	48 (44.03)	126 (36.95)	63 (36.62)	237 (38.10)

* Figures in parenthesis is percentage to total.

Table 5.10. Average number of days worked and Income per annum

	Peddagedda	Nagavali	Vamsadhara	All
Average Number of days worked (main occupation)	181.92	190.93	167.53	180.12
Average Income per annum (Rs)	9264.65	14177.22	18783.25	14075.04
Average Number of days worked (subsidiary occupation)	58.44	34.38	36.90	43.24
Average Income per annum from Subsidiary occupation	7848.30	2906.45	2245.93	4333.56

Table 5.11. Distribution of sample households by size of holdings

Size of holding	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	48 (44.03)	141(41.34)	65 (37.79)	254 (40.83)
Small (2.5 – 5 acres)	36 (33.02)	96 (28.15)	54 (31.39)	186 (29.90)
Medium (5 – 10 acres)	19 (17.43)	70 (20.52)	32 (18.60)	121 (19.45)
Large (>10 acres)	6 (5.50)	34 (9.97)	21 (12.20)	61 (9.80)
Total	109 (100)	341 (100)	172 (100)	622 (100)

* Figures in parenthesis are percentage to the total households

Table 5.12. Particulars of the loans taken by the farmers

(in rupees)

Size of holding	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	15145.94	20190.81	13540.74	16292.49
Small (2.5 – 5 acres)	23182.92	31484.89	26523.03	27063.61
Medium (5 – 10 acres)	34920.00	41581.44	59587.5	45362.98
Large (>10 acres)	65666.66	98088.23	114047.05	92600.64
Total	138915.52	191345.37	213698.32	181319.72

In all the three watersheds it was observed that the farmers have liabilities of loans taken from banks, friends and others. It is interesting to notice from Table 5.12. that the amount of loan is increasing with increasing size of land holdings. The main reasons for this is due to poor returns on the agriculture in spite of high level of investment on agriculture for fertilisers, pesticides and labour. The other main reason may be family participation in socio-political activities like contesting in elections etc. to improve their status in the society.

Table 5.13. Distribution of sample households by poverty level

Social Background	Peddagedda	Nagavali	Vamsadhara	All
Below Poverty Level				
OC	9 (8.25)	10 (2.93)	1(0.58)	20 (3.21)
BC	67 (61.46)	155 (45.45)	59 (34.30)	281 (45.17)
SC	1 (0.91)	3 (0.87)	-	4 (0.64)
ST	-	19 (5.57)	-	19 (3.05)
All	77	187	60	324
Above Poverty level	Peddagedda	Nagavali	Vamsadhara	All
OC	-	3 (0.87)	2 (1.16)	5 (0.80)
BC	30 (27.52)	144 (42.22)	109 (63.37)	283 (45.49)
SC	2 (1.83)	5 (1.46)	1 (0.58)	8 (1.28)
ST	-	2 (0.58)	-	2 (0.32)
All	32	154	112	298

* Figures in parenthesis indicates percentage to watershed total

Table 5.14. Distribution of Farmers by willingness to pay towards capital and maintenance cost

(in percent)

Type of farmer	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	33.94	22.87	23.25	26.68
Small (2.5 – 5 acres)	34.86	34.31	30.81	33.32
Medium (5 – 10 acres)	18.18	18.76	15.69	17.54
Large (>10 acres)	5.50	7.33	7.55	6.79
Total	92.48	83.27	77.3	84.35

Table 5.15. Average amount of willing to pay by farmers towards capital cost

(in rupees/HH/at once)

Type of farmer	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	406.75 (469.50)	317.34 (608.49)	460.18 (581.91)	394.75 (553.3)
Small (2.5 – 5 acres)	745.12 (944.31)	440.71 (600.85)	764.61 (884.88)	650.14 (810.01)
Medium (5 – 10 acres)	884.00 (1959.25)	538.85 (1227.31)	1165.62 (2088.77)	862.82 (1757.11)
Large (>10 acres)	883.33 (757.40)	1137.87 (4313.37)	478.57 (777.58)	833.25 (1949.45)

- Figures in parenthesis are standard deviations

Table 5.16. Average amount of willingness to pay by farmers towards Maintenance cost

(in rupees/HH/acre/year)

Type of farmer	Peddagedda	Nagavali	Vamsadhara	All
Marginal (<2.5 acres)	105.40 (105.26)	70.00 (80.80)	88.88 (114.78)	88.09 (100.28)
Small (2.5 – 5 acres)	73.43 (55.94)	88.84 (106.16)	84.30 (85.89)	82.19 (82.66)
Medium (5 – 10 acres)	113.12 (143.72)	97.42 (83.66)	107.81 (122.54)	106.11 (116.64)
Large (>10 acres)	91.66 (58.45)	73.48 (97.21)	145.23 (266.41)	103.59 (140.72)

* Figures in parenthesis are standard deviations

Demand for water for irrigation is very high in all the three watersheds. In an average about 40% of land is left un-irrigated in all the three watersheds due to water scarcity or some other problems. Farmers in these watersheds expressed their strong willingness to pay for irrigaton water. An attempt has been made to link the willingness to pay for irrigation with the other socio-economic variables associated with irrigation, which can influence willingness to pay for both for capital and maintenance cost. It is observed from questionnaire survey that more than 75% of the respondents are willing to contribute for water. From table 5.15, it can be observed that at an average the willingness to pay towards capital investment is increasing with increasing land holdings (type of farmer). The willingness to pay is thus observed to be directly proportional to the size of land holding and subsequently the profits accrued thereof. This positive relation may be attributed to the fact that a large farmer is sure of getting sufficient output on the whole, than a small farmer owning 1.5 acres of land on an average. However, not much variation was observed in the willingness to pay for maintenance among small and large farmers (Table. 5.16).

Multiple regression analysis has been carried out to understand the relationship between independent or predictor variables and a dependent or criterion variable. In the present analysis six groups of explanatory variables (Table 5.6.) have been chosen and different models are generated. Keeping the dependent variables WTPICAP constant, regression models are generated, by changing the explanatory variables in each group separately as independent variables. Like wise keeping WTPIMAIN as dependent and explanatory variables in each group as independent variables regression models are generated and the result are shown in Table 5.17 & 5.18 respectively.

