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Designing Methodologies for Evaluation of Economic and Environmental Implications of Groundwater Depletion and Quality Degradation Effects: A Study in Karnataka Peninsular India

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Final Report

Designing Methodologies for Evaluation of Economic and Environmental Implications of Groundwater Depletion and Quality Degradation Effects – A Study in Karnataka Peninsular India

(Sponsored by Indira Gandhi Institute of Development Research, Mumbai)

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I - INTRODUCTION

Prelude

The proverb "water, water everywhere but not a drop to drink" signifies the paradox that though water is plenty but often scarcity is evident in many parts of the country for different uses. In spite of highest rainfall that India receives, yet the country faces water crisis in different intensities. The total volume of water available on the earth is around 1400 million cubic meters, which can submerge the earth by 3000 meters deep. Unfortunately, over 97 per cent of this water is brackish not fit for any use; only a miniscule proportion of around 3 per cent is fresh water. Of this fresh water, around 75 per cent is frozen in the polar caps, around 2 per cent is available as surface water in the rivers, lakes and other water bodies and around 23 per cent is available as groundwater. This calls for sustainable management of water resources, as water is an indispensable resource for all living activities.

Fresh water is indispensable for human health, food production and sanitation as well as meeting other industrial uses. Water is also one of the basic needs for the survival of terrestrial and aquatic ecosystems. The number of regions in the world where human demands exceed local water supplies are growing. According to the 1997, U.N. comprehensive fresh water assessment, global water use has been growing at more than twice the rate of the population increase during this century. Thus, water scarcity could be one of the major factors limiting our ability to increase food production to feed the growing population.

Hydro-Geo-Morphological Features

Hydro-geological factors strongly influence the availability of the groundwater making it a highly location specific resource. It is invisible unlike surface water, as a result it is difficult to delineate the aquifer boundaries and the property rights. The lack of well defined property rights for groundwater, the fugitive, and uncertain nature of the resource and institutional arrangements for its sustainable management which often does not exist, results in a competitive race for its withdrawal.

Groundwater is abundant in the unconsolidated rock formation mainly occupied by Gangetic basin. Nearly two third of India's geographical area constitutes hardrock formation (consolidated) where the groundwater recharge capacities are extremely low ranging from 6-8 percent of the total precipitation. Much of the groundwater resources of the alluvial belt are in the unconsolidated formation. The whole of peninsular India and the states of Punjab, UP, Haryana and Bihar and West Bengal has hard-rock or unconsolidated formation. In the hard-rock areas of peninsular India groundwater overdraft is a growing problem due to lopsided extraction in relation to recharge.

Importance of Groundwater Irrigation in India

Groundwater irrigation has been a key component in agriculture development since 1960s. It played a complementary role in realizing the potentials of agronomic innovations, genetic improvement and contributed to food security and the success of green revolution. It also enhanced agricultural productivity and induced commercialization of agriculture by way of both crop diversification and specialization in the cultivation of high value crops. Overall, it enabled to stabilize food production in the country. The introduction of short duration, high -yielding crops along with intensive application of fertilizers, pesticides and mechanization enabled farmers to adopt multiple cropping practices that increased cropping and irrigation intensity substantially. As per the estimates given by Secler and Sampat, 1985 irrigation has contributed 60 per cent to the growth in the agriculture productivity.

It is estimated that the total available water resource potential in the country including the groundwater resource is around 1953 km^3. Country's total replenishable groundwater resource is 432 km^3. Out of which only 396 km^3 can be utilized. India presently utilizes about 33 per cent of the total replenishable groundwater resource. However, there is considerable degree of variation in the utilization of the groundwater resource. The number of dark blocks in the North and South are more than in the East and the Northeast (Raju *et al,* 2002).

Sources of Irrigation

Canals and tanks are the main sources of surface irrigation in India, while open and the tube/bore wells form the prime source of ground water irrigation. Surface water provides irrigation to the extent of 45 percent of the total irrigation and ground water accounting 55 percent. The total annual utilizable groundwater resource of the country is around 43.19 mhm. Out of this, over 7.09 mhm (16.4%) is used for domestic, industrial and other uses. The groundwater available for irrigations is around 36.08 mhm. Since independence, area irrigated by canals has been increasing at the rate of 2.4 per cent, while tank irrigation is reducing at the rate of 0.5 per cent while that of well irrigation has been increasing at 3.9 per cent.

Advantages of Groundwater Irrigation

Groundwater exploitation in India is largely in the hands of private individuals. Groundwater for irrigation is tapped through dug wells, dug-cum-bore-wells and surface bore-wells. Dug wells are traditional technology devices constructed by human labour. Borewells are drilled by using latest exploration technology to tap the ground water from the deeper layers of aquifers. The surface borwells structures could be commissioned quickly in a short gestation period and entails investments comparable to that of surface water on per acre basis. Groundwater is most preferred source of irrigation, due to greater individual control over the resource. It has been evident that crop yield/M^3 on ground water-irrigated farms tend to be 1.2 – 3 times more than on surface-water-irrigated farms (Dhawan 1989). Further, the advantages of groundwater irrigation coupled with favorable government policies and market forces induced farmers to intensify well irrigation and convert vast dryland areas into water intensive commercial crops. As a result, demand for groundwater spiraled.

Growth Pattern of Irrigation Structures

With the rapid expansion of commercialized agriculture, the traditional open-wells ability to support the increased demand for groundwater virtually crumbled. Hence, with the introduction of better techniques of groundwater exploration and extraction there has been a shift from traditional labor-intensive dug-wells to the modern capital-intensive bore-wells. Since, the onset of green revolution, groundwater development in some parts of India has grown incredibly. There has been a spurt in the number of irrigation structures over the years, notably in tube wells. There were only 386 million dug wells and 3000 deep tube wells during 1950-51. In a span of five decades (by 1999) as many as 9.5 million dug wells and 6.5 million private tube wells and 70000 deep tube wells were in operation in the country. Simultaneously the irrigation pumpsets, which are complementary to the wells, grew at the same rate.

Currently, the groundwater resource in hard-rock areas of India is facing the threat of overexploitation for different uses as well as quality impairment due to industrialization and commercialization of agriculture. This has led to much faster rate of depletion of groundwater than the natural rate of recharge resulting in secular drop in water tables, well interference, failure of dug-wells, dug-cum-bore-wells and shallow tube wells and subsequent investment loss. If this trend persists, it affects not only the interests of different users of the present and future generation but also the ecosystems sustaining on this vulnerable resource.

Factors Inducing Overexploitation of Groundwater

The tendency towards over exploitation of groundwater resources is rooted in the rapid spread of energized pumping technologies, resource characteristics, demographic shifts, and governmental policies. The sprawl of rural electrification combined with the ready availability of electrical and diesel pumpsets removed the limitation of traditional lift system encouraging over development of ground water resources. The invisible and open access nature of ground water resources also contributes to the potential for over-development, Demographic shifts may also contribute to over-development at least on a local basis. Urban areas are growing rapidly and facing serious water shortages. Electricity subsides probably have a greater impact on ground water extraction than credit availability (Moench 1994). In most areas, electricity for pumping ground water is sold at a flat annual rate based on pump horsepower or provided free of charge. As a result, marginal cost of pumping each unit of water becomes zero inducing severe competition among well owners to pump more water leading to overdraft.

Several studies indicated that groundwater in arid, semi-arid and hard-rock areas of India are overexploited (Veeman, 1978; Chandrakanth and Romm, 1990; Shah, 1993; Moench, 1991; Nagaraj et al., 1994, Nagaraj et al 1998). Yet another apprehension is that the damage caused to this fragile and fugitive resource could be irreversible in many areas, resulting in secular overdraft. The emerging problems due to overexploitation include increased depth to water due to deepening, reduced life of all types of wells, high rate of initial well failures, reduced gross irrigated area per well, reduced groundwater output and increased costs of well drilling and repairs to pump-sets. This has severe implications on investments, incomes, crop patterns, equity and ecology.

Water Scenario in Karnataka

The economy of Karnataka is predominantly agrarian in nature and nearly 75 per cent of the area is under dryland. In view of this, irrigation has been considered as lifeline for assured and stabilized crop production programme. Accordingly, greater emphasis is placed by the Government to develop both major and medium irrigation projects. In Karnataka, the sources of irrigation are canals, tanks and wells, the net irrigated area under different sources of irrigation during 1998-99 was around 24.90 lakh hectares, of which the canal accounted for about 40.7 percent followed by open well irrigation (19.23 %), bore wells (18.06 %) and tanks (10.56 %)

Currently the groundwater resource for irrigation is facing the threat of overexploitation in this region. Though the Government of India hinted at a regulation of groundwater through groundwater law on several occasions, concerted efforts have not been forthcoming for several economic and political reasons. In addition, the markets have failed to correct the existing distortions in groundwater irrigation. In India, the lack of groundwater institutions has led to intergenerational, inter-temporal and inter-spatial misallocation and serious overdraft situation creating several externalities, which are pervasive. Thus, a part of the social cost of pumping by a farmer is imposed on neighboring farmer(s).

Water Pollution – The Quality Concern

Though groundwater is considered to be the pristine resource but its quality has been degraded due to contamination of a variety of chemicals into the aquifers limiting its usability. Groundwater scarcity is exacerbated not only because of groundwater depletion but also due to its quality impairment. Use of poor quality water is a slow poison for all forms of life, as it gets increases salinity, ion toxicity and infiltration problems in soil. Of late, water quality issues from point and non-point sources are increasingly causing environmental concern as groundwater serves many purposes including drinking water for humans and livestock. Non-point source water pollution is called "diffuse" source pollution due to anthropogenic activities. Point source pollution of water is, where contaminated water is let directly into water bodies. The non-point source of pollution is more difficult to identify, measure and regulate than the point sources. Groundwater contamination results in chronic health problems due to infected drinking water. Since agriculture is by far the largest consumer of water, it suffers when water quality deteriorate in terms of reducing the productivity of the irrigated lands and hence the quality of the output.

Use of polluted surface and groundwater for the production of crops and domestic use pose a variety of health hazards to the producers, consumers and farm workers. Once the groundwater aquifers are polluted it is extremely difficult to remedy. Thus, quality freshwater is becoming the major constraint. This "crisis” has many implications on food security and water scarcity. Pollution occurs when water quality is degraded in excess of established regulatory norms. Industrial pollution has been one of the most important factors causing water pollution. Industries release effluents and wastes into the water containing chemicals and heavy metals such as arsenic, lead, mercury, cadmium and zinc.

Though there are several empirical studies on groundwater depletion and its impact on food security and environment, only a few studies were conducted on water quality degradation and its impact on agricultural production system, health and environment

Adverse Effects of Poor Quality Water

Indiscriminate use of poor quality water leads to alkalinity/salinity and water logging. Use of poor quality water for crop production in the absence of proper soil, water and crop management practices poses a risk to soil health, ecology and environment. In India about 36 per cent of the irrigated area suffers from soil and water related problems (Datta and Jong 1997). Injudicious use of poor quality groundwater for irrigation also reflects adversely on crop productivity and soil health. Maximum yield level of crops was observed with good quality irrigation water and as the water quality deteriorated, the productivity declines and maximum reduction was observed where irrigation with saline water. Th average yield of wheat decreased by 24 per cent over normal. The relative decline in the yield of mustard on high saline water situation is about 20 per cent (Datta and Dayal, 2000).

Nitrate concentration in drinking water at 10-45 mg/lt or more is considered to be carcinogenic and a causative factor for methaemoglobinemia. It is a disease resulting in restlessness and bluish tinge of the skin. Infants are in danger by using nitrate-polluted water, while adults and children are usually not affected. Cattle, too, are extremely susceptible to the disease and loss of milk production and abortion are two signs of nitrate poisoning (Murthy *et al.,* 2001). Continuous high intake of fluoride will result in mottled enamel of the teeth, skeletal florosis and sometimes severe osteosleosis (Lokesh and Shenoy, 1996). The water quality surveys conducted in the Karnataka state during 2000-01 indicated that 37 per cent (20929) habitations are facing quality problems. The problems included excess fluoride in 5822 habitations, excess iron in 6629 habitations excess nitrate in 4077 habitations and brackishness in 4401 habitations.

Need for Sustainable Development of Groundwater

In the arid and semi arid regions, groundwater is subjected to both depletion and quality impairment hence its sustainability is at stake. Since, more than 50 per cent of the total irrigation requirement is met through groundwater, it is imperative that its sustainable management emerges as one of the policy issues. Threat to groundwater sustenance arises out of the following factors viz., competitive access to groundwater and unrestricted access; over exploitation of aquifer; the fugitive nature of aquifer; cumulative interference of the wells; low recharge rate; rambling of wells per unit volume of water; silting up of irrigation tanks and pollution of groundwater due to point and non-point sources. In this endeavor groundwater resource should not be viewed in isolation rather it should be treated in an integrated holistic manner. Groundwater irrigation system includes groundwater resource, crop production and the environment. In this context, sustainable development of groundwater should aim at not only sustaining irrigated agriculture for ensuring food security but also preserving the associated natural environment now and in future.

Problem Statement

Water quantity and quality problems caused by intensive commercialized agriculture, in particular, pose challenges to sustainability of current practices in the irrigated agriculture. The sustainable use of groundwater is a critical issue for different sectors and regions in the country, as there is an intense pressure on this fragile resource. Of late, groundwater depletion and quality degradation are the emerging issues posing a major threat to sustainability of ecosystems and food security in peninsular India, as the scope for further expansion of surface irrigation is bleak. Further, the lack of institutional framework to integrate groundwater with surface water among competing users and uses, spatially and temporally within the sustainable use limits is posing a policy concern. In order to assess the implications of groundwater overdraft and quality deterioration on sustainability, efficiency, equity, food security and ecosystems, the typologies/methodologies are still emerging. The proposed study aims at devising economic approaches and methodologies to quantify the economic impact of groundwater depletion and degradation. The focus of the study is to analyze the economics of groundwater irrigation under groundwater depletion and conjunctive use water regimes along with the coping mechanisms adopted by the farmers in response to scarcity of water. Further, the study also delves into the economic and environmental effects of poor quality water on crop production human health and ecology.

Objectives of The Study

This research focuses on the following objectives:

1. To devise framework and typologies for evaluating sustainability, efficiency and equity issues concerning groundwater overdraft and quality degradation in different water exploitation regimes
2. To evaluate the economic consequences of groundwater depletion on food security and sustainability
3. To analyze the economics of conjunctive use of groundwater and surface water resources in ameliorating quantitative and qualitative depletion of groundwater.
4. To study the economics of alternative options that reduce the environmental problems associated with groundwater agriculture –
5. To study the groundwater regulation enacted in the state and examine the relationship with other institutions such as land reforms, credit system, electricity reforms and markets

II – METHODOLOGY

GROUNDWATER DEPLETION

Choice of the Study Area

The study is based in the State of Karnataka representing a typical hard rock area in the peninsular India. The state has been delineated into 10 Agro-climatic zones based on the topography, rainfall and soil characteristics. Of the ten agro-climatic zones, four represents dry zones, four fall under transitional zones and one each fall under hilly and coastal zones respectively. The districts in the State have been ranked in the descending order of groundwater over-exploitation. Based on this criterion, Tumkur district has emerged as the most over-exploited area in the State in terms of groundwater extraction and use (Table 1).

Table 1: District-wise critical blocks in Karnataka

District	Total no. of blocks	No. of dark blocks		No. of grey blocks		No. of white blocks		Total no of critical blocks		% of critical blocks in the district	
		As on 1994	As on 1999	As on 1994	As on 1999	As on 1994	As on 1999	As on 1994	As on 1999	As on 1994	As on 1999
Bangalore	11	6	6	2	2	3	3	8	8	72.73	72.73
Belgaum	10	2	3	2	3	6	4	4	6	40.00	60.00
Bellary	8	-	-	1	1	7	7	1	1	12.50	12.50
Bidar	5	-	-	1	2	4	3	1	2	20.00	40.00
Bijapur	11	1	2	2	1	8	8	3	3	27.27	27.27
Chamarajnagar	4	1	1	1	1	3	3	1	1	25.00	25.00
Chitradurga	9	-	1	2	2	7	6	2	3	22.22	33.33
Dakshina Kannada	8	2	2	1	1	5	5	3	3	37.50	37.50
Hassan	8	1	1	1	1	7	7	1	1	12.50	12.50
Kolar	11	3	5	5	4	3	2	8	9	72.73	81.82
Tumkur	10	5	7	3	2	2	1	8	9	80.00	90.00

Tumkur district comprises 10 taluks and comes under Central Dry Zone of Karnataka. In the Central Dry Zone (CDZ) of Karnataka, the agricultural activities are greatly induced by physical and economic access to groundwater. After discussion with the groundwater experts and heads of different institutions, the reconnaissance survey has been conducted in different parts of Tumkur district in order to locate different pockets, which are facing acute groundwater scarcity (groundwater depletion) and the areas where the farmers follow conjunctive use of surface and groundwater for irrigation.

NABARD has classified all the taluks of the State into overexploited, dark, grey and white based on the ratio of extraction to natural rate of recharge. In an overexploited area the ratio of extraction to recharge exceeds 100 percent. Similarly, in a dark area, this ratio is above 85 per cent and in grey areas between 65 and 85 per cent and in white areas it is less than 65 per cent. According to the NABARD report, out of ten blocks (Taluks) in the Tumkur district, seven blocks are dark, two are grey and one is white. As compared to any other district in the State, Tumkur district has the highest number of critical blocks (dark and grey) reflecting groundwater overexploitation. This shows that about 90% of the district is under critical stage of ground water development (Table 2).

Table 2: Block wise stage of groundwater development in Tumkur district

Blocks	As on 1995				As on 1999			
	Utilizable recharge (ha.m.)	Net draft (ha.m.)	Stage of develo-pment (%)	Category	Utilizable recharge (ha.m.)	Net draft (ha.m.)	Stage of develo-pment (%)	Category
C.N.Halli	8747	4565	52.19	W	8747	4834	55	G
Gubbi	7028	7892	112.20	D	7028	8769	125	D
Koratagere	3503	2743	70.58	G	3503	3964	113	D
Kunigal	6911	4386	63.46	G	6911	4644	67	G
Madhugiri	8762	7273	83.00	D	8762	7700	88	D
Pavagada	9787	4524	46.22	W	9787	4790	49	W
Sira	9602	6929	72.00	G	9602	7338	86	D
Tiptur	5733	7565	131.95	D	5733	7417	129	D
Tumkur	**7607**	**8364**	**109.95**	**D**	**7607**	**8200**	**108**	**D**
Turuvekere	6424	5230	81.41	G	6424	5537	86	D
Total					**74104**	**63193**	**90**	

Sampling Procedure

The study area in the Tumkur district of Karnataka State is given in the Fig. 1. The study is undertaken in two distinct irrigation regimes i.e., groundwater alone and conjunctive use regime. Again within the conjunctive use regime comparisons were made across tank irrigation supplemented with groundwater and canal irrigation supplemented with groundwater. The details of the sampling method employed are detailed here under.

The Tiptur taluk of Tumkur district with the highest net draft to utilizable recharge ratio (129%) (Table 2), classified under dark category, has been selected to study the groundwater overdraft implications in the ground water regime. In the same taluk, having access to canal irrigation in some pockets has been selected to study the effect of conjunctive use where the canal irrigation is supplemented with groundwater. The Koratagere taluk, which comes under dark category with 113% of net draft-utilizable recharge ratio, has been selected to study the conjunctive use of tank irrigation supplemented with groundwater. Based on PRA survey and statistics provided by Primary Agricultural Cooperative Bank, a cluster of villages has been identified experiencing groundwater overexploitation and having the source of irrigation through borewells, canals and tanks. Thus, in consonance with the study objectives, the database for the study was drawn in three different scenarios namely,

1) Area dominated by only well irrigation
2) Area in which groundwater supplements canal water for irrigation
3) Area in which groundwater supplements tank water for irrigation

The PRA maps indicating distribution of sample spaces, villages, working wells failed wells is provided in Fig 2-4.

Selection of the Sample Villages

For locating the sample villages the reconnaissance survey was conducted during the month of April 2000. The resource persons from developmental departments and village level institutions were consulted for choosing the villages. The villages namely Biligere, Kibbanahalli and Timlapura of Tiptur taluk, Tumkur which have highest number of bore wells, highest number of failed borewells and highest number of average borewells per farm among surrounding villages are considered for the study purpose under the groundwater regime where groundwater is the sole source of irrigation.

A cluster of villages under command areas of Nonavinakere tank, (system tank) in Tiptur taluk, were considered for the conjunctive use under canal irrigation regime. Similarly, the villages under the command area of Mavathur tank (non-system tank), Koratagere taluk, were chosen for conjunctive use under tank irrigation.

A random sampling procedure was followed to identify the sample farmers in groundwater alone regime, while the snow ball sampling procedure was followed to identify sample farmers in case of conjunctive use regime. A sample of the 35 farmers were drawn from each of the groundwater, groundwater + canal and groundwater + tank regimes constituting a total sample size of 105. Primary data for the study was elicited from the personal interviews during the month of May, June and July 2001 with structured pre-tested schedules. The respondents were enlightened about the purpose of the study, and practical utility of the study.

The information collected from the field survey include 1) general information regarding the socioeconomic features of the respondents 2) cropping pattern 3) sources of irrigation 4) investment on wells and on failed wells 5) number of irrigation structures 6) number of failed wells, 7) causes of well failures, 8) HP of the pump, 9) hours of pumping 10) farmers responses in relation to declining water yield in their wells, opinion towards electricity pricing 11) input-output data for the principle crops grown under well irrigation and 12) problems pertaining to well irrigation.

PART II- GROUNDWATER QUALITY

Choice of the Study Area

The study aims at analyzing the economic and environmental implications of groundwater quality on agricultural production, human and livestock health and surrounding ecology. In this regard, a survey was conducted in the month of March 2000 in the State to locate the areas affected by groundwater quality problems. The research studies conducted in Vrishabavathi basin, by the Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Bangalore, indicated that water in the open as wells as bore-wells has been polluted and contain heavy metals. Upon reconnaissance survey in this area, farmers also indicated that water quality problems are evident in the area. Hence, it was decided to select Bidadi hobli of Ramanagaram Taluk, Bangalore rural district purposively (Fig 5). Area under this Hobli is irrigated by Vrishabavathi river, which is polluted with sewage, sludge and industrial effluents, in addition to nutrients, often contain high concentration of heavy metals like copper, zinc, lead, nickel, cadmium and chromium. The area irrigated by this river (1,347 ha) are severely contaminated and the groundwater is also polluted through seepage of polluted river water into the aquifers (Siddaramapa and Nair 1997)

A list of villages in the Bidadi hobli having groundwater irrigation, which is polluted due to seepage of canal water, was identified. Based on the intensity of groundwater pollution, the villages of Ittamadu, Ramanahalli and Gopahalli, have been chosen for detailed economic investigation (Fig. 6). These villages are located in the proximity of Vribhavathi basin flowing untreated industrial effluents. In addition, as a control Bananduru village was selected which is 10 km away from the river where the groundwater quality is normal. In the control area, soil characteristics, crop patterns, rainfall, agro climatic conditions and hydro geological characters are similar to that of affected area and thus enable for comparison of the differential impacts of quality of water on production, health and environment.

Sampling Procedure

The procedure followed in the selection of the study area, sampling and collection of data as well as the analytical techniques used for organizing and interpreting the data are briefly outlined here under: In the first stage, among the villages of Bidadi hobli, three villages were identified with the help of Agricultural Assistants in the area, which were highly exposed to the water quality problems. The location of these villages is depicted in the Figure 6. Participatory Rural Appraisal (PRA) mapping was done in the selected villages in order to locate the wells and well density in the proximity of the polluted water channel. A list of farmers facing water quality problems was prepared in the selected villages. Out of this list, 10 farmers in each village were chosen at random for detailed economic investigation. Thus, the sample size comprised 30 farmers from the three villages. Further, the study area was delineated into three categories namely, irrigation wells located closer to the polluted water source (10 to 25 mts) and moderately closer (25 to 50 mts). A sample of 30 farmers having groundwater irrigation were chosen at random in the Bananduru was selected as a control village which was not affected by Vrishabavathi river located far away from the polluted channel (> 5 kms).

III - DATA ANALYSIS

QUANTITY DEPLETION

Framework and typologies for evaluating sustainability, efficiency and equity issues concerning groundwater overdraft

The primary data was analyzed by using some of the analytical and econometric tools. These include functional analysis, ratio analysis, partial budgeting, costing of the well by amortization, residual method to estimate the economic value of water, contingent valuation and discounting cash flow techniques. The analytical framework employed is listed below:

1. **Sustainability measures**: Well density and area per well, well age, yield of irrigation wells, area irrigated per well, water extracted per annum, decline in groundwater table, well frequency and distribution, gradual and initial well failure, damage and loss to ecosystem, loss of employment, cropping pattern changes, distortion in balance of food and non-food crop area, loss of income, employment and labor migration.

2. **Efficiency measures**: Amortized cost of well, Annual cost of irrigation, computation of cost of production, cost per acre –inch of water extracted, water use in crop production, irrigation intensity, cost of irrigation, net returns and output per acre-inch of water used, reduction in pump efficiency, higher consumption of power, investment on failed bore wells, deepening of bore wells, drilling of additional well and economic value of water (marginal value product of water).

3. **Equity measures**: wells owned and area operated by each size class, irrigation cost across farmer groups, income distribution and volume of water extracted, Gini co-efficient, Lorenz curve and the comparisons of relevant economic variables across the size class were made.

4. **Coping mechanisms**: adoption of drip, venturing well improvement and additional well, water transfer, shift to dryland low water intensive crops. These alternative options were evaluated using the partial budgeting technique and cash flow analysis wherever conceivable. In addition the cost of electricity on pro-rata basis was worked out.

Well Density and Area per Well

Well density refers to the number of wells per unit area and the area per well is the reciprocal of the well density. While calculating well density total land holdings of the entire sample farmers and total number of all types of wells were considered whether failed or working.

$$\text{Well density} = \frac{\text{Total wells of sample farmers}}{\text{Total land holdings of all sample farmers}}$$

$$\text{Area per well} = \frac{\text{Total land holdings of all sample farmers}}{\text{Total wells of sample farmers}}$$

Well Age

Average age of the well was calculated by arriving at frequency of wells of different age groups. Where age of the well is the difference between the year of drilling to the reference year.

Yield of Irrigation Wells

The yield of the water in the well is estimated considering the perception of the well owners. Further, to revalidate the figures given by the well owners a few cases of measurements of groundwater yield from the selected borewells of the sample farmers were made during the collection of primary data. The measurements recorded were converted into gallons per hour by using appropriate conversion. The number of seconds required to fill a pot of known volume was recorded and converted to gallons per hour.

Water Extracted per Annum per Well

Water extracted per farm is computed and is expressed in terms of acre-inches. The procedure followed in computing the water extraction is as follows:

Water extracted = (Average Number of days pumped in a year * Average Number of
(in acre inches) hours pumped per day * yield of the bore wells in gallons)/22611

The number of days the pump put to use to draw water was 225 days and 180 days in ground water regime and conjunctive use regimes respectively. The numbers of pumping days were estimated based on the information given by the farmers. The number of hours pumped in groundwater alone regime was 8 hours and that of in groundwater + canal and groundwater +tank regimes it was 5 hours per day. The division factor 22611 is used to convert from gallons to acre-inches.

Amortized Cost of Well

In order to arrive at the annual share of groundwater irrigation cost the well investment has been amortized. It varies with the amount of capital investment, the average well life, interest rate, year of construction. While finding out the amortization cost of well irrigation, the investment at current prices is considered. Amortization cost of well was worked out by adopting the following procedure

Amortized cost of borewell = Amortized cost of drilling cost + amortized pump and conveyance cost + amortized cost of pump house

Amortd. drilling cost =[drilling cost at current prices * $[(1+i)^{AL} * i] \div [(1+i)^{AL}-1]$

Where, AL = Average life of borewell (5, 15 and 15 years respectively for GW, GW + canal and GW + tank regimes)

Amortized overhead cost = [Sum of compounded cost of overhead cost * $[(1+i)^{AL} * i] \div [(1+i)^{AL}-1]$

The working life of pump set, pump house, conveyance pipe etc. which are under over head cost are assumed to be ten years. In this study an interest rate of 2 percent is considered for amortization. In the context of natural resource economics, the choice of discount rate needs to be reflective of the criterion of sustainability and intra and inter generational equity. For amortization, choice of discount rate above 2 per cent did not yield pragmatic estimates of annual costs. Here higher rates of interest resulted in future values which increased at compound rates unmatched with current rates of inflation.

Computation of Cost of Production

The cost of production includes expenses on seed, manure, fertilizers, plant protections, labour charges (both hired and family labour), bullock labor (both hired and family). All the input prices are valued at prevailing prices in the locality. The costs like marketing of the produce, rental value of land and depreciation on farm equipments other than irrigation equipments are not considered. However, interest on variable capital at the rate of 12 per cent was considered for the variable expenses incurred by the farmers during the crop season. The output value includes both main product and the bye-product in case of paddy.

a. Gross returns = quantity of product * market price and

b. Net returns = Gross return - total costs

The costs of production was calculated for paddy, coconut and coconut + arecanut plantation crops. While calculating the cost of production for plantation crops the establishment cost was amortized over the 50 years life span.