Table 5.17. Results Of Multiple Regression Analysis

Dependent Variable	**WTPICAP**						
Independent Variables	**HH_SIZE**	**MAIN_OCC**	**NO_DAYS**	**SUB_OCC**	**S_NO_DAY**	**OWN_LA_TOT**	**W_OP**
Coefficient	-0.0236	-0.0048	-0.0226	-0.0431	0.0243	0.3277*	0.0469
t-ratio	-0.6094	-0.1260	-0.5841	-0.9263	-0.5186	8.4126	1.2249

Dependent Variable	**WTPICAP**			
Independent Variables	**RESP_AGE**	**EDUCA**	**MAR_STA**	**COMM_PART**
Coefficient	0.0200	0.004	0.0223	0.0551
t-ratio	0.4944	0.0105	0.5505	1.3669

Dependent Variable	**WTPICAP**					
Independent Variables	**RAIN_CHANGE**	**DEC_TANKS**	**DEC_CAN**	**DEC_WELL**	**DEC_IRR_AREA**	**DEC_YIELD**
Coefficient	**0.0008**	0.0182	0.0109	0.1314*	-0.0533	0.1610*
t-ratio	**0.0222**	0.4262	0.2777	4.1821	-1.3679	4.0204

Dependent Variable	**WTPICAP**		
Independent Variables	**IRR_NET_COC**	**DRY_NET_COC**	**TOT_TAX**
Coefficient	0.0514	0.0040	-0.0488
t-ratio	1.1925	0.0965	-1.1729

Dependent Variable	**WTPICAP**		
Independent Variables	**WAT_AVAIL**	**DIST_TRAVAL**	**WAT_QUA**
Coefficient	-0.0335	-0.0094	-0.0353

t-ratio	-0.8201	-0.2310	-0.8647
Dependent Variable	**WTPICAP**		
Independent Variables	**S_ANN_INC**	**ANN_YIELD**	**AVE_INCO**
Coefficient	-0.0266	0.0658	0.0279
t-ratio	-0.6572	1.6236	-0.6902

* Significant at 95% confidence level

Table 5.18. Results Of Multiple Regression Analysis

Dependent Variable	**WTPIMAIN**						
Independent Variables	**HH_SIZE**	**MAIN_OCC**	**NO_DAYS**	**SUB_OCC**	**S_NO_DAY**	**OWN_LA_TOT**	**W_OP**
Coefficient	-0.0039	0.0055	-0.007	0.0578	0.0553	0.2038*	-0.0009
t-ratio	-0.0968	0.1404	-0.1786	1.1948	1.1344	4.6799	-0.0241

Dependent Variable	**WTPIMAIN**			
Independent Variables	**RESP_AGE**	**EDUCA**	**MAR_STA**	**COMM_PART**
Coefficient	-0.1098	-0.0269	-0.0049	-0.0720
t-ratio	-2.7274	-0.740	-0.1224	-1.8023

Dependent Variable	**WTPIMAIN**					
Independent Variables	**RAIN_CHANGE**	**DEC_TANKS**	**DEC_CAN**	**DEC_WELL**	**DEC_IRR_AREA**	**DEC_YIELD**
Coefficient	0.0994	0.0562	-0.0012	0.0423	-0.0647	-0.0254
t-ratio	2.4741	1.2786	-0.0328	0.9490	-1.6163	-0.6192

Dependent Variable	**WTPIMAIN**		
Independent Variables	**IRR_NET_COC**	**DRY_NET_COC**	**TOT_TAX**
Coefficient	0.0438	0.0862	0.0021
t-ratio	1.066	2.066	0.0523

Dependent Variable	**WTPIMAIN**		
Independent Variables	**WAR_AVAIL**	**DIST_TRAVAL**	**WAT_QUA**
Coefficient	0.0445	0.008	-0.0283
t-ratio	1.087	0.1956	0.6940
Dependent Variable	**WTPIMAIN**		
Independent Variables	**S_ANN_INC**	**ANN_YIELD**	**AVE_INCO**
Coefficient	0.0810	0.0458	0.0112
t-ratio	2.0221	1.1430	-0.0231

* Significant at 95% confidence level

Table. 5.19. Results of regression analysis among all the significant variables and WTPICAP

Dependent Variable	WTPICAP		
Independent Variables	**OWN_LA_TOT**	**DEC_WELL**	**DEC_YIELD**
Coefficient	0.3179*	0.1761*	0.1606*
t-ratio	8.659	4.732	4.3210

* Significant at 95% confidence level

Table.5.20. Results of regression analysis among all the significant variables and WTPIMAINT

Dependent Variable	WTPIMAIN				
Independent Variables	**RESP_AGE**	**S_ANN_INC**	**OWN_LA_TOT**	**DRY_NET_COC**	**RAIN_CHANGE**
Coefficient	-01348*	0.0790*	0.1960*	0.0569	0.0964*
t-ratio	-3.4396	2.0301	4.9942	1.4587	2.4787

* Significant at 95% confidence level

The multiple regression results show how the willingness to pay for capital cost and maintenance of irrigation is being effected by the groups of explanatory variables. In the first model the only total owned land showed positive correlation with WTPICAP. In the second model out of four variables no variable showed significant relation with WTPICAP. In the third group of variables DEC_WELL, DEC_YIELD showed significant positive relation with WTPICAP. In the last three groups out of 9 variables no variable showed significant relation. The regression models with WTPIMAIN, in the first group OWN_LA_TOT showed significant positive relation. In the second group RESP_AGE showed negative significance with WTPIMAIN. In the third group RAIN_CHANGE, DEC_WELL, showed positive relation while DEC_YIELD showed negative significance with WTPIMAIN. In the fourth group only DRY_NET_COC showed significant relation. The results of the multiple regression model obtained keeping WTPICAP, WTPIMAIN as dependent variables and all significant variables obtained from previous models as independent variables are shown in Tables 5.19 and 5.20.

CHAPTER 6: RESULTS AND RECOMMENDATIONS

Srkakulam, one of the north coastal district of Andhra Pradesh, is facing water problem for irrigation and drinking. The capacities of the tanks in this area have come down drastically due to accumulation of silt and weed resulting in severe loss in ayacut and yield. It is also observed that some of the villages are facing water quality problem due to excess fluoride and nitrate. Keeping these problems it is proposed to study the water balance, water quality, conditions of tanks, and willingness to pay by the farmers for irrigation water. The study area is divided into three watersheds named Peddagedda, Nagavali and Vamsadhara.

The first chapter of this report consists of introduction, which includes description on the three watersheds and the district, irrigation system and sources of irrigation, and cropping pattern. In the second chapter water balance study has been carried out in all the three watersheds. The rainfall years from 1971-86 and 1987-1995 have been considered in this study. Parameters like rainfall, precipitation, interception, evapotranspiration, run-off and groundwater recharge were estimated. From the water balance statistics, it is found that in Peddagedda watershed the total water stocks are 13409.5 ha-m. of which contribution by groundwater is about 13,409 ha-m., and 5928 ha-m. contributed by tanks. But the water consumption from tanks is highest (3241 ha-m.) for irrigation, followed by groundwater. Tank water used for irrigation purpose, while groundwater is used maximum for drinking purpose. The stock in the river water is estimated to be 12278 ha-m. It is observed that this river water is entirely going waste as run-off into the Bay of Bengal. In Nagavali watershed, the total stocks are estimated at as 104,120 ha-m. including river discharge. The groundwater stocks are more, which is estimated to be as 41996 ha-m. From the studies it is found in this watershed that the maximum (86%) tank water is used for irrigation. Run-off in the rivers and streams is estimated at as 29,732 ha-m. Very less amount of groundwater (6580 ha-m) is being extracted for irrigation in this watershed. In Vamsadhara watershed, the total water stocks are about 74946 ha-m. The groundwater stock is estimated at as 29937 ha-m. The amount of water leaving the watershed is about 22692 ha-m. In all the three watersheds together about 64702 ha-m. of water is going waste as run-off. From the water balance studies it is also observed that in all the three watersheds the groundwater is under utilized and the agriculture is mainly dependent on tanks and canals. During low rainfall years the stock in the tanks is almost nil. In case of water scarcity in tanks, farmers are reportedly going for other crops for which water requirement is less. About 95% of the farmers in this watershed are small farmers owning 0.5 to 1 acre land holding and they cannot afford the capital amount to explore groundwater. Hence, if the tanks in these watersheds are brought to their original capacities and maintained properly, there is a possibility to stop the excess run-off water by diverting into tanks to irrigate the large tracts of un-irrigated land, and substantially improve the agricultural production. This can improve the agriculture economy and living standards of the rural population.

Water quality analysis has been carried out in all the three watersheds the third chapter. Emphasis was laid on fluoride and nitrate concentrations in drinking water sources. Since, no secondary data was available in Peddagedda and Nagavali watersheds, water samples were collected from 15 villages in the former and 25 villages in the later. These analyzed samples showed that two villages in Peddagedda watershed have fluoride concentrations of 2.00 mg/l. and 1.80 mg/l., while the accepted WHO limit is 1.5 mg/l. On the other hand nitrate concentrations of above 45 ppm. were observed in ten villages of Peddagedda watershed varying from 65 ppm. to 145 ppm. In the Nagavali watershed, sixteen villages were found to have nitrate concentrations of above 45 ppm. ranging from 55 ppm to 420 ppm. Fluoride concentrations of above 1.5 ppm. were observed in three villages ranging from 1.56 ppm. to 1.90 ppm. In the Vamsadhara watershed, secondary data was available in isolated pockets. Hence, water samples were collected in this watershed also and a total of 75 villages were analyzed. Out of these villages, 25 villages were observed to have nitrate concentrations of above 45 ppm. ranging from 50 ppm. to 404 ppm. Only two villages were found to be affected by excess fluoride concentrations in Vamsadhara watershed.

To summarize the highest concentrations of fluoride and nitrate are found in the following villages.

Watershed	**Village**	**Flouride**

		Concentration
Peddagedda watershed	Ranasthalam	2.00 mg/l
Nagavali	Vanjangi	1.90 mg/l.
Vamsadhara	Mamidivalasa	2.40 mg/l

Watershed	**Village**	**Flouride Concentration**
Peddagedda watershed	Patharlapalli	145 ppm.
Nagavali	Kusimi	420 ppm.
Vamsadhara	Srikurmam	404 ppm.

From the study, all the techniques available for the removal of fluoride, the Nalgonda technique proposed by NEERI is found to be the most economical and easy to implement in rural areas with minimum requirement of skilled personnel. From this technique it is estimated that the treatment cost per capita (@40 lpcd) comes to Rs. 0.20. On the other hand, the treatment of excess nitrate is still an ongoing research and the methods currently available are also not known to remove the nitrate completely. Moreover, the occurrence of nitrate is only due to point sources. Hence, the best remedy for prevention of excess nitrate accumulation lies in better management of water disposal.

Irregular rainfall has lead to enormous crop loss. To overcome the shortage of irrigation water, the run-off from rainfall needs to be stored efficiently to ensure proper water management. The study area has a number of tanks of varying sizes. Lack of maintenance by way of disiltation has been observed to be the major problem with these tanks. As a result, only those few farmers who can afford to invest to tap groundwater are using groundwater. On the contrary, a majority of the farmer who come under small and marginal category are leaving their lands as fallow, especially those in the tail end of the tank command areas. Keeping these problems in view, a systematic analysis of 23 tanks whose command areas are above 100 acres have been selected for the study from all the three watersheds. These tanks were analyzed for their present performance by computing the performance indicators like effectiveness ratio and deviation factors. The bed areas and command areas required for computing these indicators were obtained from the concerned state government departments and were checked with the remote sensing data to ascertain their present condition. In all the major tanks in three watersheds excluding Asarla Sagaram tank in Vamsadhara watershed, significant loss in bed areas was observed. This loss is due to unchecked silt accumulation over the last five decades. In some cases, the registered bed areas of tanks as per the village records were found to much higher than those measured from Survey of India topographic maps. For instance, the bed areas of Narayana Sagaram tank in Peddagedda watershed as per the village records is 300.19 acres, where as it is only 103.72 acres as measured from Survey of India topographic maps. The current bed area as measured from IRS 1D satellite data is much less at 103.72 acres. This suggests a declining trend in the bed areas.