Annual Cost of Irrigation

The annualized cost of irrigation is estimated by amortizing the capital cost on well investment as indicated above. The maintenance and repair cost is added to the annualized cost to get the total cost of irrigation. The cost of irrigation represents the cost involved in providing irrigation for an acre of land per annum. The irrigation cost mainly depends on the depth of the well, yield of the borewells, area irrigated per bore well, probability of the well failures, number of borewells in the farm.

Annual irrigation cost = [The amortized cost of irrigation wells + amortized cost (per acre) of conveyance structures + annual cost of repairs and maintenance +electricity charges] / Area irrigated by well

Cost per Acre-Inch of Water Extracted

In order to compare the cost of one acre inch of water abstracted across the different regimes and among different categories of the farmers, cost per acre-inch of water is calculated. It is calculated using following formula

$$\text{Cost per acre-inch} = \frac{\text{annual cost of irrigation}}{\text{total volume of water extracted in acre-inches}}$$

Water Use in Each Crop

The water applied for a particular crop in the season is estimated by using the following conversions and expressed in acre-inches.

The water applied for a crop = (area irrigated * number of irrigations per crop * duration of the crop * number of hours to irrigate per acre * average yield of the well in GPH)/ 22611

Cost of Irrigation for Each Crop

Cost of irrigation for different crops is computed by the water applied in acre-inches for a crop multiplied by cost per acre-inch of water.

Irrigation cost = water used for crop in acre-inches* cost per acre-inch of water

Net Returns and Output per Acre-Inch of Water Used for Different Crops

Output and income per acre-inch of water were calculated for paddy, coconut and mixed crop of coconut and arecanut, which are the main crops in all the three regimes. The net income and output per acre-inch of water are worked out in order to compare the water use efficiency of the particular crop across different regimes. This is computed by using the following formulae.

$$\text{Income per acre-inch of water used for the crop} = \frac{\text{Net income per acre of the crop}}{\text{Total volume of water applied per acre of the crop}}$$

$$\text{Output per acre-inch of water used for the crop} = \frac{\text{Out put per acre of the crop}}{\text{Total volume of water applied per acre of the crop}}$$

Negative externality cost

The forced investments on deepening wells and or drilling of deeper wells and the costs incurred on coping mechanisms in response to well failures and scarcity of groundwater is treated as the cost of negative externality.

Economic Value of Water - Residual Imputation Method

The value of water to a user is the maximum amount the user would be willing to pay for the use of the resource. Assessing the value of the ground water is not easy. Since market for the ground water services do not exist, nevertheless, several method have been devised to assess the value of water for private, commercial and environmental users, in this regard, the residual computation approach is one of the methods employed to estimate the value of water as an intermediate good in agriculture production.

Using the residual imputation method accurate results are guarantied only if the quantities and price of the other factors of production, excluding water are estimated correctly at marginal values. The technology requires that all non-water factor inputs be detected from the total value of the product produced by an agriculture activity. Using this method, the additional contribution of each input in the production process is determined. Following Gregor (2000), the residual imputation value can be derived by using production function with 4 factors of production: Capital (k), labour (L) land(R) and water (W). Assuming that the value of the marginal product of a production factor is equals its price. The residual value of water used in agriculture can be computed by using following Production function,

$$TVP = (P_K * Q_K) + (P_L * Q_L) + (P_R * Q_R) + (P_W * Q_W)$$

By re arranging the terms to arrive at value of the water the following equation was used.

$$P_W = \{TVP - [(P_K * Q_K) + (P_L * Q_L) + (P_R * Q_R)] \} / Q_W$$

Where,

P_W = Shadow price of water.

TVP = Total value product

P and Q = Prices and quantities of the non-water factor inputs.

Q_W = Quantity of water used.

The calculation of a residual method was done on per acre basis and for particular crop. The total output value, input value including labour is considered as whole. In attempting to specify the production function for the residual imputation method, three main problems arise, (1) Listing of all relevant inputs and assigning productivities to them. If one or more important inputs are excluded from the specification of the production function, the productivity of the omitted inputs is incorrectly attributed to the residual claimant. (2) Correct forecasting of the levels of an output associated with given factor inputs. Over or under estimating the level of production result in a corresponding over or under estimate of the residual value (3) related to difficulties in empirical measurement.

Equity - Lorenz Curve and Gini Co-Efficient

The Lorenz curve and Gini co-efficients are used to measure inequality in income distribution among different categories of farmers in the groundwater regime and across different water use regimes and also to examine the inequality in extraction of water across different regimes. If the coefficient is zero it indicates perfect equality whereas coefficient of one indicates perfect inequality in distribution.

The perfect equality in the distribution is obtained when the curve lies along the 45^0 angle. The deviation from 45^0 indicates the inequality. Gini coefficient is calculated by using the following formula

$$G = 1 + \frac{1}{n} - \frac{1}{n^2Y} [y_1+2y_2 + 3y_3 + ...ny_n]$$

Where,

G = Gini coefficient

n = Sample size

Y = Average income of the sample farmers

$y_1, y_2, y_3 ....y_n$ = individual income of the farmers in decreasing order of size.

Economic Feasibility of Drip Irrigation over Flood Irrigation - Partial Budgeting Approach

Partial budgeting technique was used to evaluate the economic feasibility of adoption of drip system of irrigation (conservation) over drilling an additional well (depletion). The same formula was utilized for estimating the economic feasibility of surface drainage followed by some of the farmers, to mitigate the water quality problems.

Investment Appraisal on Drip V/S Drilling of Additional Well - Discounted Cash Flow Analysis

Discounted cash flow technique was adopted to appraise the economic feasibility of investment on drilling an additional well vs. drip irrigation. Economic life of investment on ground water irrigation was found to be seven years and the discount rate used was 10 per cent. Accordingly the benefit cost ratio, net present worth and internal rate of return were estimated using the standard formula.

Estimation of Cost of Electricity on Pro-Rata Basis

Currently, the electricity is charged on flat-rate basis at the rate of Rs.300 per hp (Horse Power) of the pump to lift groundwater for irrigation. It has been estimated scientifically that one HP pump consumes 0.75 kwh's of energy per hour. Based on this, energy consumption for the various pump capacities is computed as follows:

Total energy consumed = (0.75) X (HP of the pump) X (number of days pumped in a year) X (number of hours pumped per day)

Of late, in the study area it was observed that on an average the depth of the bore wells in the groundwater regime has been increasing at the rate of 20 ft per year hence farmers are constantly updating the HP of the pump in order to cope with the increasing depth in drawing water from deeper depth. An increase of 2 HP over the existing pump capacity per every 5 years was observed in the study area, hence, this increase was considered while calculating the electricity cost on pro-rata basis.

WATER QUALITY

Method of Analysis

Measures of central tendency were employed to analyze the data pertaining to the size of holding, family size, education, gross cropped area, returns from crops and well investments. Further, simple averages, percentages and proportions are computed in order to draw meaningful inferences.

Cropping intensity (CI)

The cropping intensity ignores the relative importance of long duration or perennial crops. For short duration crops it reflects a higher cropping intensity weightage, while for long duration perennial crops it shows a lower cropping intensity weightage. Hence, in this study, for perennial crops like sugarcane, mulberry and banana, which occupied the field all through the year, considered as equivalent to two times the sown area. For instance, if the area under sugarcane is one acre, it is considered as equivalent to two acres in calculating the cropping intensity index.

Cropping intensity was calculated by using the standard formula.

Investment Particulars, Well Age, Costing Irrigation Well, Amortized Cost of Well

The procedure for computing these is clearly depicted in the methodology section outlined in the unit with respect to the groundwater quantity depletion. And hence the formulae used do not vary. Some of the considerations and observations specific to this study are; Most of the dug wells and bore wells have been productive since their construction. In the case of dug well the average age is 23 years, while for bore well it is 11 years. The existing flat rate electricity at Rs. 300/hp is considered (The average hp in case of bore well is 5, while for dug well it is 3).

Computation of Production Costs

The costs and returns of production are accounted as per the standard procedure. Some of the special observations noticed in the investigation are outlined here under. The costs like depreciation on equipments (other than irrigation equipments) and rental value of land are not considered. However, interest on variable capital at the rate of 10 per cent was considered for the variable expenses incurred by the farmers during the crop season, since this was the interest charged by the commercial banks for crop loans.

Estimation of Explicit and Implicit Loss of Output in Affected Area

The per acre productivity differential of paddy and sugarcane between affected versus normal conditions valued at market price is considered as the amount of monetary loss incurred by the producers. Based on the per acre monetary loss of paddy and sugarcane yield, the total monetary loss for the entire affected command is estimated.

Negative Externality

The avertive expenditure/ negative externality cost of poor quality water reflects the forced investments/expenditure, farmers need to incur on well irrigation due to the problem of poor quality water. In the study, application of poor quality water resulted in negative externalities in terms of profuse growth of weeds, hardening of the soil requiring extra labour for weeding and other expenditures Accordingly, the additional labour used towards weeding per acre of crop is included under negative externalities.

Estimation of Health Costs

The study area is fraught with a variety of health problems on account of incessant use of polluted water. As a result, the average health expenditure per family per year has been escalating in the area compared to the control area. The extra expenditure incurred on health care by the affected respondents was considered as health costs.

Loss in Labor Employment

It is calculated by taking the difference in working days by a worker in a crop season between normal and affected. Accordingly, the total employment days lost was estimated and valued with the current market wage rate.

Estimation of Transaction Cost of Drinking Water

In the study area, due to poor quality of water in the wells, farmers fetch potable water from the radius of 1 to 1.5 kms. In this regard, the transaction cost associated with the drinking water was estimated by considering a) Average distance traveled to fetch potable water per day (in Kms), b) Average time spent on fetching potable water per day (in hours) Number of women-days spent in fetching potable water per year is estimated by multiplying item ‘ b’ with 365 days, then divide by number of working hours per day (8).

Then the imputed cost is calculated by multiplying the number of women-days spent in fetching potable water per year considering a wage rate of Rs 30 per day. The transaction cost is the difference in the imputed cost between the normal and affected.

Water Used in Crops, Cost and Returns per Acre-Inch of Water Used

The procedure is outlined in the quantity depletion part-1

Estimation of Gross Income Function for Paddy and Sugarcane

The multiple regressions were run by regressing gross income on productivity, quantity of water used in acre-inches and dummy variable was used to discriminate quality of water. The functional form used is as given below:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 D + e$$

Where,

Y_i = Gross income from paddy for i^{th} household.

X_1= Water used for paddy in acre inches

X_2 = Productivity of paddy in qtls/ acre

D = Dummy for water quality, 1= Poor quality, 0 = Normal quality.

e disturbance term

The same functional form is used for sugarcane also.

Equity Issues

In this study equity refers to the existing variation in the cost and benefit of groundwater irrigation experienced by different categories of farmers in the affected area.

Sustainability Index

The sustainability index has been worked out by considering indicators, which influence the quality of resource base, production system and human health and animal health. These three indicators were considered to represent the impact on resource base viz., soil quality or productivity, water quality and biomass production, which includes population of aquatic flora and fauna.

In respect of production system, the indicators considered to measure sustainability are, agricultural productivity, cost of production and income per acre. To capture impact on human and animal health, the indicators include annual expenditure on animal and human health, labor productivity and livestock price. The weightages assigned for each indicator ranged from 0.5 for less polluted attribute and 0.15 for highly polluted attribute and 0.35 for moderately polluted attribute. These are the relative weights for the polluted water. Based on the scores obtained for each individual, they are classified into three groups viz., less sustainable, moderately sustainable and sustainable. The respondents who obtained scores < ($\bar{X}$ - $^{1/2}$ SD) are categorized as households having resource which are less sustainable, similarly if respondents score fall between ($\bar{X}$ - $^{1/2}$ SD - $\bar{X}$ + $^{1/2}$ SD) are classified as moderately sustainable and if the respondents score is > ($\bar{X}$ + $^{1/2}$ SD) they are classified as sustainable.

Compound Growth Rate (CGR)

The compound growth rates for area, production and productivity was computed for 10 years data at the hobli level. The exponential functional form of the CGR is used and is given below:

$Y = A B^{t} e^{u}$

Where, Y = variable under study

t = time trend

A = intercept

B = trend co-efficient

u = disturbance or error term

The Compound Growth Rate in percentage is given by

$(e^{B} – 1) \times 100$

Coefficient of Variation

The coefficient of variation measures variability relative to the mean and is computed as per the accepted statistical connotations.

Land Degradation Ratio (LDR)

It is another indicator to measure the environmental damage. The percentage of area lost/added due to poor quality water is calculated by taking the ratio of current irrigable area to initial irrigable area. Initial irrigable area is the crop area under cultivation before pollution. Current irrigable area is the crop area under cultivation after pollution.

The formula to compute LDR is given below.

$$LDR = \frac{\text{Area under cultivation after pollution}}{\text{Area under cultivation before pollution}} \times 100$$

Estimation of Cost of Treating Polluted Water

In order to assess the cost of treating polluted water of Vrishibhavathi valley, the data relating to capital investments, operating and maintenance costs involved in the primary and secondary treatment of effluents was obtained from Bangalore Water Supply and Sewage Board (BWSSB). The treatment plant comprised civil structures and mechanical components. The fixed investments have been amortized to get the annualized apportioned cost. The rated capacity of the plant is 70 milliom litre per day (MLD).The estimated capital outlay on the treatment plant is approximately 50 crores, of which, around 40 percent accounted towards civil structures and the remaining towards the mechanical components. For amortization, a discount rate of four per cent is considered since; BWSSB is expecting the funding from French Government for this water treatment plant at four per cent concessional interest rate. Based on the information provided by the Bangalore Water Supply and Sewage Board, a life span of 80 years for civil structures and 30 years for mechanical components were assumed.

The total cost incurred to treat one million liters of wastewater was worked out by adding annual amortized cost to the maintenance costs. Further, the calculations were made to arrive at cost of one acre-inch of treated wastewater.

IV - RESULTS

GROUNDWATER DEPLETION

In consonance with the study objectives the results are presented as detailed below.

Socio-Economic Profile

The socio-economic profile of the sample households under different water regimes is provided in the table 3. These include family size, educational status, age, land holding and income of the sample farmers. On an average, the family size per family ranged between 6-7 members. The literacy level was fairly high among the sample households of different irrigated source groups, as more than 85 per cent of all the sample respondents were literate.

Table 3: Socio-economic indicators of the sample farmers in different water regimes

Particulars	GW	Canal + GW	Tank+ GW
1. Family size (no.)	6.00	7.00	7.00
2. Percentage of persons working on farm	33.33	42.85	28.57
3. Education status (No of years of Schooling)	8.00	7.00	7.00
4. Percentage of literates	81.00	83.00	89.00
5. Respondents age (years)	45.00	46.00	54.00
6. Gross irrigated area (acres)	6.24	4.99	5.61
7. Net irrigated area (acres)	6.22	4.95	4.94
8. Irrigation intensity (%)	100.32	100.80	113.56
9. Proportion of dry land (%)	27.00	26.00	39.00
10. Average land holdings (acres)	8.49	6.70	8.08
11. Off-farm income (Rs./annum/acre)	28200.00	17566.00	34531.00
12. Net farm income (Rs./annum/acre)	86123.00	61767.00	140687.00
13. Total income [10+11](Rs./annum)	114323.00	80333.00	175218.00
14. Share of off-farm income in total income (%)	24.66	21.86	19.70

The mean age of the respondents was around 45 and 46 years in groundwater and conjunctive use supplemented with canal water respectively as compared to the respondents of conjunctive tank irrigation (54years). On an average, the gross irrigated area was 6.24 acres in case of groundwater (GW) as against 4.99 and 5.61 acres in GW + Canal and GW + Tank regimes.

The net irrigated area was 6.22, 4.95 and 4.94 acres in groundwater, groundwater + canal and groundwater + tank regimes, respectively. The size of land holdings of the farmers was the highest in groundwater irrigation regime (8.49 acres) followed by groundwater + tank regime (8.08 acres) and groundwater + canal regime (6.7 acres). Concentration of the dry land was highest in case of groundwater + tank regime (39 per cent) followed by groundwater regime (27 per cent) and canal + groundwater regime (26 per cent).

It was observed from the table 3, that the annual farm income of the households in groundwater + tank irrigation was higher by 63.36 per cent and 127.77 per cent when compared to only groundwater and canal + groundwater respectively. The share of off-farm income out of the total income was marginally higher in groundwater regime vis-à-vis canal + groundwater and tank + groundwater regimes.

Cropping Pattern

The cropping pattern of the sample respondents in the three irrigation situations is given in the Table 4. Most of the cereals and pulses are grown under rain fed conditions in all the three regimes. The area share of irrigated seasonal crops was highest in groundwater with tank irrigation (58 %) followed by groundwater with canal (31%) and groundwater (7%). The cropping pattern followed indicates that the area under perennial crops dominated in groundwater irrigation (93 %) as compared to other two irrigation situations (68.7 % and 41.2 %). The area under paddy in summer season was predominant in canal + groundwater and tank + groundwater regime (22.7 % and 26.5 %) as compared to situation where only groundwater is used for irrigation (1.2 per cent). The finger millet (ragi), being the staple food crop, has occupied a lion’s share in rainfed areas. In case of irrigation from tank supplemented by groundwater around 18 percent of the area was under maize both under irrigation as well as under rainfed conditions.

It is noteworthy that farmers under only groundwater source allotted 91 per cent of their irrigated area to perennials. On the other hand where groundwater was supplemented the proportion of field crops had increased.

Table 4: Cropping pattern followed across different water regimes

(Per cent area under crop)

Crops	GW regime		Canal + GW		Tank +GW	
	Rain fed	Irrigated	Rain fed	Irrigated	Rain fed	Irrigated
I Annual crops						
1) Kharif						
a) Jowar	3.80		3.40	1.40		
b) Horse gram	5.60	1.30				
c) Green gram	7.00	2.80	26.80	0.70		
d) Paddy						
e) Black gram	1.00		1.50			
f) Niger			3.80		61.90	1.50
g) Ragi	63.00	0.50	63.00	5.80		
2) Rabi						
a) Paddy		1.20		0.68		9.70
b) Maize					17.70	17.90
c) Ground nut					20.40	1.70
d) Redgram						0.70
e) Chillies						0.80
3) Summer						
a) Paddy		1.20		22.70		26.50
Total	**80.40**	**7.00**	**98.50**	**31.28**	**100.00**	**58.80**
II Perennial crops						
a) Coconut	19.60	79.30	1.50	58.60		7.60
b) Areca		1.25		1.00		23.70
c) Areca+Coconut		12.00		5.60		2.50
d) Areca+Coconut+Beetle				1.50		4.80
e) Banana		0.45				0.80
f) Mulberry				2.00		1.80
Total	**19.60**	**93.00**	**1.50**	**68.70**		**41.20**

Physical and Economic Consequences of Groundwater Depletion

1. Frequency distribution of wells across different water regimes

Over two thirds of the respondents either own less than three bore wells in groundwater regime. On the other hand, one third of the respondents either own four or more than four bore wells in groundwater regime. In the areas where canal and tank water is supplemented with groundwater irrigation, nearly seventy per cent of the farmers own one bore well. Groundwater exploitation intensity is relatively less in canal and tank irrigation areas when compared to area where irrigation is mainly from groundwater source (Table 5).

Table 5 Distribution of wells across different water regimes

(Per cent farmers owning)

No. of wells	GW regime			GW + Canal regime			GW + Tank regime		
	DW	DCBW	BW	DW	DCBW	BW	DW	DCBW	BW
1	20.0	14.0	20.0	11.5	14.3	74.3	22.9	11.5	71.5
2	-	9.0	17.0	-	-	11.5	2.9	-	14.3
3	-	3.0	23.0	-	-	2.9	-	-	2.9
4	-	-	14.0	-	-	-	-	-	-
5	-	-	11.0	-	-	-	-	-	-
6	-	-	6.0	-	-	-	-	-	-
>6	-	-	11.0	-	-	-	-	-	-

2. Working and failed wells in different water regimes

The total number of wells distributed across different water regimes is given in the Table 6 It is clear from the table that the total number of wells possessed was three times more in case of groundwater regime (147) as compared to other two regimes (47 and 50 in canal + groundwater and tank + groundwater respectively). It was observed that around 58.5 per cent of the borewells had failed in the groundwater regime whereas in the other two regimes the failed borewells proportion was negligible.

The dug-cum borewells in the canal + groundwater and tank + groundwater regimes are still functioning. Around 40 per cent of dug wells in groundwater + canal and 63 per cent of the dug wells in groundwater + tank regime are still working. Contrary to this, most of the dug cum bore-wells and the dug wells in the groundwater regime are defunct.. As observed from the table in case of groundwater regime the well density is 0.5 per acre implying one well for 2 acres while in case of other two regimes the well density are very low (0.2) reflecting one well for 5 acres.

Table 6 Particulars of functional wells, failed wells and well density across different water regimes

Particulars	GW	Canal +GW	Tank +GW
1. Total number of wells	147.00	47.00	50.00
2. Number of bore-wells	123.00	37.00	38.00
3. Number of working bore-wells	51.00	37.00	38.00
4. Number of dug wells	10.00	5.00	11.00
5. Number of working dug wells	0.00	2.00	7.00
6. Number of dug-cum bore-wells	14.00	5.00	4.00
7. Number of working dug-cum bore-wells	2.00	5.00	4.00
8. Total land holdings (acres)	297.15	234.50	282.80
9. Area per unit well (acres)	2.02	4.99	5.66
10. Well density (No.)	0.50	0.20	0.18

3. Well density

The well density per unit area was 0.5 in groundwater regime, which is very high as compared to conjunctive use regime of 0.2. Higher number of bore wells per unit area in groundwater regime indicates high well failure rates and consequently more investments on borewells. Well density is one of the indicators to measure the sustainability. In over exploited area, if proper isolation distance and optimum well density in relation to the recharge capacity is not maintained it is bound to create cumulative well interference problem. As a result, the surrounding wells would dry up and unfructuos. In case of groundwater regime, the well density is very high reflecting the un-sustainability of the groundwater resource. Though the well density in terms of increased number of wells indicates wider access , the resource needed to own a well and pump are beyond the reach of small and marginal farmers considering high capital cost (table 6).

4. Average depth and life of the irrigation wells in different water regimes

The depth and average productive life span of wells according to the source of irrigation are provided in table 7. Though the traditional dugwells existed during 1950s but it was on a limited scale and the water lifting devices were labour intensive. Very prominently, the dug-wells emerged during 1960's in the area with the rural electrification. The productive period of these wells was fairly long functioning until 1970's. During 1970s dug-cum borewells became prominent with a depth ranging between 80 to 160 ft and their productive period was shrunken compared with dug wells. Consequent on failure of dug-cum borewells, since 1990's farmers ventured drilling surface borewells with a depth ranging from 200 to 400 ft. This was facilitated mainly by access to improved exploration and extraction technology. The mode of extraction of groundwater during 1970's and 80's in all the regimes was by using the ordinary 3 HP pumpset, later after 1980's these were replaced by submersible pumpsets with the existence of dug-cum borewell and dugwells in all the three regimes used to extract water from the deeper layers of the aquifer. In canal and tank commands, the centrifugal pumpsets are being used to pump water from dug wells and some of the dug-cum-bore wells, as the water tables in these areas are sufficiently high which is the result of synergistic effect of surface irrigation.

Table 7: Average depth and life of irrigation wells in different regime

Year	GW			GW + canal			GW + Tank		
	Avg. Depth (ft)	Avg. life (yr.)	Mode of extraction	Avg. Depth (ft)	Avg. life (yr.)	Mode of extraction	Avg. Depth (ft)	Avg. life (yr.)	Mode of extraction
1965-80	25- 40	11.00	Centrifugal	25- 35	17	Centrifugal	25- 40	15.5	Centrifugal
1975-85	80-160	6.20	Centrifugal	40- 250	*	Centrifugal	100-150	*	Centrifugal
1986-90	90- 150	5.75	Submersible	40- 250	*	Submersible	100-150	*	Submersible
1985-95	100-320	6.50	Submersible	30 – 250	*	Centrifugal	130-260	*	Centrifugal
1996-01	220-495	3.00	Submersible	100-250	*	Submersible	162-360	*	Submersible

Note: * Still working (age more than 15 years) DW = dug well DCBW = dug-cum borewell BW = borewell

5. Investment on irrigation wells in different water use regimes

The investments on irrigation well at historical as well as at current prices are provided in the table 8. For estimation of investment on bore-wells at historical prices the modal year of 1985 was considered. The total investment was around Rs. 35420, of which 21 per cent accounted for exploration cost and the remaining amount represented extraction component. The investments on wells at current prices have also been up-dated in order to know the scale of investment at currently. As apparent from the table, the investment on a bore-well at current prices is almost double the historical cost amounting to Rs 71295, which includes 31 per cent of drilling cost, and remaining extraction cost. Due to failure of bore wells in the groundwater regime, the investment on additional wells and cost of deepening was accounted to the tune of Rs.35294 and Rs.17880, respectively. On an average, the investment on wells per farm including the investment on additional wells and deepening is to the tune of Rs. 124469. The scale of investment varied according to the depth of the wells and further improvement of bore wells. As clear from the table.8, in the only groundwater source, the investment on a well at current prices entailed Rs.124469 vis-à-vis Rs.53150 and Rs. 60600 in case of other two regimes having canal and tank irrigation source, respectively.

Table 8:Details of Investment on borewells across different regimes

Particulars	**GW regime**	**Canal +GW regime**	**Tank+ GW regime**
Investment at historical *prices (Rs.)*			
1. Drilling cost	7900	6875	6871
2. Pump and conveyance cost	27520	28400	33320
Total	**35420**	**35795**	**36870**
Investment at current *prices (Rs.)*			
1. Drilling cost	21745	12450	14700
2. Pump and conveyance cost	49550	40700	45900
Total	**71295**	**53150**	**60600**
3. Investment on failed borewells	35294	0	0
4. Deepening of bore well	17880	0	0
Total	**124469**	**53150**	**60600**

6. Implicit cost of energy in lifting groundwater

The electricity charges what farmers presently paying on flat rate basis and if paid on the prorate basis is estimated and presented in the table 9.

Table 9: Difference in cost of electricity charge on prorate basis and flat rate basis

Year	Depth of borewell (ft)	Pump Capacity (HP)	Electricity cost on prorate basis at Rs.1/kwh's (per well per annum)	Electricity cost on flat rate basis (per well per annum)	Difference over flat rate cost (per well per annum)
1985	150	3	4050	900	3150
1990	213	5	6750	1500	5250
1995	380	6	8100	1800	6300
2000	422	8	10800	2400	8400
2005	499	10	13500	3000	10500
2010	599	12	16200	3600	12600

Number of days used 225; Number of hours per irrigation – 8 hrs

If electricity charges are paid on prorata at cost price of electricity generation (at the rate of Rs.1 per kwh) for a 5 HP pump it would be around Rs.6750, per well per annum, while on flat rate basis currently farmers are paying around Rs.1500, which is almost 4 times lesser and works out to be 0.22 paise per kwh. For different HP and depth of the well, the gap in what the well owners are presently paying and if charged at cost price has been surging indicating the implicit cost on the society.

7. Groundwater irrigation cost

Cost of irrigation across different water regimes in terms of cost per acre and cost per acre-inch of water was computed and presented in table 10. The cost of groundwater irrigation where only groundwater is used was the highest (Rs.3933.23 per acre) as against conjunctive use of groundwater + tank regime (Rs.2617.79 per acre) and groundwater + canal (Rs.2468.69 per acre) regime. The water extracted per acre was highest in groundwater + tank regime (98.04 acre-inches) followed by groundwater use (65.57 acre-inches) and groundwater + canal regime (62.53 acre-inches). It could be observed from the table that the highest cost per acre-inch of water was recorded in groundwater regime (Rs.242.94) followed by groundwater + canal regime (Rs.156.74) and groundwater + tank regime (Rs.114.02).

Table 10: Cost of irrigation across different water regime

Particulars	GW regime	GW + canal regime	GW + tank regime
1. Drilling cost of a well (Rs.)	21745.00	12450.00	14100.00
2. Pumping and conveyance cost (Rs)	49550.00	40700.00	46500.00
3. Amortization of drilling cost (Rs)	4613.38	969.00	1097.00
4. Amortization of pumping and conveyance cost (Rs)	5516.23	4530.00	5177.00
5. Operation and maintenance cost (Rs)	4000.00	2500.00	2500.00
6. Electricity cost (Rs)	1800.00	1800.00	1800.00
7. Annual irrigation Cost/well (Rs)	15929.61	9799.00	11174.00
8. Area irrigated/well (acres)	4.05	3.97	4.27
9. Water extracted per acre (acre-inches)	16.19	15.75	22.96
10. Water extracted per well (in acre inches)	65.57	62.53	98.04
11. Annual irrigation Cost/acre(Rs)	3933.24	2468.69	2617.79
12. Cost per acre-inch of water (Rs)	242.94	156.74	114.02

8. Economics of different crops across different regimes;

a. Cost of paddy cultivation

The economics of paddy production for all the three regimes was calculated and the results are given in Table 11.