S. No	Tank Name	Village	Mandal	Regd. Bed area	Present bed area (IRS data)	(1/2)	SCA	Present Command Area	(4/5)
				1	2	3	4	5	6
Peddagedda Watershed									
PW1	Narayana Sagaram	Budumuru	Laveru	300.19	103.72	0.35	697.94	225.60	0.32
PW2	Devala Tank	Bejjipuram	Laveru	160.55	132.92	0.83	500	427.64	0.86
PW3	Raju Tank	Punnam	G. Sigadam	30	19.42	0.65	500	206.00	0.41
PW4	Lanka Tank	Patharlapalli	Ranasthalam	50	47.49	0.95	400	150.00	0.38
PW5	Daba Tank	Chinna Murapaka	Laveru	112.91	22.65	0.20	200	73.61	0.37
PW6	Nidigandlam Tank	Adapaka	Laveru	72	15.04	0.21	162	75.31	0.46
PW7	Pedda Tank	Budatavalasa	Laveru	49.4	19.49	0.39	150	63.87	0.43
PW8	Tammi Naidu Tank	Peda Rompivalasa	Laveru	43.2	18.53	0.43	140	57.23	0.41
PW9	Borra Patuvani Tank	Batuva	G. Sigadam	33.96	16.81	0.49	135	73.29	0.54
PW10	Pedda Tank	Batuva	G. Sigadam	40.14	24.72	0.62	133	92.80	0.70
Nagavali Watershed									
NW1	Pedda Tank	Shermohammad-puram	Etcherla	160	96.1	0.60	312	153.04	0.49
NW2	Tamara Tank	Siripuram	Santakaviti	625	311.67	0.50	784	344.84	0.44
NW3	Mandavakuriti Tank	Mandavakuriti	Santakaviti	300	161.9	0.54	1600	673.08	0.42
NW4	Salavani Tank	Seetampeta	Ponduru	58	48.83	0.84	247	165.56	0.67
NW5	Meduri Krishnamma Tank	Boddavalasa	Rajam	66.66	38.31	0.57	300	121.13	0.40
NW6	C. R. Raju Tank	Unukuru	Vangara	92.74	79.1	0.85	204.7	164.15	0.80
NW7	Subbi Tank	Arasada	Vangara	82.69	78.46	0.95	307	251.13	0.82
NW8	Tamara Tank	Ungarada	R. Amadalavalasa	67	67	1.00	251	208.88	0.83
NW9	Gudivada	Lumburu	Palakonda	113	86.01	0.76	500	309.69	0.62
NW10	Yebbaji Tank	Vadada	Gara	125.8	106.78	0.85	670	412.69	0.62
Vamsadhara Watershed									
VW1	Asarla Sagaram	Temburu	Saravakota	368.26	359.3	0.98	5400	3479.98	0.64
VW2	Ranga Sagaram	Poppangi	Saravakota	326.86	302.33	0.92	1920.68	1429.06	0.74
VW3	Pedda Tank	Kottakota	Sarubujjili	175	153.69	0.88	477.95	319.58	0.67

From the above table it may be observed that ratio of registered bed areas to the present bed areas varies from 0.32 to 0.86 for the Peddagedda Watershed. Out of the 10 selected tanks in this watershed 7 tanks have lost more than 50% of their bed areas. The tanks in the Nagavali watershed are observed to be a little better than those in the Peddagedda watershed. The bed area ratios in this watershed vary from 0.40 to 0.80. Only four tanks are observed to have lost more than 50% of their bed areas. All the three tanks in the Vamsadhara watershed are observed to be have almost retained their original bed areas. Thus, the tanks in Peddagedda Watershed and Nagavali Watershed are in a state of total neglect and need immediate desiltation works to restore their original capacities and efficiencies.

As can be seen from the table 4.20 in Peddagedda watershed the gross irrigated area under canals and tanks is following slowly decreasing trend and at the same time the area under groundwater sources is increasing. The area under canals was 1536 acres in 1998-86 was reduced to 1352 acres in 1994-95. The groundwater-irrigated area (tube wells and other wells) has been increased from 83 (in 1985-86) to 1608 acres (in 1994-95) in case of tube wells and 224 to 4230 acres in case of other wells. In Nagavali watershed, the area irrigated under canals and tanks in 1985-86 was 74211 and 54008 acres was decreased to 66706 and 48314 acres by 1994-95. The tube well –irrigated area has been increased from 2161 acres to 7496 acres and the area irrigated from other wells was increased from 883 acres to 10159 acres. In Vamsadhara watershed, the area irrigated by canals has been increased from 69795 acres to 73118 acres from 1985-86 to 1994-95 and tank irrigated area was decreased from 39696 acres to 36818 acres. The increase in canal-irrigated area is due to construction of Vamsadhara project. The groundwater-irrigated area has been increased from 2557 acres to 9665 acres in 1985-86 in case of tube wells from 906 acres to 3250 acres by other wells.

Providing irrigation facility will result in substantial increase in crop productivity and yield in the watersheds. If the tanks are repaired and irrigation facility is provided there is a social benefit of increase in employment to the landless labour. If the irrigation facility is provided landless people who are migrating else where for part of the year in search of employment, no longer had to do so. The present studies show that the employment potential will raise to almost 100% in all the three watersheds of irrigation facility is provided.

The major findings based on the analysis of willingness to pay are summarized below:

10. Total 622 sample households in all the three watersheds surveyed to study their willingness to pay for irrigation towards capital expenditure and maintenance. The per capita land owned is 1.15 acres.

11. Majority of the farmers in all the three watersheds belong to backward community (87.15% in Peddagedda, 87.68% in Nagavali and 97.68% in Vamsadhara). It is found that 61.46%, 45.45%, 34.30% of farmers fall in below poverty level in three watersheds respectively.

12. It is observed that more than 75% of the respondents are willing to pay for water in these watersheds and in Peddagedda watershed alone about 92% people are willing to pay. The main reason for this high willingness to pay is the absence of irrigation projects in this area.

13. The average willingness to pay in three watersheds is Rs. 582/- towards capital cost to be paid at a time once for all and Rs. 49.50/- paid per acre/year/household. About 18% of the respondents expressed their inability to pay due to their low income. It is observed that the willingness to pay is increasing with the increasing land owned from less 1.5 acres (Rs. 388.57) to greater than 11 acres (Rs. 872.72) per household.

14. Community participation is found to be of very low in all the three watersheds. This is partly due to lack of unity among the villagers. However, Water Users' Associations are given fruitful results in some villages. By creating better awareness and education and by providing better leadership, this community participation can be promoted.

15. Loans taken by the farmers are increasing with increase in size of land holdings due to loss in agricultural output.

16. Total agricultural land owned is showing more influence on willingness to pay. Because agriculture land is the wealth of the villagers, it showed positive willingness to pay. They can be assured that the un-irrigated land will also come to irrigation and the willingness to pay would also increase.

17. Change in water level in tanks, canals and wells showed positive influence on willingness to pay. Decrease in tanks and other sources seem to make the villagers to lose their faith on them in supplying water to their fields. As the villagers know that improvement of these can be a benefit to them.

18. Variables such as total land owned, irrigation output, education, decrease in yield due to lack of water, decrease of water level in wells are positively significant in influencing the peoples' thought on willingness to pay of irrigation water.

19. Variables such as size of the household, number of days in main occupation, age of the respondent, net income and water tax showed negative thought on willingness to pay.

Policy Issues

a) River water should be conserved properly by following watershed management techniques, by constructing dams/ barrages/anicuts, and to preserve their reservoir capacities, suitable soil conservation techniques be enforced in all the three watersheds.

b) Desiltation works have to be carried out to restore the tank capacities and command areas, wherever possible.

c) The release of water from tanks is presently unrestricted in most of the tanks. Hence, proper water regulatory structures have to be constructed for effective water management.

d) All the tanks within a watershed should be connected. Though most of the tanks are connected in series by streams/canals. The canals also need to be repaired. This helps the farmers not just in the command area of a single tank, but also protects the riparian rights of the farmers in the down stream of the watershed.