Table 11: Economics of paddy production in different regimes

(Per acre)

Particulars	GW Regime	GW+ Canal regime	GW + Tank regime
Amt. of groundwater used (acre-inches)	44.53	4.78	21.29
Percent to total water used	100.00	6.90	36.33
Cost per acre-inch of groundwater (Rs.)	242.94	156.74	114.02
Groundwater irrigation cost (Rs)	10818.12	749.22	2427.49
Per cent to irrigation cost	100.00	88.22	96.04
Percent to total cost	71.63	13.95	33.06
Amt. of surface water used (acre-inches)		64.54	37.31
Percent to total water used		93.10	63.67
Actual water charge for surface water (Rs)		100.00	100.00
Per cent to irrigation cost		11.78	3.96
Per cent to total cost		1.86	1.36
Total amount of water used (acre-inches)	44.53	69.32	58.60
Irrigation cost (Rs)	10818.12	849.22	2527.49
Per cent to total cost	71.63	15.81	34.42
Input cost (Rs)	4285.71	4522.00	4816.00
Per cent to total cost	28.37	84.19	65.58
Yield a) Paddy (qtls)	22.00	24.00	25.00
B) Straw (in tones)	2.00	2.25	2.30
Total cost of cultivation (irrigation cost + input cost) (Rs)	15103.83	5371.22	7343.49
Gross income (Rs)	10350.00	11325.00	11775.00
Per cent income taken by irrigation cost	104.52	7.50	22.95
Net income (Rs)	-4753.83	5953.78	4256.51
Benefit-cost ratio	0.69	2.11	1.60

Total volume of water used was the highest in groundwater + canal (69.32 acre-inches), followed by groundwater + tank and groundwater regime with 58.6 acre-inches and 44.53 acre-inches, respectively. About 36.33 and 6.9 per cent of groundwater was used to grow paddy on an acre of irrigated area in ground +tank regime and in groundwater +canal regime in that order. The paddy yield realized was 22, 24 and 25 qtls in groundwater + tank, groundwater + canal and groundwater regime, respectively. The cost of cultivation was highest in groundwater regime (Rs.15103.71) upon inclusion of irrigation cost which formed around 71.63 per cent of total cost of cultivation followed by groundwater + tank (Rs.7343.49) and groundwater + canal (Rs.5371.22) regime where in the irrigation cost formed over 33.06 and 13.95 per cent respectively. The net returns from paddy (Rs.- 4753.00) was negative upon inclusion of irrigation cost in the case of groundwater regime, while it was positive in case of conjunctive use.

The net returns realized per acre in groundwater + canal regime was 28.5 per cent higher (Rs. 5953) than groundwater + tank regime (Rs. 4256). The higher benefit cost ratio was observed in groundwater + canal area (2.11) and the least was in groundwater regime (0.69).

The sources of irrigation other than exclusive groundwater have a clear cost advantage ranging between Rs. 7500 to Rs. 10000 per acre in irrigation costs alone in paddy cultivation. With this high cost, this category of farmers should deploy their resources to crops, which do not consume much water.

b. Coconut plantation

The economics of coconut cultivation in different irrigation regimes is depicted in the Table 12. It was apparent that the volume of water applied per acre by the farmers in groundwater + tank regime is more (16.14 acre-inches) followed by groundwater + canal (12 acre-inches) and groundwater (9 acre-inches) regimes. The yield of copra was 5.8, 5.77 and 3.76 qtls in groundwater + tank, groundwater + canal regime and groundwater regime, respectively.

The cost of inputs was highest in groundwater regime 3779.70 followed by groundwater + tank (Rs. 3581.92) and groundwater +canal regime (Rs.3152.65).

The irrigation cost, out of the total cost of cultivation accounted 24.32 per cent in case of groundwater regime while it was 31.24 and 27.55 per cent in the case of tank and canal irrigated regime. The highest net return was recorded in groundwater + canal regime (Rs.12190.04) followed by groundwater + tank regime (Rs.12190.04) and groundwater regime (Rs. 5313.84). The benefit cost ratios were 3.91, 3..33 and 1.89 in groundwater + canal, groundwater + tank and groundwater regime, respectively.

Table 12: Economics of coconut cultivation in different regimes

(per acre)

Particulars	GW Regime	GW + Canal regime	GW + Tankregime
Amt. of groundwater (acre-inches)	9.00 (100)	7.76 (64.66)	13.84 (85.74)
Amt. of surface water (acre-inches)	-	4.24 (35.34)	2.30 (14.26)
Total amount of water used (acre-inches)	9.00	12.00	16.14
Yield of copra (qtls)	3.76	5.77	5.8
Price/unit (Rs)	2862.00	2990.00	3233.00
Input cost (Rs)	3779.70	3152.65	3581.92
Surface water charges (Rs)	-	50.00 (3.95)	50.00 (3.07)
Cost of groundwater (Rs)	2186.46 (100)	1216.30 (96.05)	1578.04 (96.92)
Total irrigation cost (Rs)	2186.46 (24.32)	1266.30 (27.55)	1628.04 (31.24)
Total cost of cultivation (irrigation cost + input cost) (Rs)	5966.16	4418.95	5209.96
Gross income (Rs)	11280	17310	17400
Net income (Rs)	5313.84	12891.65	12190.04
Benefit-cost ratio	1.89	3.91	3.33

Note: Figures in the parentheses indicate the percentages to the total
The amortized cost of the orchard is not included

c. Mixed plantation

It can be noted from the Table 13 that the mixed crop of coconut and arecanut plantation in the groundwater regime utilizes less water (22.55 acre inches) as compared to groundwater + canal regime (24.99 acre-inches) and groundwater + tank regime (35.60 acre-inches). The irrigation cost formed 54.14 per cent of the total cost of cultivation Rs.10119.65 in groundwater regime while in groundwater + canal and groundwater + tank regimes the irrigation cost constitutes 39.95 and 33.64 per cent out of total cost of cultivation of Rs.7771.1 and Rs.7470.83, respectively.

The net returns was highest in groundwater + tank regime (Rs.45029.2) followed by groundwater + canal regime (Rs.37533.9) and groundwater regime (Rs3256.35). The benefit cost ratio in groundwater + tank, groundwater + canal and groundwater regime were 7.02, 5.83 and 4.23, in that order.

Table 13: Economics of coconut + arecanut in different regimes

(per acre)

Particulars	GW Regime	GW + Canal regime	GW + Tank regime
Amt. of groundwater (acre-inches)	22.55 (100)	19.44 (77.79)	21.60 (60.67)
Amt. of surface water (acre-inches)	-	5.55 (22.21)	14.00 (39.33)
Total amount of water used (acre-inches)	22.55	24.99	35.60
Yield (Qtls) a) Coconut b) Arecanut	4.06 2.66	5.48 2.51	6 3
Input cost (Rs)	4641.35	4674.07	4958.00
Surface water charges (Rs)	-	50.00 (1.62)	50.00 (1.98)
Cost of groundwater (Rs)	5478.30 (100)	3047.03 (98.38)	2462.83 (98.02)
Total irrigation cost (Rs)	5478.30 (54.14)	3097.03 (39.95)	2513.83 (33.64)
Total cost of cultivation (irrigation cost + input cost) (Rs)	10119.65	7771.1	7470.83
Gross income (Rs)	42770	45303	52500
Net income (Rs)	32560.35	37533.9	45029.2
Benefit-cost ratio	4.23	5.83	7.02

Note: Figures in the parentheses indicate the percentages to the total
The amortized cost of the orchard is not included

9. Implications of groundwater depletion

The historical details of bore-wells at different points of time are given in the table 14. The depth of bore-wells, which was 80 to 150 feet in 1980's, almost doubled during 1995. It is interesting to note that the yield of the borewells, which was 3500 gallons per hour during 1985, virtually dwindled to 800 gallons per hour in 1995. Further, there has been an increase in irrigation pump capacity from 5 to 7.5 HP accompanied by higher number of stages of pump due to increased depth to groundwater table. There has been sharp increase in the total investments on wells from Rs. 21560 to Rs.71295 within two decades. This increased scale of investment was due to deepening of the wells (Rs.17880) and drilling addition wells (Rs.15000 to Rs. 35294). The additional expenditure on pump repairs also increased alarmingly over the years from Rs. 1000 in 1985 to Rs.4000 after 1995. Thus, the

Table 14: Details of irrigation wells in groundwater regime at different points of time

Particulars	Before 1985	1985-95	1995-2001
Depth (ft)	80-150 (124)	100-320 (202)	220-495 (327)
Yield (gallons/hr)	3500	2000	800
Pump capacity (HP)	5	6	7.5
Stages of pump (no.)	6	8	12
Placement of pump from the top (ft)	60-120	80-240	200-340
Average length of pump placement	(100)	(150)	(230)
Gradual failure of wells (no.)	0	14	14
Initial failure of wells (no.)	0	13	18
Investment on wells			
a) Drilling cost (Rs)	3300	7560	21745
b) Pump and conveyance cost (Rs)	18260	31050	49550
Total cost (Rs.)	21560	38610	71295
Deepening cost (Rs.)	0	12733	17880
Investment on additional well (Rs.)	15000	25178	35294
Expenditure on pump repairs(Rs.)	1000	2500	4000
Cost of pump replacement (Rs.)	0	7000	10000
Isolation distance (ft)	850	500	225

Note : Figures in the parenthesis are the mean values.

increased intensity of well investments indicated the economic scarcity of the groundwater and to some extent overexploitation of the groundwater potential.

Food security - Status of paddy production before and after scarcity period

As evident from the table 15, there has been steep fall in the area as well as production of paddy during kharif, Rabi and Summer season reflecting the scarcity of groundwater. The area under paddy and production in Kharif and Rabi dipped nearly 90 percent. While in the summer season there was a drop of 50 percent both in the area and production. The proportion of farmers growing paddy during Kharif, rabi and summer season also drastically reduced. Around 74 and 80 percent of the farmers completely stopped cultivating paddy under groundwater in Kharif and Rabi seasons respectively. Nearly 33 per cent of the farmers discontinued growing paddy in summer season.

Table 15: Area under paddy during previous to scarcity period (before 1995) and scarcity period (after 1995)

Particulars	Kharif		Rabi		Summer	
	PSP	SP	PSP	SP	PSP	SP
Paddy growing farmers (No.)	19.00	5.00	10.00	2.00	3.00	2.00
Reduction in farmers growing the paddy crop (%)		73.60		80.00		33.30
Average area per farm (acres)	1.38	0.50	2.00	1.13	1.67	1.25
Total area of all farmers (acres)	26.25	2.50	20.00	2.25	5.00	2.50
Reduction in area %		90.50		88.80		50.00
Production from all farms (qtls)	741.00	78.00	545.00	60.00	138.00	64.00
Reduction of production in %		89.50		88.90		53.60

Note: PSP indicates previous to scarcity period, SP; scarcity period

10. Decline in area under food crops v/s non-food crops – cause for concern

Area and growth of food crops and non-food crops of the study area is depicted in table 16.

Table 16: Area and growth of food crops and non-food crops in Tumkur district and Tiptur taluk

(Area in hectares)

Year	Total food crops area (in ha.)		Annual Growth rate in total food crop area		Total non-food crops area(ha.)		Annual Growth rate in non-food crops area	
	Tiptur	Tumkur	Tiptur	Tumkur	Tiptur	Tumkur	Tiptur	Tumkur
1989-90	34393	332182			17239	265510		
1990-91	29440	307445	-14.43	-7.44	17223	272927	-0.09	2.79
1991-92	33470	346123	13.68	12.58	19780	288023	14.84	5.53
1992-93	34128	325403	1.96	-5.98	20645	288388	4.37	0.12
1993-94	32380	314007	-5.12	-3.50	20064	286367	-2.81	-0.70
1994-95	34009	302537	5.03	-3.65	21418	287459	6.74	0.38
1995-96	34014	309720	0.01	2.37	21869	558831	2.10	94.40
1996-97	32282	330363	-5.09	6.66	23649	308472	8.13	-44.80
1997-98	30712	299393	-4.86	-9.37	25596	244260	8.23	-20.81
1998-99	30491	336024	-0.71	12.23	25629	322032	0.12	31.83
	CGR		-1.19	0.11			4.04	1.94
CV	5.46	4.93			97.74	28.58		

As evident from the Table 16 the total food crops area in the Tiptur taluk is showing a decreasing trend over the years from 1989-90 to 1998-99. The total area under food crops was 34,393 ha in 1989-90 decreased to 30,491 ha during 1998-99 in Tiptur taluk while there was marginal increase from 3,32,182 ha. to 3,36,024 ha. for the Tumkur district during the same time period. The growth rate in the total food crops area for the Tiptur taluk was negative (-1.19 %) and it was positive for the district (0.11 %). On the contrary, the area under non-food crops is showing increasing trend with a positive growth rate of 4.05 per cent for Tiptur taluk and 1.95 per cent for Tumkur district**.** The coefficient of variation was less for area under total food crops in Tumkur district (4.93%) and Tiptur taluk (5.46 %), where as the area under non-food crops for the Tumkur district and Tiptur taluk was showing higher coefficient of variation viz. 28.58 and 97.74 per cent, respectively.

Irrigation Efficiency Across Different Regimes

As apparent from the Table 17, the volume of groundwater used per acre was highest in the conjunctive use with tank water (22.96 acre-inches), followed by groundwater (16.19 acre-inches) and groundwater + canal regimes (157.75 acre-inches).

Table 17: Irrigation efficiency in different regimes

Particulars	GW	Canal + GW	Tank+ GW
Water used per farm (acre-inches)	101.03	78.59	128.8
Water used per acre (inches)	16.19	15.75	22.96
Average income from the gross irrigated area	74647.85	57737.00	104953.16
Income per acre of gross irrigated area	11962.8	11570.54	18708.23
Net income per acre of gross irrigated area after deducting the irrigation cost	8029.56	9101.85	16091.53
Net income/acre-inch of water used	495.96	577.89	700.80

The volume of water extracted per farm was 128, 101.03 and 78.59 acre-inches in groundwater + tank, groundwater and groundwater + tank regime, respectively. The net income obtained per acre of gross cropped area after accounting most of the explicit and irrigation cost was found to be highest in case groundwater + tank regime farmers (Rs. 16090.40), while the farmers in the groundwater regime realized the lowest net income of Rs 8029.56 per acre of gross irrigated. The net returns received per acre-inch of water by farmers of groundwater + tank regime (Rs.700.80) was highest followed by groundwater + canal (Rs.577.89) and groundwater regime (Rs.495.96).

Water Use Efficiency of Different Crops

As clear from the Table 18, paddy output per acre-inch of water used was the highest in groundwater regime (0.50 qtls.) followed by groundwater + tank regime (0.43 qtls.) and groundwater + canal regime (0.35 qtls). Output per acre-inch of water applied for coconut was highest in case of groundwater + canal regime (0.48qtls) followed by Groundwater regime (0.42 qtls) and groundwater + Tank

(0.36 qtls). In the case of the mixed plantation, crops having coconut and areca, the higher output of the coconut was observed in groundwater + canal regime (0.22 qtl) and the arecanut were found to be highest in groundwater use regime (0.11 qtl).

The volume of water consumed to produce one quintal of paddy was the highest in groundwater +canal regime (2.89 acre-inches) followed by groundwater + tank (2.34 acre-inches) and the least was in groundwater regime (2.02 acre-inches). Similarly to produce one quintal of copra, in case of conjunctive use with groundwater + tank regime consumed highest amount of water (2.78 acre-inches) followed by groundwater regime (2.39 acre-inches) and groundwater + canal regimes (2.08 acre-inches). Production efficiency is higher in groundwater regime, while low in the other two regimes because water is highly subsidized.

Table 18: Water use efficiency of different crop in Tumkur district (Per Acre)

	Physical efficiency				Economic efficiency	
	Out put per acre-inch of water (qtls.)		Water used per quintal of output (acre-inch)		Netincome per acre-inch of water (Rs.)	Net income (Rs.)
Paddy						
GW regime	0.50		2.02		-106.74	-4753.00
GW + canal regime	0.35		2.89		85.88	5953.78
GW + tank regime	0.43		2.34		72.64	4256.04
Coconut						
GW regime	0.42		2.39		590.43	5313.84
GW + canal regime	0.48		2.08		1074.30	12891.65
GW + tank regime	0.36		2.78		755.27	12190.04
Coconut + Arecanut	c. nut	areca	c. nut	areca	c. nut	areca
GW regime	0.18	0.11	5.55	8.48	1443.92	32560.35
GW + canal regime	0.22	0.10	4.56	9.96	1790.00	37533.90
GW + tank regime	0.17	0.08	5.93	11.87	1264.87	45029.02

Economic Efficiency of Water

Net returns received per acre-inch of water used from paddy was negative (Rs. –106.74) in groundwater regime while in case of groundwater + canal it was around Rs. 85.88 and in groundwater + tank it was Rs. 72.64. The net income per acre of paddy after accounting the irrigation cost was negative in groundwater regime (Rs.-4753.00) while positive and higher net income was realized in groundwater + canal

(Rs.5953) and groundwater + tank (Rs.4256) regimes. Net income per acre-inch of water in coconut plantation was highest in groundwater +canal (Rs. 1074.3) followed by groundwater + Tank (Rs. 755.27) and groundwater regime (Rs.590.43).

The net income obtained per acre of coconut plantation in groundwater + canal regime was relatively higher (Rs. 12891.65) than groundwater + tank (Rs.12190.04) and groundwater alone regime. Rs. 5313.84. In case of mixed plantation crop, the highest net income per acre was obtained in groundwater + tank regime (Rs.45029.20) while the farmers in groundwater + canal and groundwater regimes could realize a net income of Rs.37533.9 and Rs.32560.35 per acre, respectively. In mixed plantation, the highest income per acre-inch of water used was observed in groundwater + canal regime (Rs.1790.00) followed by groundwater regime (Rs.1443.92) and groundwater + tank (Rs.1264.44) regimes.

Marginal Value Product of Water

Marginal value product of water for paddy and coconut are presented in Table 19. It can be observed from the table that marginal value product of water for paddy, in case of groundwater alone and groundwater + tank regime was almost similar with Rs.193.4 and Rs.197.7 per acre-inch respectively. While in case of groundwater + canal regime, the marginal value product of water was less (Rs.161.9 per acre-inch). The marginal value product of water for coconut was the highest (Rs.1396.3 per acre-inch) in groundwater, followed by groundwater + canal (Rs.1175 per acre-inch) and groundwater + tank regime (Rs.1081 per acre-inch) (table 4.21).

Table 19: Marginal value product of water per acre-inch of water

(Rupees)

Crops	GW Regime	GW + canal regime	GW + Tank regime
Paddy	193.40	161.90	197.70
Coconut	1396.30	1175.00	1081.00

The marginal value product is compared with the cost per acre of water applied and it was found that in all the cases the value product is higher than the irrigation cost per acre.

Equity Issue in Groundwater Use Regime – Wells Owned and Area Operated by Different Size Groups

Asymmetric distribution of wells as well as the area irrigated across different size of holdings is evident from Table 20. Out of total irrigated wells, medium and large farmers together owned 80 per cent of the wells. Similarly, out of total gross irrigated area, 88 per cent of the gross irrigated area operated by medium and lager farmers. The gross irrigated area per well was higher in case of large farmers (4.68 acres) followed by medium farmers (3.97 acres) and the small farmers (2.86 acres).

Table 20: Particulars of wells owned and area operated by different size groups

Particulars	Small farmers	Medium Farmers	Large farmers	Total
Number of farmers	11(31.4)	16(45.7)	8(22.9)	35(100)
<u>Well details</u>				
a) No. of DW	1(11.2)	4(44.4)	4(44.4)	9(100)
➢ Working	0	0	0	0
➢ Failed	1	4	4	9
b) No. of DCBW	2(14.3)	5(35.7)	7(50)	14(100)
➢ Working	0	0	3	3
➢ Failed	2	5	4	11
c) No. of BW	29(23.6)	52(42.3)	42(34.1)	123(100)
➢ Working	9	23	19	51
➢ Failed	20	29	23	72
Total gross irrigated area (acres)	26(11.9)	91.5(42)	101(46.1)	218.5
Gross irrigated area /well (acres)	2.88	3.97	4.68	4.05
Average gross irrigated area (acres)	2.36	5.72	12.63	6.24

**Figures in the parentheses are the percentages;*

DW = dug well *DCBW = dug-cum borewell* *BW = borewell*

The proportion of working bore wells among small farmers was around 31 % where as for the medium and large farmers, it was around 44 and 45 per cent respectively. Out of the total 218.5 acres of gross irrigated area, around 12 per cent was owned by small farmers (26 acres), 42 per cent owned by medium farmers (91.5 acres) and 46 per cent by large farmers (101 acres). The highest gross irrigated area per well was observed with large farmers (4.68 acres) followed by medium (3.97 acres) and small farmers (2.86 acres). The total irrigated area per farm was found to be the highest in case of large farmers (12.63 acres) followed by medium (5.72 acres) and small farmers (2.36 acres). Thus, the inequity in terms of less physical access to groundwater for the vulnerable resource poor farmers is persisting. Their proportion among well owners is far les than the proportion among all farmers put together.

Cost of Irrigation Across Different Categories of the Farmers in Groundwater Regime

The cost of groundwater irrigation per acre among different categories of the farmers is provided in the Table 21.

Table 21: Cost of irrigation across different categories of the farmers in groundwater regime

Particulars	SF	MF	LF
Annual irrigation Cost/well (Rs)	15929.61	15929.61	15929.61
Area irrigated/well (acres)	2.88	3.97	4.68
Water extracted per well (acre-inches)	61.28	62.26	66.12
Annual irrigation Cost/acre(Rs)	5531.11	4012.50	3403.76
Cost per acre-inch of water (Rs)	259.95	255.87	240.93

As reflected from the table, the cost of groundwater irrigation decreased with increase in the size of holding. It was highest for small farmers (Rs.5531.11 per acre) followed by medium (Rs.4012.5 per acre) and large farmers (Rs.3403.76 per acre). With regard to the cost per acre-inch of water extracted, it was highest in case of small farmers (Rs.259.95 per acre-inch) who extracted 61.28 acre-inches of groundwater per well. In contrast to this, the large farmers extracted 14.13 acre-inches per well of groundwater incurring an irrigation cost of Rs. 240.93 per acre-inch of water.

Equity in Income Distribution and Water Extraction Across Different Categories of The Farmers

The measure of equity in income distribution and water extraction among different categories of the farmers is presented in table 22. The income distribution among different categories of the farmers within groundwater regime was found unequal. The estimated Gini coefficient for small farmers was (0.78) followed by large farmer (0.68) and marginal farmers (0.65). The Gini co-efficient with respect to water extraction across different categories of farmers in ground water regime did not show any reasonable difference but indicated the presence of inequality in all categories of the farmers with the Gini-coefficient value ranging from 0.70 to 0.73.

Table 22: Gini coefficients indicating income distribution and water extracted per farm across different categories of the farmers

Farmer Category	Income distribution	Water extracted
Small farmers	0.78	0.71
Medium farmers	0.65	0.70
Large farmers	0.68	0.73

Equity in Income Distribution and Water Extraction Across Different Water Use Regimes

The equity in income distribution and water extracted across the different water regimes was estimated by using the Gini-coefficient measure and the results are given in the Table 23. As clear from the table the Gini-coefficient value varied from 0.64 to 0.71 across different water regimes implying that the inequity with respect to income distribution due to irrigation is relatively more with the groundwater regime alone compared to the conjunctive use regimes. Inequity in water extraction was more in groundwater regime than in the conjunctive use regimes, which was supported by the Gini-coefficient, value varies from 72 to 62 across the three regimes.

Table 23: Gini coefficients indicating income distribution and water extracted across different water use regimes

Water use regime	Income distribution	Water extracted
GW regime	0.71	0.72
GW+ canal regime	0.64	0.62
GW + tank regime	0.66	0.62

Conjunctive Use – Returns to Supplementary Irrigation

Returns to supplementary irrigation due to increased in yield by providing the supplementary irrigation through groundwater at critical stages of the crop growth during surface water scarcity in the conjunctive use regimes was provided in table 24. Due to shortage of surface water, the yield of paddy in groundwater + canal area and groundwater + tank regime was 21.25 and 20.85, respectively. By supplementing the groundwater to the paddy during shortage of surface water yield was increased to the tune of 3.08 quintals in groundwater+canal regime and it was 4.09 quintals in groundwater + tank regime. About 6 and 8 supplementary irrigation's were given in groundwater + canal and groundwater + tank regime, respectively. Each supplementary irrigation augmented the gross income by Rs.218.17 and Rs.270.41 in groundwater + canal and groundwater + tank regime, respectively.

Table 24: Returns to supplementary irrigations in paddy production

Particulars	Yield (qtl)	Income (Rs.)	Returns per supplementary irrigations (Rs.)
GW+ canal regime			
1. Canal water experiencing scarcity	21.25	9031.25	-
2. Canal water supplemented with groundwater during scarcity			
a) Six irrigations	24.33	10340.25	218.17
GW + tank			
1. Tank water experiencing scarcity	20.85	8861.25	-
2. Tank water supplemented with groundwater during scarcity			
a) 8 irrigations	25.94	11024.5	270.41

Impacts of Conjunctive Use of Water

The physical and economic impacts due to the conjunctive use of groundwater and surface water were listed in table 25. The results reveal that the well life of DCBW and BW was 5-6 years in the groundwater regime, while it was higher in conjunctive use regimes (>15 years). The DW life was the highest in GW + canal (17 years) regime followed by GW + tank (15.5 years) and groundwater alone use regime (11 years). About 60 and 37 percent of the dug wells had failed in the conjunctive use regimes with canal and tank, respectively, while all the dug wells in the groundwater alone use regime had failed. About 85.7 and 48.54 per cent of the DCBW and BW were failed in groundwater alone regime where as well failure is uncommon in both conjunctive use regimes. The crop diversity was higher in conjunctive use regimes than groundwater use regime.

It was evident from the table 25 that the investment on bore wells in the conjunctive use regimes, with canal (Rs.57450) and tank (Rs.65500) water, were lower than that of the groundwater alone use regime (Rs.77095). The investments on additional well, deepening of the borewells and adoption of drip irrigation were not seen in the conjunctive use regimes. Where as in groundwater regime facing predicament of groundwater scarcity, the farmers has to incur Rs.35294, Rs.17880 and Rs.11000 on additional well, deepening of the borewells and adoption of drip irrigation, respectively. The cost per acre-inch of water was low in conjunctive use i.e., the groundwater + canal (Rs.156.74) and groundwater + tank (Rs.114.02) regime.

Table 25: Impacts of conjunctive use of water

Particulars	GW regime	GW + canal regime	GW + tank regime
I. Physical impacts			
1. Well life (years)			
a. DW	11	17	15.5
b. DCBW	6	>15	>15
c. BW	5	>15	>15
2. Well failures (%)			
d. DW	100	60	37
e. DCBW	85.7	nil	nil
f. BW	48.54	nil	nil
3. Yield of water from borewells (GPH)			
4. Well density	800	3000	3000
5. Crop diversity	0.5	0.2	0.18
	coconut, arecanut, paddy.	coconut, beetle vein, arecanut, paddy, mulberry, green gram, nizer.	coconut, areca, betel vine Banana, maize, Mulberry groundnut, Paddy,
II. Economic impacts (Rs.)			
1. Investment on borewells	77095	57450	65500
2. Investment on additional well	35294	nil	nil
3. Investment on deepening of well			
4. Investment on drip irrigation system (Rs/acre)	17880	nil	nil
5. Cost per acre-inch of water			
6. Income per acre of gross irrigated	11000	nil	nil
area	242.94	156.74	114.02
	8029.56	9101.85	16090.40

than in groundwater alone use regime (Rs.242.94). Income per acre of gross irrigated area was least in groundwater regime (Rs.8029.56) than in groundwater + canal (Rs.9101.85) and groundwater + tank regime (Rs.16090.40).

Water Crisis - Options to Mitigate

In response to the scarcity of groundwater, the coping mechanisms adopted by different categories of the farmers are presented in Table 26.

Table 26: Coping mechanisms adopted by different size groups

(In percentage)

Coping mechanism	Small Farmers n = 11	Medium Farmers n = 16	Large Farmers n = 8
Well improvement	18.2	62.3	75.0
Going for additional well	63.7	56.2	100.0
Transfer of water	36.0	75.0	100.0
Adopting drip system	9.1	-	37.5
Adopting indigenous drip	54.5	43.7	25.0
Buying water	72.7	56.2	25.0

It is interesting to note that all the large farmers of the sample respondents in the study area ventured in drilling additional wells and transferring water from far off place to the gardens through a network of conveyance pipes as coping mechanism to overcome the water stress. The cost of these coping mechanisms adopted by the farmers represents negative externality cost. The percentage of large farmers who invested on well improvement, drip irrigation was 75 and 37.5, respectively. Nearly 62.3 and 56.2 per cent of the medium farmers have gone for well improvement and additional wells respectively, whereas in case of small farmers about 18.2, 63.7 and 9.1 per cent of the farmers adopted well improvement, additional well and drip system as coping mechanism in that order. All the large farmers resorted to transferring of water from the bore-wells drilled in the distant place as one of the coping mechanism followed by medium farmers(75 %) and small farmers (36.1 %). The coping mechanisms such as adoption of indigenous drip system (54.5 %) and buying water (72.7%) were largely followed by small and medium (432.7 and 56.2 %) farmers.

Drip Adoption in Coconut Plants

The table 27 reveals that, out of 11 small farmers only one small farmer adopted the drip for 200 coconut plants with the total investment of Rs.40000, where as for every 4 large farmers one farmer invested on the drip for 400 plants with the total investment of Rs.95000. The investment per 100 plants was more in case of large farmers (Rs.23750) followed by small farmers (Rs. 20000). Thus, it is evident that farmers are not inclined to resort to efficiency in water use.