Since there are no major irrigation projects in Peddagedda and Nagavali watersheds, the construction of such canal network would be extremely beneficial from the socio-economic as well as environmental aspects.

e) The presence of water users associations has significant positive effect on water management. If internal bickering within the association can be curtailed by educating the members of these associations, and also participation of women is made compulsory, and by close monitoring of the working of these associations, more fruitful results can be realized. These associations should be made fully accountable for all the maintenance and repairs works under taken. The engineers of the A.P. Government agencies must advice and help the associations.

f) Water User's Associations can also be motivated to monitor groundwater in respect of water level and quality. They can also take up soil fertility, agro-pollutant level. Water quality awareness camps should be organized in the villages to prevent groundwater pollution due to human interference.

g) Farmers should be trained for balanced and efficient use of chemical fertilizers, bio-fertilizers, making them clear about environmental issues due to excess use of them.

h) The water tax according to present structure is very low when compared to the financial resources required for maintenance of the tanks and in no way reflect the value of water which is scarce. The main reason for not increasing the fees is on the premise that the farmers may not be able to meet the extra financial burden but yet it is inevitable. Water charges should be raised with assurance of water through the infrastructure improvement. Volumetric pricing of water instead of crop-wise pricing would result in more beneficial and can control the wastage of water.

i) Since, the villagers are very much interested to contribute for water resources projects, i.e., betterment levy, in all the three watersheds, government can take further steps to improve the living standards of the villagers in this area.

Table 1.4 : Area under principal crops in Srikakulam district and mandals of three watersheds

(area in acres)

District/ Mandal	Year	Paddy	Jowar	Bajra	Ragi	Sugarcane	Mesta	Groundnut	Sesamum	Total pulses
Srikakulam district	1986-87	521071	9868	19224	52291	11875	38122	128547	18014	117157
	1992-93	531725	6084	8375	40514	13544	54336	39660	19884	297212
	1998-99	485303(-6.9)	1525	10061	14822	24658	47563	114678	16365	198774
Seetampeta	1986-87	4606	133	100	2908	25	700	80	5	479
	1992-93	5877	821	927	5065	211	887	237	88	2221
	1994-95	5081	879	1060	4122	10	467	237	81	790
Veeraghattam	1986-87	20319	0	0	375	265	1468	3643	2168	8280
	1992-93	18749	37	15	395	267	1551	1645	1783	9764
	1994-95	18592	15	0	128	146	2542	1366	1344	5283
Palakonda	1986-87	17260	54	0	700	3010	1322	1026	397	4788
	1992-93	16240	0	0	458	2238	1640	605	98	10372
	1994-95	15963	0	0	296	1887	1255	546	25	1939
Vangara	1986-87	9015	279	60	998	343	2764	2297	842	2681
	1992-93	9380	139	0	872	367	4687	1989	998	6238
	1994-95	9915	12	0	534	212	6046	3796	929	10781
R. Amadalavalasa	1986-87	15796	325	0	879	792	2271	10100	871	7295
	1992-93	16281	800	0	553	840	1804	9780	435	9349
	1994-95	13207	49	0	585	1210	4271	6649	215	11164
Rajam	1986-87	10000	505	0	842	69	6231	7366	474	2232
	1992-93	9670	561	0	1517	150	5245	9261	533	8368
	1994-95	8294	469	0	825	186	5305	8581	474	14551
Burja	1986-87	12875	56	0	673	1189	1095	1321	102	1398
	1992-93	13575	0	0	555	2506	1428	808	152	10513
	1994-95	12916	469	0	684	4890	1534	637	44	2275
Kotabommali	1986-87	16634	157	71	1210	0	679	5193	121	2336
	1992-93	18255	229	0	951	0	665	4210	129	6557
	1994-95	17433	244	0	620	15	751	5629	148	6558
Saravakota	1986-87	15792	0	0	974	141	1105	1964	365	711
	1992-93	16680	0	0	1080	136	865	1829	1067	9628
	1994-95	15156	0	0	9845	207	1107	1623	1531	4263
Pathapatnam	1986-87	18181	0	0	1586	133	972	1748	740	2773
	1992-93	16610	0	0	994	173	1886	1485	621	7820
	1994-95	16445	0	0	966	348	1299	1297	282	2902

Hiramandalam	1986-87	10621	0	0	606	236	1135	906	380	835
	1992-93	12370	4	0	840	119	1807	1138	485	6761
	1994-95	12345	0	0	694	148	1615	1034	479	3164
Jalumuru	1986-87	20079	17	78	745	87	532	1825	425	4018
	1992-93	21368	37	25	647	49	368	1756	412	10046
	1998-99	21471(+6.5)	0	0	201	156	300	1946	333	8319
Santhakaviti	1986-87	13537	888	0	877	579	3315	7217	813	6193
	1992-93	13562	264	78	482	687	3130	7179	368	17438
	1998-99	11882(-12.0)	29	10	191	958	3015	6722	93	10698
Narasannapeta	1986-87	19729	128	40	646	80	98	3648	262	7421
	1992-93	20316	30	0	382	116	118	1018	419	14678
	1998-99	20672(+4.8)	0	0	215	366	108	1422	295	11448
Polaki	1986-87	21000	286	137	1125	195	346	3130	615	4260
	1992-93	21495	0	15	823	684	474	2514	503	12946
	1998-99	20125(-4.10)	0	0	579	951	869	2182	395	12549
Srikakulam	1986-87	17337	1125	262	1017	780	1294	6397	162	5162
	1992-93	15970	1013	217	935	614	4801	6098	0	9021
	1998-99	12116(-30.0)	0	64	720	2014	2073	4191	108	9445
Gara	1986-87	18201	1568	1402	2239	31	318	4692	242	5218
	1992-93	17208	287	2386	2712	37	1487	5334	478	14656
	1998-99	15440(-15.0)	36	4826	685	1286	1981	2856	184	14376
Amdalavalasa	1986-87	11513	46	0	905	751	925	1391	84	1585
	1992-93	11624	62	0	984	931	1260	1466	83	6725
	1998-99	9990(-13.0)	0	0	316	1953	1037	871	160	5618
Sarubujjili	1986-87	21211	78	0	1071	1255	790	1831	105	1864
	1992-93	21513	9	0	806	1467	1050	2129	67	11082
	1998-99	21936(+3.4)	0	0	186	371	1977	250	0	4760
Etchcherla	1986-87	11467	1165	3609	2942	138	2026	8423	913	5152
	1992-93	9697	36	2368	2523	67	5570	7443	2495	7560
	1998-99	8283(-27.76)	54	2699	1371	569	4259	8580	2034	7356
G. Sigadam	1986-87	10252	590	694	584	16	669	10188	326	4055
	1992-93	11120	587	69	248	118	2069	11727	845	11309
	1998-99	9684(-5.5)	0	13	240	154	1424	10100	166	5951
Ponduru	1986-87	11438	1213	372	723	623	1760	7457	154	7341
	1992-93	10162	781	426	820	919	3731	6702	996	10296
	1998-99	7255(-36.6)	198	99	654	2259	1198	7659	422	7618
Laveru	1986-87	7952	335	3184	1119	16	1098	8434	264	2976

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	1992-93	8426	41	900	921	2	870	17098	441	11741
	1998-99	3792(-52.3)	4	901	552	392	462	14699	449	7985

Source: Chief Planning Officer, Srikakulam District.
* Figures in parenthesis shows percentage change.

Table 2.16. Source and Crop wise Irrigated area and water Consumption in Peddagedda Watershed (1985-86)

Source	Paddy	Water Consumption	Ragi	Water Consumption	Chillies	Water Consumption	Sugarcane	Water Consumption	Groundnut	Water Consumption	Others	Water Consumption
1985-86												
Canal	1063	559	30	6	41	10	13	7	16	4	2	0
Tank	6127	3225	630	117	440	107	30	17	40	11	13	3
Tubewell	1987	1046	229	43	129	31	8	4	7	2	2	0
Otherwell	3707	1951	437	81	250	61	17	10	12	3	4	1
Othersource	336	177	10	2	13	3	1	0	5	1	1	0
Total	13219	6957	1336	249	874	212	69	39	81	21	23	5
1988-89												
Canal	1114	586	70	13	55	13	12	7	41	11	4	1
Tank	6424	3381	555	103	460	112	33	19	145	38	15	3
Tubewell	2026	1066	200	37	138	34	7	4	32	8	4	1
Otherwell	3781	1990	382	71	264	64	11	6	60	16	7	1
Othersource	357	188	23	4	18	4	4	2	14	4	1	0
Total	13701	7211	1230	229	936	227	67	38	292	77	31	6
1994-95												
Canal	920	484	72	13	67	16	38	22	76	20	0	0
Tank	4042	2127	335	62	748	182	45	25	727	191	0	0
Tubewell	1291	680	111	21	253	61	7	4	235	62	0	0
Otherwell	2410	1269	214	40	480	117	13	7	461	121	0	0
Othersource	298	157	25	5	22	5	10	6	25	7	0	0
Total	8961	4716	756	141	1570	381	113	64	1524	401	0	0

* Area in acres, consumption in Ha-m., N.A. – Not Available

Table 2.17. Source and Crop wise Irrigated area and water Consumption in Nagavali Watershed (1985-86)

Source	Paddy	Water Consumption	Ragi	Water Consumption	Chillies	Water Consumption	Sugarcane	Water Consumption	Groundnut	Water Consumption	Others	Water Consumption
1985-86												
Canal	62459	32873	1268	236	1088	264	4263	2416	1918	505	213	43
Tank	48427	25488	2172	405	1453	353	1796	1018	1715	451	152	31
Tubewell	3334	1755	126	23	119	29	31	18	181	48	34	7
Otherwell	6829	3594	272	51	232	56	242	137	213	56	30	6
Othersource	5837	3072	174	32	125	30	370	210	137	36	8	2
Total	126886	66782	4012	747	3016	733	6703	3799	4165	1096	438	89
1988-89												
Canal	62394	32839	1084	202	1124	273	2321	1316	2460	647	239	48
Tank	49019	25799	951	177	1409	342	1803	1022	1662	437	123	25
Tubewell	3448	1815	107	20	137	33	83	47	170	45	35	7
Otherwell	6923	3644	190	35	238	58	233	132	242	64	25	5
Othersource	6038	3178	244	45	153	37	67	38	132	35	28	6
Total	127822	67275	2576	480	3060	743	4508	2555	4666	1228	450	91
1994-95												
Canal	57343	30181	1163	217	1082	263	4538	2572	2884	759	NA	NA
Tank	37078	19515	821	153	1234	300	2613	1481	2368	623	NA	NA
Tubewell	5954	3134	134	25	159	39	424	240	324	85	NA	NA
Otherwell	7563	3980	298	55	429	104	450	255	587	154	NA	NA
Othersource	5453	2870	231	43	176	43	229	130	338	89	NA	NA
Total	113391	59679	2647	493	3080	748	8253	4678	6501	1711	NA	NA

* Area in acres, consumption in Ha-m., N.A. – Not Available

Table. 2.18 Source and Crop wise Irrigated area and water Consumption in Vamsahdara Watershed (1985-86)

Source	Paddy	Water Consumption	Ragi	Water Consumption	Chillies	Water Consumption	Sugarcane	Water Consumption	Groundnut	Water Consumption	Others	Water Consumption
1985-86												
Canal	66975	35250	1301	242	991	241	1252	710	4890	1287	139	28
Tank	33965	17876	483	90	418	102	667	378	1444	380	61	12
Tubewell	4821	2537	153	29	86	21	32	18	559	147	23	5
Otherwell	3999	2105	92	17	64	16	50	29	253	67	10	2
Othersource	22233	11701	233	43	138	33	242	137	2608	686	2	0
Total	131993	69470	2263	421	1697	412	2242	1271	9755	2567	236	48
1988-89												
Canal	69192	36417	3418	636	1056	256	1878	1064	2349	618	0	0
Tank	40472	21301	2511	468	603	147	819	464	785	206	0	0
Tubewell	5154	2713	252	47	68	16	53	30	209	55	0	0
Otherwell	4560	2400	251	47	86	21	86	49	155	41	0	0
Othersource	23875	12566	551	103	179	44	394	223	999	263	0	0
Total	143253	75396	6983	1301	1992	484	3229	1830	4497	1183	0	0
1994-95												
Canal	69248	36446	710	132	623	151	2360	1337	2789	734	NA	NA
Tank	26790	14100	255	48	461	112	938	532	641	169	NA	NA
Tubewell	7412	3901	83	16	79	19	401	227	308	81	NA	NA
Otherwell	2930	1542	25	5	40	10	99	56	113	30	NA	NA
Othersource	23714	12481	318	59	130	32	402	228	824	217	NA	NA
Total	130094	68470	1392	259	1333	324	4200	2380	4676	1230	NA	NA

* Area in acres, consumption in Ha-m., N.A. – Not Available

Table 4.1. Area under principal crops in Peddagedda watershed

(Area in acres)

Year	Paddy	Jowar	Bajra	Ragi	Sugarcane	Mesta	Groundnut	Sesamum	Total Pulses
1985-86	14758	2844	7343	4151	2071	7748	14365	2578	8822
1986-87	14914	931	5461	2276	463	3110	15610	1347	6641
1987-88	2220	743	5481	2067	183	2763	16697	1182	5890
1988-89	14989	798	5347	1895	88	3825	16091	685	5773
1989-90	16370	383	2414	1790	53	3906	23146	1265	4626
1990-91	16410	250	2997	1872	65	4846	22079	772	6318
1991-92	12887	146	2564	2280	59	5125	25133	314	17641
1992-93	14608	215	1521	2056	108	4028	27809	1175	20217
1993-94	6555	233	1816	1492	128	3086	25906	1016	NA
1994-95	9454	282	1879	1094	253	3047	23003	1065	NA

Source: Handbook of Statistics Srikakulam District.