Table 27: Details of drip adoption in coconut plants

Farmer category	Number of plants	Total investment	Investment per 100 plants
Small farmers	200	40000	20000
Medium farmers	*None of the medium farmers adopted drip system.*		
Large farmers	400	95000	23750

Does Well Improvement Leads to well-being of the Farmers?

Table 28 portrays the details of farmers going for improvement of wells. The results indicated higher proportion of large farmers (75 %) going for improvement of wells, followed by medium farmers (62 %) and small farmers (18 %). The percentage of farmers going for one improvement was 56 in case of medium farmers while only 37 per cent of large farmers ventured only one time improvement. More number of improvements (more than 2) was seen in case of large farmers. The small farmers were involved in improving only one well.

Table 28: Details of farmers going for improvement of well

No of improvements	Small farmers			Medium farmers			Large farmers		
	Per cent of farmers	Depth (ft)	Total Investment (Rs)	Per cent of farmers	Depth (ft)	Total Investment (Rs)	Per cent of farmers	Depth (ft)	Total Investment (Rs.)
1	18.2	105	8000	56.3	119.4	10511.11	37.5	110	11808.3
2	-	-	-	-	-	-	12.5	137.5	31255
3	-	-	-	6	241.6	72700	-	-	-
4	-	-	-	-	-	-	25	145.6	54237

Chasing the Fugitive – Investment on Well Improvement

Over 25 per cent of the large farmers attempted improvement of their wells by deepening them within a period of ten years. The total investment expended towards improvement was to the tune of Rs. 54237.6. The highest improvement in depth (241.6 ft) and investment (Rs. 72,700) were observed in case of medium farmers for the improvement of three wells. In case of small farmers, well improvement depth was 105 ft with an investment of Rs.8000. The improvement depth of one well was 119 ft. and 110 ft with the total investment of Rs.10511 and Rs.11808, respectively for medium and large farmers (table 28).

Penetrating the Aquifer – Drive to Drill Additional Well

The percentage of farmers who ventured in drilling additional wells is given in table 29. From the table it is evident that all the categories of farmers had gone for additional wells as coping mechanism, but the number of additional wells drilled on their farms varied across the categories. All the large farmers adopted drilling additional well as one of the coping mechanisms while, 63.5 per cent of small farmers and 56.5 per cent of medium farmers drilled additional wells in response to groundwater scarcity. Among large farmers, 50 per cent of them drilled one additional well and out of the remaining 50 per cent of the large farmers each 12. 5 per cent of the farmers drilled two, three, four and five additional wells. In case of both small and medium farmers, 18 per cent have gone for one additional well. About 31.3per cent of the medium farmers, 27.3 per cent of the small farmers have gone for two additional wells. About 9 per cent of the small farmers, 6.3 per cent of the medium farmers drilled three additional wells and about 9 per cent of the small farmers have gone for four additional wells.

Table 29: Details of farmers going for additional well

No. of additional wells	Small farmers			Medium farmers			Large farmers		
	% farmers	Depth (ft)	Total Investment (Rs.)	% farmers	Depth (ft)	Total Investment (Rs.)	% farmers	Depth (ft)	Total Investment (Rs.)
1	18.2	332.5	42500	18.8	265	33333	50	221	36250
2	27.3	290	40000	31.3	293	26100	12.5	185	35000
3	9	290	93750	6.3	190	13333	12.5	220	52050
4	9	345	106664	-	-	-	12.5	229	80000
5	-	-	-	-	--	-	12.5	278	200000

Economics of Additional Well – Depth and Investment Indicators

The depth of a single additional well was more in case of small farmers (332.5 ft.) with the investment of Rs.42500 followed by the medium farmers with the depth of 265 ft and the corresponding investment of Rs. 33,333. The least depth was observed in case of large farmers with 221 ft. entailing an investment of Rs. 36250. Drilling of additional wells with a depth of about 345 ft was observed for four additional wells in case of small farmers entailing an investment of Rs. 1,06,664. The average depth of 4 additional wells in case of large farmers was 228.75 ft. expanding an investment of Rs. 80,000 form all the additional wells. The total investment for 5 additional wells in case of large farmers was Rs. 2 lakh with the average depth of 278 ft and average investment per well was Rs. 40,000 (table 29).

Water Transfer Details

The details of water transfer are presented in Table 30.

Table 30: Water transfer details

Particulars	Small farmers	Medium farmers	Large farmers
Distance from which the water is transferred from source to the point of use (mt)	372	519	974
Investment on conveyance structures (Rs)	3536	4565	15208

The results indicated that the maximum distance that the water transferred was 974 mts in case of large farmers (974 mts) followed by medium (519 mts) and small farmers (372 m.). The investment on conveyance structure was over Rs.15,208 in case of large farmers, Rs. 4505 in case of medium farmers and Rs.3,530 in case of small farmers.

Shift to Other Occupations

The table 31 clearly depicts that the trend in shift to other occupations due to the non-assured groundwater irrigation was observed among all type of the farmers. Upon failure of wells some of the farmers turned to other occupations, which are less capital intensive like providing wood scaffolding material for construction on rent basis and running petty business shops. One of the medium farmers turned into an electrical contractor and other some other affected farmers ventured to purchase tractors on loan and hired them out on rental basis. One of the big farmers set up nursery for supplying areca seedlings on commercial basis.

Table 31: Shift to other occupation

Particulars	Occupation (each occupation represent one case)	Income/year (Rs)
Small farmers	Providing wood scaffolding material for construction of houses Petty business shops	20000 50000
Medium farmers	Electric contractor Purchased a tractor by loan and renting	50000 75000
Large farmers	Maintaining arecanut nursery and marketing	20000

Income Loss Due to Failure of Borewells

As clear from the table 32, the higher income loss due to the failure of existing bore well was observed in case of the small and marginal farmers. Due to non-availability of well water, the small and medium farmers stop irrigating coconut gardens. One of the small farmers found to remove their areca plantation, which was 2 year old and incurred a total loss of Rs.12, 000. It could be observed from the table that all type of farmers bore the brunt of well failure subsequently losing not only their investments on wells but also income.

Table 32: Income loss due to failure of borewells

Particulars	% of farmers	Avg. area (acres)	Crop irrigated by well	Crop grown after failure of bore well	Loss of income in (Rs)
Small farmers	18.00	2.00	Irrigated coconut	Dry land coconut	12000
	9.00	0.75	Areca	Two year old areca was completely removed	10000
	18.00	0.50	Paddy	Ragi	
Medium farmers	6.30	2.00	Irrigated coconut	Dry land coconut	9000
	19.00	1.00	paddy	Ragi	8000
Large farmers	25.00	1.50	paddy	No crop	14000

Some of the observations and considerations in partial budgeting analysis

a. Partial budgeting was done for the data considering the existing 5-acre coconut orchard with 250 plants, yielding 70 nuts per plant in a year.

b. The life span of the drip system is assumed to be 10 years and that of borewell is assumed to be 5 years irrigating by using flow method and replacing another borewell after the end of 5 years.

c. The incremental income from bore well irrigation and drip adoption was obtained by deducting the income from dry land coconut plantation income. An yield of about 70, 105 and 120 nuts per plant per annum was assumed from dry land coconut, coconut under bore well irrigation and coconut under drip irrigation, respectively.

d. It is assumed that 6 coconuts form one kg of copra and one kg of copra is Rs.30. the income of the farmer is as follows

Income = (70 nuts X 250 plants)/ 6 nuts per kg

= number of kg's of copra X Rs.30 per kg = gross income

e. Water applied in drip system = 4 micro tubes/plant X 6 lts./hour X70 hours/irri. X 300 plants * 5 irrigations.

f. Water applied by additional well = 150hours X 5 irrigations with 1600 GPH of water yield and the well yield was assumed to remain same at the existing level.

g. Savings in labour = 1 Manday X 225 days (@Rs 50/MD)
= 11250.

Saving in water applied (acre inch) = water applied by flow system – Water applied by drip method = 53 – 25 = 28 acre-inches

Table 33: Economics of conservation (Drip) Vs depletion (flood)

(Rupees)

Costs (**A**)	Returns (**B**)
I. Increased costs a) Annual Amortization cost =Amortization cost of drip system – Amortization cost of Additional well = 19915 – 17666 = **2249** b) Maintenance expenses = Maintenance cost of drip system - Maintenance cost of borewell = 4500-4000 = **500** II. Decrease in Returns = **0**	Decrease in costs Savings in labour = 1 Manday X 225 days (@Rs50/MD) = **11250** Increase in returns = Incremental return from drip adoption over dry land coconut - Incremental return from well irrigstion over dry land coconut = 62500 - 43750 = **18750**
A = 2249 + 500 + 0 **= 2749**	**B** = a + b = 11250 + 18750 = **30000**
B – A = **Net Profit** = 30000 - – 2749 **= 27251**	

Table 34: Cost of drip irrigation to adopt five acre of coconut garden

Particulars	Quantity	Value (Rs.)
a. Farm filter	1	4000
b. Main line		
c. Sub main		6000
d. Lateral pipes		
e. Drippers		40000
f. Miscellaneous (T-color, bend, connectors, Sphagetti, Gramet, washers, head connectors, endcap, etc.)		5000
g. Earth work and lab our for laying out the system		
Total (Rs.)		**55000**
Water applied by flow system (Acre-inches)	45	
Water applied by drip method (Acre-inches)	25	
Percentage of water saved by drip irrigation		44.44
Income per rupee of investment on drip system per year		1.51

The details of cash flow technique analysis for drip irrigation adoption are given in the table 36. The IRR for drip method was 46 per cent, which is higher than flow method of irrigation with additional well. The NPV was positive accounting Rs. 129539 with the discount rate of 10 per cent in drip method, the same was 48993 for flow method with additional well indicating preference of drip method over additional well. The results indicated that the discounted cost-benefit ratio was more than one (1.51) in drip method indicating economic feasibility of the drip system, while discounted cost benefit ratio for additional well showed the value which was less than the drip adoption (1.22). These results firmly established the economic viability of the drip system and therefore can be advocated as water saving mechanism.

Financial feasibility of drip Vs additional well

The observations and considerations in cash flow analysis

a) A discount rate of 10 per cent is assumed as the opportunity cost of capital and the benefits and costs are discounted at this rate.
b) Cash flow technique was computed for 10 years life span
c) Partial budgeting was done for the data considering the existing 5-acre coconut orchard with 250 plants, yielding 70 nuts per plant in a year.
d) The life span of the drip system is assumed to be 10 years and that of borewell is assumed to be 5 years irrigating by using flow method and replacing another borewell after the end of 5 years.
e) The incremental income from bore well irrigation and drip adoption was obtained by deducting the income from dry land coconut plantation income. An yield of about 70, 105 and 120 nuts per plant per annum was assumed from dry land coconut, coconut under bore well irrigation and coconut under drip irrigation, respectively.
f) It is assumed that 6 coconuts form one kg of copra and one kg of copra is Rs.30. the income of the farmer is as follows
Income = (70 nuts X 250 plants)/ 6 nuts per kg
= Number of kg's of copra X Rs.30 per kg = gross income
g) Water applied by additional well = 150hours X 5 irrigations with 1600 GPH of water yield and the well yield was assumed to remain same at the existing level.

Table 35: Financial feasibility of drip Vs additional well

Particulars	Drip method	Flow method with additional well
IRR(%)	46	37
NPV (Rs.)	129539	48993
DCBR	1.51	1.22

Policies for Groundwater regulations

As a matter of policy, it is always easier to grant subsidies and benefits than to regulate or withdraw them once they are introduced. Some of the policy measures enacted by the state with respect to groundwater utilization are summarized and presented in table 37. Policies such as rural electrification, flat power tariffs and the provision of irrigation well loans on soft terms encouraged explosive growth in bore well investments. Electricity supplies in Karnataka State are the worst in the whole country with exception of Bihar. As per the findings of Nagaraj and Chandrakanth, 1995 farmer s of Kolar district of the State, experiencing water drought, well failure are increasingly demanding improvements in power supply. In addition, the farmers were taken on ride to cope with the high cost of pump repairs due to poor electricity. National Council of Power Utilities has expressed that; about 80 per cent of the losses suffered by the State Electricity Boards (SEBs) are result of policies to provide low (in some cases zero) power tariffs for irrigation wells.

Farmers of the Karnataka State were paying the electricity cost for irrigation based on pump capacity (HP) since 1982. Later from April 1992 even the flat rate was eliminated for pump set of up to 10 HP. Nearly 98 per cent of the pump sets in Karnataka are below 10 HP. Again in 1999 the present government introduced electricity charges on flat rate basis at Rs 300 per HP per annum. There is also move to price the electricity based on pro-rata for which farmers are vehemently opposing, since the quality of power supplied is very poor. Though government promised to provide un interrupted power supply at least for eight hours a day, in this regard government has completely failed. The unscheduled power cut in rural areas is not uncommon.

Table 36: Policies influencing groundwater use in Karnataka State

Particulars	Features	Implications
Policy of subsidized Electricity	Flat rate pricing at Rs. 300 per HP per annum	Irregular and inadequate supply of power, scheduled and unscheduled power cuts are rampants Promoted equity, efficiency is severely affected since marginal cost of power is zero and hence no incentive to conservation tending unsustainable development. Power theft, use of higher capacity pump sets unnoticed.
Credit policy	Credit facility for well drilling in the “dark” areas is completely stopped. Selective lending in “gray” areas and no restrictions in the white areas.	Restrictions only to institutional borrowers and not for private investors. Imbalance in both physical and economic access to groundwater.
Land reforms	Land ceiling act, which is currently in vogue for surface irrigation is not applicable to groundwater, irrigated lands.	Wrong notion of irrigated lands.
Groundwater regulations	Maintaining isolation distance of 600 meters	Optimum well density and isolation distance in relation to recharge is not maintained. This yardstick is not applicable to private investment, hence regulation is not effective.
Model groundwater bill	Creation of Groundwater Authority	Though the idea is well conceived, it is yet to be translated into policy, if implemented groundwater situation could be improved.
Markets	Commercialization of agriculture had induced over exploitation of groundwater and has resulted in emergence of groundwater markets.	Extraction exceeding recharge, over development of groundwater and associated socio-economic negative externalities.