Table 4.2. Area under principal crops in Nagavali watershed

(Area in acres)

Year	Paddy	Jowar	Bajra	Ragi	Sugarcane	Mesta	Groundnut	Sesamum	Total Pulses
1985-86	128703	6121	4349	9897	6996	34083	40556	5327	39116
1986-87	131240	5513	4398	10425	7351	21467	57061	5334	45494
1987-88	44722	NA	NA	2582	6967	NA	6729	NA	63364
1988-89	131547	5737	5358	5880	7019	27171	54626	5968	43883
1989-90	128872	NA	0	8862	7735	NA	5831	NA	296571
1990-91	128684	3957	4860	9045	6614	35112	45096	4825	52360
1991-92	127508	3248	4384	9850	7089	38988	43381	2896	60497
1992-93	128411	3790	3269	9878	8138	28887	65093	6617	107673
1993-94	108708	2754	3791	7860	10494	27034	52859	5181	Na
1994-95	111710	3764	4032	6581	14582	25840	41231	13215	NA

Source: Handbook of Statistics Srikakulam District.

Table 4.3. Area under principal crops in Vamsadhara watershed

(Area in acres)

Year	Paddy	Jowar	Bajra	Ragi	Sugarcane	Mesta	Groundnut	Sesamum	Total Pulses
1985-86	104078	1956	1556	6589	931	5176	15863	1537	20706
1986-87	105074	2068	1540	6879	1152	3813	17206	2150	23062
1987-88	39487	NA	NA	1228	1211	NA	7705	NA	52503
1988-89	104577	2095	2095	7129	1160	4556	14525	1672	27602
1989-90	105029	NA	NA	6232	1385	NA	3361	NA	176036
1990-91	104911	1164	1338	6226	1316	4830	14100	2408	41062
1991-92	105737	1179	1729	5375	1360	6734	15240	2953	50864
1992-93	107076	855	2253	6986	1606	6452	14615	2941	65625
1993-94	98069	575	2101	5352	2315	6589	13653	2409	0
1994-95	103586	2553	3563	12527	2774	5566	12284	3256	NA

Source: Handbook of Statistics Srikakulam District.

Table 4.28. Costs and benefits of tank irrigation to the project authority in Peddagedda, Nagavali and Vamsadhra watersheds

Tank	SCA (acres)	Total cost of the Project (Rs. '000)	Cost/acre (Rs)	Present Value/acre assuring 22 yrs life period at 5.75% interest (Rs)	Total cost/acre including Rs. 117/-acre for maintenance and repairs	Revenue collected (Rs/acre)	BCR
Peddagedda							
PW1	697.9	2381	3411.66	997.2349	1114.235	160	0.144
PW2	500	1657	3314.00	968.6887	1085.689	160	0.147
PW3	500	1410	2820.00	824.2915	941.2915	160	0.170
PW4	400	1625	4062.00	1187.477	1304.477	160	0.123
PW5	200	805	4025.00	1176.515	1293.515	160	0.124
PW6	162	571	3524.69	1030.274	1147.274	160	0.139
PW7	150	603	4020.00	1175.054	1292.054	160	0.124
PW8	140	589	4207.14	1229.755	1346.755	160	0.119
PW9	135	583	4318.51	1262.309	1379.309	160	0.116
PW10	133	403	3030.08	885.6983	1002.698	160	0.160
Nagavali							
NW1	312	1045	3349.35	979.0216	1096.022	160	0.146
NW2	784	2634	3359.65	982.0323	1099.032	160	0.146
NW3	1600	5415	3384.75	989.3691	1106.369	160	0.145
NW4	247	878	3554.65	1039.031	1156.031	160	0.138
NW5	300	1135	3783.33	1105.875	1222.875	160	0.131
NW6	204.7	697	3404.98	995.2823	1112.282	160	0.144
NW7	307	1182	3850.16	1125.409	1242.409	160	0.129
NW8	251	943	3756.97	1098.17	1215.17	160	0.132
NW9	500	1875	3750.00	1096.132	1213.132	160	0.132
NW10	670	2319	3461.19	1011.713	1128.713	160	0.142
Vamsadhara							
VW1	5400	16879	3125.74	913.6599	1030.66	160	0.155
VW2	478	1755	3671.55	1073.201	1190.201	160	0.134
VW3	1921	6324	3292.03	962.2668	1079.267	160	0.148

Table 1.6: Source wise Gross Area Irrigated in Mandals of three watersheds

(Area in Acres)

District/ Mandal	Source	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Srikakulam district	Canals	209510	237415	97485	217663	250562	257612	264722	265355	232899	219487	NA	NA	NA
	Tanks	221491	213546	51769	236067	200916	195731	193063	203827	175992	185949	NA	NA	NA
	TW/OW	8298	34900	31492	39027	42990	44565	47484	49747	46520	42518	NA	NA	NA
Seetampeta	Canals	0	1200	0	0	0	0	0	0	0	0	NA	NA	NA
	Tanks	1000	0	48	1162	554	885	760	976	0	0	NA	NA	NA
	TW/OW	0	0	158	0	96	235	76	433	0	0	NA	NA	NA
Veeraghattam	Canals	18207	4567	11447	19407	19177	18451	18581	17487	16450	15223	NA	NA	NA
	Tanks	1480	18633	3453	2023	547	15706	625	0	30	689	NA	NA	NA
	TW/OW	35	105	73	71	39	106	107	629	930	815	NA	NA	NA
Palakonda	Canals	17032	2402	9984	16928	16445	15917	15876	17280	16237	13703	NA	NA	NA
	Tanks	1862	17815	1152	2133	306	14951	327	0	0	667	NA	NA	NA
	TW/OW	40	217	230	226	276	181	571	1311	2061	1428	NA	NA	NA
Vangara	Canals	5728	3442	1924	5376	4155	3960	3974	4051	6469	5545	NA	NA	NA
	Tanks	2730	5838	916	3202	4689	4840	4843	4914	3342	3710	NA	NA	NA
	TW/OW	70	304	243	299	673	358	388	2030	646	1282	NA	NA	NA
R. Amadalavalasa	Canals	7085	9588	4413	6093	6270	6187	6870	7270	5036	5874	NA	NA	NA
	Tanks	9493	7085	2040	9457	10357	10641	10204	10327	7196	7911	NA	NA	NA
	TW/OW	65	1051	1012	975	1895	608	1068	1009	609	929	NA	NA	NA
Rajam	Canals	0	0	0	0	0	0	0	0	0	0	NA	NA	NA
	Tanks	9589	9720	2761	9166	9257	9378	9357	9764	4389	8344	NA	NA	NA
	TW/OW	380	935	810	998	1188	1154	1140	1970	1155	1899	NA	NA	NA
Burja	Canals	10622	3269	2088	9770	11171	11869	13048	13076	10279	9672	NA	NA	NA
	Tanks	2870	10622	745	3812	2095	1724	1902	12179	4500	4434	NA	NA	NA
	TW/OW	60	317	278	191	375	1115	569	952	518	533	NA	NA	NA
Kotabommali	Canals	4752	8571	3900	6035	11840	13765	13768	14429	7619	7146	NA	NA	NA
	Tanks	8176	4850	1937	8651	2930	1132	1266	791	7619	7363	NA	NA	NA
	TW/OW	18	1051	1061	1534	1620	1693	1150	2427	1352	1648	NA	NA	NA
Saravakota	Canals	5100	9852	1876	6050	2312	2310	2314	2314	2015	2146	NA	NA	NA
	Tanks	9569	5100	1464	9524	10657	10772	11062	11049	10932	9915	NA	NA	NA
	TW/OW	149	394	378	688	920	967	1021	1694	920	899	NA	NA	NA
Pathapatnam	Canals	5800	9216	3089	5816	4675	4623	5123	5163	3972	86	NA	NA	NA
	Tanks	8915	5771	1090	9256	7280	7400	6899	7119	8120	10942	NA	NA	NA
	TW/OW	81	610	582	854	1306	968	1228	1077	913	558	NA	NA	NA
Hiramandalam	Canals	1822	6305	1500	1783	1359	1372	1499	1718	1718	1588	NA	NA	NA

	Tanks	6204	1822	2838	6305	7970	7875	8206	8184	8032	7667	NA	NA	NA
	TW/OW	123	273	249	474	362	227	436	306	491	612	NA	NA	NA
Jalumuru	Canals	7985	8425	8242	9020	14310	15347	16008	16020	13958	14225	15150	14317	14030
	Tanks	8035	8110	3098	8150	2613	1148	1051	2663	1437	2280	1704	1789	2630
	TW/OW	80	827	822	586	669	144	911	428	1104	1237	1257	938	807
Santhakaviti	Canals	5510	9068	2846	5374	6189	5890	5526	5739	5628	5799	6050	4444	4515
	Tanks	8605	5498	2416	8402	8275	8541	9048	8943	8340	3362	8835	1421	6952
	TW/OW	194	927	857	1257	1213	1191	999	856	919	1183	1522	1200	1832
Narasannapeta	Canals	15756	2405	11033	16393	18118	18214	18796	19794	19790	19328	19014	19675	19632
	Tanks	1780	16794	665	2182	240	344	463	350	0	324	300	255	254
	TW/OW	568	3394	3239	1833	1945	1698	1106	2424	1975	1623	2011	1010	1155
Polaki	Canals	17647	2393	10577	18245	20251	20772	22329	22314	20160	20686	20258	20510	19863
	Tanks	2080	17373	849	2405	186	0	369	0	0	0	0	53	53
	TW/OW	546	2611	2365	839	3443	3912	1608	569	3828	3434	3520	3290	3292
Srikakulam	Canals	10620	4988	6200	10780	9226	9219	11854	13042	12942	11688	10092	9137	8635
	Tanks	4450	10920	1423	4404	4421	4430	3959	3294	1861	3164	4464	3551	2365
	TW/OW	1121	2615	2333	2746	4554	4745	3577	507	1954	3263	3616	3172	2936
Gara	Canals	12970	2870	1573	12250	13045	13146	13032	13904	12106	13338	13126	13357	13283
	Tanks	2200	13470	525	2745	2245	2298	1683	2094	0	1838	2011	1941	1496
	TW/OW	1686	3752	3644	3832	1035	2393	5632	944	3865	3764	3923	4202	2969
Amdalavalasa	Canals	5279	6620	4062	5270	5454	5505	5658	9225	6196	6461	6211	6151	7449
	Tanks	6310	5394	720	5875	5902	5862	5702	5574	6100	6135	6052	5335	2427
	TW/OW	0	248	279	892	904	813	900	1492	957	1471	706	448	1126
Sarubujjili	Canals	10277	9363	804	10560	6845	6851	5402	5575	4802	4774	5195	4805	4807
	Tanks	9025	10377	840	9649	13508	12522	13869	15389	14547	13587	15382	13703	13510
	TW/OW	490	1117	907	1024	775	555	612	278	1813	1760	935	615	296
Etchcherla	Canals	7506	3557	2128	7628	5730	5772	7011	8845	5371	7230	6850	6063	5903
	Tanks	2955	7506	736	3701	4025	4180	1756	2043	756	3058	3401	2254	1990
	TW/OW	535	2307	2128	2349	2813	2540	3315	3400	3526	3811	3600	3689	4161
G. Sigadam	Canals	0	8888	0	0	0	0	0	0	0	0	0	0	0
	Tanks	8241	0	1683	9122	10079	10010	10078	10239	8413	4779	9993	4336	8935
	TW/OW	498	1683	0	1917	1499	1748	1979	1866	2122	2090	1853	1986	1360
Ponduru	Canals	8202	2920	6675	7972	6629	6640	6616	6644	6623	6474	5362	5857	4882
	Tanks	2905	8214	1752	2803	3581	3587	3379	3680	2225	1806	4119	1720	2654
	TW/OW	465	1228	1438	2049	2995	2935	2810	7245	2490	3176	3087	2949	3613
Laveru	Canals	0	7137	0	0	0	0	0	0	0	0	0	0	0
	Tanks	6996	0	1404	6990	8320	8812	6865	9346	2469	2558	9425	2775	7895

	TW/OW	60	1512	1532	1560	2032	2037	3090	2886	2529	3776	4191	5412	3180

Source: Chief Planning Officer, Srikakulam District.
TW: Tube Wells, **OW**: Open Well, **NA:** Not available

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