GROUNDWATER QUALITY

Socio- Economic Indicators

The socio-economic indicator of the sample respondents is presented in the Table-1. The important socioeconomic indicators considered in this study are given below. The average family size in case of 'poor' quality groundwater regime comprised eight members as against five members in the case of 'normal'. The number of persons dependent on agriculture in the case of 'poor' quality groundwater was five while it was only three in 'normal' area. In the case of 'poor' quality groundwater area, the number of years exposed to education was relatively high (8) as against the 'normal' (5). The percentage of illiterates was less in case of

Table 1: Socio Economic indicators of sample farmers

(Area in acres)

Particulars/Categories	Affected	Normal
Family size (Nos.)	8	5
a) No. of working persons (on the farm)	5	3
Formal Education status (Yrs)	8	5
Percentage of illiterates	23.3	43.3
Respondents age (yrs)	47	48
Holding size (acres)	7.6	4.66
Area under:		
a) Rain fed	1.58 (21)	0.866 (19)
b) Irrigation well	2.08 (27)	2.13 (46)
c) Urban sewage irrigation (effluent water)	1.85 (24)	0 (0)
d) Irrigation tank	0 (0)	0.72 (15)
e) Tree crops	2.08 (27)	0.95 (20)
f) Permanent fallow	0.06 (1)	0 (0)
6. Gross income from rain fed agriculture/ annum	10,425	4,475
7. Non agricultural income/year/family	19,800	5000
8. Proportion of different categories of farmers:	7	30
a) Marginal farmers (< 2.5 acres)	7	30
b) Small farmers (2.5 -5 acres)	43	27
c) Large farmers (> 5 acres)	50	43

Note: Figures in the parentheses are percentages to total.

affected groups (23.3%) as against the 'normal' (43.3 %). Age is an important factor that might have a bearing on the decision making of the respondent, especially with respect to heavy investments in the farm organization. In both the groups, average age was around 47-48 years. In the affected area, gross income from the non-agricultural activities was four timeshigher than in the control (Table 4.1). This comprised the earnings from the surrounding factories located close to Bangalore city. Gross income from the rainfed agriculture, in affected area was two times higher than in the normal (Appendix-III). The proportion of large sized holdings (owning more than five acres) was almost 50 per cent in affected area compared to 43 per cent in control. The percentage of smallholdings in the affected area was 43 per cent while in the control it was 27 per cent. The percentage of marginal holdings (owning less than 2.5 acres) was meager in affected area (7%) compared to normal (30 %) (Table 1).

The average size of the holding in the case of affected group was almost twice (7.6 acres) that of control (4.6 acres). About 27 per cent of the total area was under bore well irrigation in affected area, which was 46 per cent in the control area. The proportion of area allocated for perennial crops like coconut and mango was higher in affected area (27 %) compared with the control farms (20 %). The area under well irrigation and urban sewage was almost equal in affected area than the control .In both the groups around 20 percent of the cultivable area was under rain fed agriculture. On an average, the farmers in the polluted area realized two times more gross income than the control area due to the large area operated by them.

Cropping pattern and cropping intensity

Paddy and Sugarcane were the crops extensively cultivated in 'poor' quality groundwater as compared with 'normal' groundwater farms where there was a considerable diversity in crop pattern (Table 2). In good quality water area, commercial perennials like mulberry and seasonal commercial crops like tomato and Lady's finger occupied the major share. The share of cereals was lower (36 %)

compared with non- cereals (64 %) in both the areas. In both the situations, the non-cereals crops occupied major share in the cropping pattern with groundwater irrigation

The intensity of cropping was computed by considering the area under perennial crops such as mulberry and sugarcane and other perennials as two times the actual area. Since the land is under cultivation in all the two seasons in a year for these crops, this procedure was adopted to standardize cropping intensity with regard to perennial and annual crops for better comparison.

Table 2: Cropping pattern and cropping intensity

(Area in acres)

Crops	Affected		Control	
	Irrigated	Rain fed	Irrigated	Rain fed
Kharif:				
Paddy	53		26.5	
Ragi				12.5
Tomato			7.5	
Bhendi			11.5	
Rabi:				
Paddy			3	
Ragi			2	
Summer:				
Paddy	54		29.5	
Ragi			10	
Tomato			5	
Bhendi			12	
Annuals				
Sugarcane	113		42	
Banana	39		6	
Mulberry	7		22.5	
Fodder	1		1.5	
Perennials				
Mango		27	-	
Coconut	37		55	
Intercrop (Coconut + ragi)		20		13.5
Total	304	47	234	26
Gross area	351		260	
Net cultivated area	230		140	
Cropping intensity (%)	152		186	

Details of sample wells in the affected study area

In 'poor' quality water regime, the cropping intensity was 152 per cent, as compared to the normal area (186 per cent). The introduction of vegetable crops during summer season increased the cropping intensity in control area (Table 2).

Since three decades, open wells have been the major source of irrigation in the area. Groundwater in the area has been polluted due to flow of untreated sewage water in the Vrishbavathi basin. Hence, the area of the river has been affected with different intensities. As evident from the Table 3, around 22.5 per cent of the open-wells have been abandoned by the farmers due to contamination of the groundwater. However, despite the problem of pollution all the bore-wells in the area were used for irrigation. Examination of quality parameters of water in the bore-wells indicated that the water was not potable. The pH is more than 8 and EC is more than 1 ds/mt, affecting the crop performance. Another feature in the area was closing down of all the drinking water wells after the pollution problem. Though the Eastern Dry Zone is fraught with groundwater quantity depletion, in this area poor water quality is the major problem. The depth of the wells has been 180 –200 ft since two decades, while in other area of Eastern Dry Zone the depth has reached beyond 500 ft. Here, the poor groundwater quality resulted in scarcity of quality groundwater (Table 4.3).

Table 3: Details of sample wells in the affected study area

Particulars	Before pollution	After pollution
Open wells (No)	80	62
Bore wells (No)	50	50
Percentage of the open wells abandoned due to pollution	-	22.5
Drinking water wells in use (No)	6	1
Depth of the dug-wells (range in ft)	25- 50	25-50
Depth of the bore-wells (range in ft)	150-180	150-180

Profile of well investments

The well investments at current prices for both affected and normal areas were given in the Tables 4 and 5. To calculate the annual well irrigation cost, the well investments were amortized at two per cent interest rate. In the affected area dug wells were considered for the study, accordingly the amortized cost of dug well works out to be around Rs. 5883, which accounted for 11 per cent of the total investment on dug well. In normal area, the amortized cost of bore well was around Rs. 8501, which accounts for 14.5 per cent of the total bore well investment.

Table 4: Investment for a dug well at current prices (Affected area)

Particulars	Value (RS)
Water Divining charges	250
Cost of digging (25 ft)	12500 (24.00)
Stone lining cost	22500 (43.00)
Cost of irrigation pump set (3HP)	8000 (15.00)
Electricity installation charges	4500 (8.50)
Pump house cost	5000 (9.50)
Total	**52750**
Amortized cost of investment	2883
Annual repairs and maintenance	1500
Annual electricity charges	1500
Annual irrigation cost per well	**5883**

Note: Figures in the parentheses are percentages to total.

Table 5: Investment for a bore well at current prices (Normal area)

Particulars	Value (RS)
I. Cost of drilling	
a) Water divining charges	255
b) Transportation of rig	480
c) Drilling charges (180 ft)	10000
d) Casing cost	6000
Sub Total	**16735** (28.5)
II. Cost of water lifting	
a) Pump cost	10200
b) Panel board	2650
c) Cable wire cost	800
d) Automatic starter	5400
e) GI pipes	5400
f) Cost of accessories	1650
g) Electricity installation charges	5300
Sub Total	**31400** (53.5)
III. Other costs	
a) Pump house cost	5000
b) Pipe line cost	5600
Sub Total	**10600** (18)

Total	**58735**
Amortized cost of investment	6001
Annual repairs and maintenance	1000
Annual electricity charges	1500
Annual irrigation cost/well	**8501**

Note: Figures in the parentheses are percentages to total.

Annual cost of irrigation

To calculate the irrigation cost in both the areas the amortized cost of the well and the gross irrigated area per well was considered (Table 6). The per acre irrigation cost under affected area was lower (Rs. 1861), compared to the control area (Rs. 2146). Irrigation cost per acre-inch of water works out to be Rs. 39 under poor quality water regime compared to control (Rs 34).

Table 6: Annual cost of irrigation

Particulars	Affected area	Normal area
Gross area irrigated per well (acre)	3.16	3.96
Amortized cost of well (Rs)	5883	8501
Irrigation cost /acre of gross cropped area (Rs)	1861	2146
Irrigation cost per acre inch of water (Rs)	39	34

Cost of production of paddy and Sugarcane

Based on the proximity of wells to the sewage flow, groundwater is classified as ‘poor’, ‘moderate’ and ‘normal’. Paddy and sugarcane occupied a major share of area in the ‘poor’ groundwater quality area.

Economics of Paddy production

In the case of poor quality water, the total cost of paddy production was Rs. 8738 per acre as against Rs.7790 and Rs. 9181 in ‘moderate’ and ‘normal’ quality water (Table 7). The labor component accounted 35 per cent of the cost in ‘poor’ and ‘moderate’ quality water, which includes the additional expenditure on weeding. Similarly, the labor cost in ‘normal’ water situation formed 24 per cent. The farmers using ‘poor’ quality water incurred Rs. 1800 per acre towards bullock labor, which comprised an additional amount of Rs. 600 due to externality induced by ‘poor’ quality water. Thus, labor cost formed 21 per cent of the total cost. In ‘normal’ and ‘moderate’ quality water, bullock labor cost formed 15 and 18 per cent, respectively. The expenditure on chemical fertilizers and manure was relatively low with ‘poor’ quality water situation (Rs. 760) and moderate (Rs. 800) while it was Rs. 2181.5 with ‘normal’ quality water situation. Plant protection expenditure was comparatively low in all the cases. Expenditure on seed varied from Rs. 356 to Rs. 414 across all the three situations.

Table 7: Comparative Cost-Return profile for Paddy production under different Quality of ground water

(Rupees per acre)

Cost/Return items	Water quality		
	‘Poor’	‘Moderate’	‘Normal’
Seed	356 (4)	370 (5.5)	414 (5)
Fertilizers and manures	760 (9)	800 (10)	2181.5 (24)
LABOUR			
a) Human labour	2050 (23.5)	2100 (27)	2200 (24)
b) Bullock labour	1200 (14)	1000 (13)	1400 (15)
Plant protection chemicals	286 (3)	220 (3)	200 (2)
NEGATIVE EXTERNALITY COST			
a) Extra ploughing	600 (7)	400 (5)	
b) Extra weeding	1000 (11.5)	500 (6)	
Irrigation cost	1861 (21)	1861 (24)	2146 (23)
Interest on variable capital @ 10%	625.2 (7)	539 (7)	639.55 (7)
TOTAL INPUT COST	8738 (100)	7790 (100)	9181 (100)
RETURNS			
Yield (qtls/acre)	6.2	8.5	16.5
Output price (Rs/qtl)	400	450	500
Value of the output	2480	3825	8250
Value of the By- product	-	800	1500

Gross income	2480	4825	9750
Net return	- 6258	- 3165	569
Cost/quintal	1409	916	556
Net return/quintal	- 1009	-372	34.5
Net return without implicit cost	- 636	455	4955

Note: Figures in the parentheses are percentages to total.

The annual cost of well irrigation comprised amortized cost, and maintenance cost. This formed 21 per cent of total cost. In ‘moderate’ and ‘good’ quality water situation, irrigation cost was 23 and 24 per cent of the total cost respectively. Farmers incurred loss of Rs. –6258 per acre using ‘poor’ quality water and a loss of Rs. –3165 using ‘moderate’ quality water. The net returns inclusive of all explicit costs and implicit costs was Rs. 569 in ‘normal’ quality water situation. However, even after excluding implicit costs from gross income, the net returns realized were negative in ‘poor’ quality water. Cost of production of paddy was Rs. 1409 per quintal in ‘poor’ quality irrigation water and Rs. 916 and Rs. 556 per quintal with ‘moderate’ and ‘normal’ quality water, respectively. The cost of production of paddy per quintal was two and halftimes higher than the normal, due to ‘poor’ quality water.

Economics of sugarcane production

Farmers incurred Rs. 18797 per acre towards production of sugarcane in the affected area as against to Rs.17525 and Rs. 19064 in ‘moderate’ and ‘normal’ quality water (Table 8). The labor cost formed 41 per cent of the cost in poor quality and 37.5 per cent in ‘moderate’ quality water respectively, which included the additional expenditure on extra weeding. Similarly, the labor cost of sugarcane production in ‘normal’ water formed around 31 per cent. The farmers using ‘poor’ quality water incurred an expenditure of Rs 2200 per acre towards bullock labor. This includes an additional expenditure of Rs. 600 on labor negative externality cost attributed to the ‘poor’ quality water. Thus, bullock labor cost formed 11.5 per cent of total cost. In ‘normal’ and ‘moderate’ quality water, the bullock labor cost formed around 9.5 and 12 per cent respectively. The expenditure on chemical fertilizers with ‘poor’ quality water situation was Rs. 821, which is 20 per cent lower than ‘moderate’ (Rs. 1029) and 76 per cent lower than ‘normal’ quality (Rs. 3480) water situation. Plant protection chemical expenses were comparatively low in all the situations. The expenditure on planting material varied from Rs. 4000 to Rs. 4375 across all the groups.

The annual cost of well irrigation comprising the amortized cost and the maintenance cost formed 10 to 11 per cent of total cost in all the three situations of water quality. The cost of transportation was Rs. 206 per tone in ‘poor’ quality water as against Rs. 165 and Rs 187 in ‘moderate’ and ‘normal’ quality water. Farmers incurred a loss of Rs. – 11172.7 and Rs. –2482 in both ‘poor’ and ‘moderate’ quality water situation. The net return accounting for explicit costs was Rs. 10936 per acre in normal quality water situation. In sugarcane crop, most of the farmers realized positive returns after excluding the implicit cost from the output value. On an average, cost of production of sugarcane was Rs. 910 per tone in ‘poor’ quality water and Rs. 730 and Rs. 576 with moderate and ‘normal’ quality water respectively. Thus, with ‘poor’ quality water, farmers incurred 37 per cent higher expenditure to produce every tone of sugarcane compared to the ‘normal’.

Table 8: Comparative Cost-Return profile for Sugarcane production under different Quality of ground Water

(Rupees Per acre)

Cost/Return items	Water quality		
	‘Poor’	‘Moderate’	‘Normal’
Sugarcane sets	4375 (23)	4209 (24)	4000 (21)
Fertilizers and manures	821 (4.5)	1029 (6)	3480 (18)
LABOUR			
a) Human labour	5880 (31)	5180 (29.5)	5850 (31)
b) Bullock labour	1600 (8.5)	1600 (9)	1800 (9.5)
Plant protection chemicals	321 (2)	272 (1.5)	250 (1.25)
AVERTIVE EXPENDITURE			
a) Extra ploughing	600 (3)	600 (3)	
b) Extra weeding	1800 (10)	1350 (8)	
Irrigation cost	1861 (10)	1861 (11)	2146 (11.25)

Interest on variable capital @ 10%	1539.7 (8)	1424 (8)	1538 (8)
TOTAL INPUT COST	18797.7 (100)	17525 (100)	19064 (100)
TRANSPORTATION COST	5375	5107	9200
TOTAL COST	24172.7	22632	28264
RETURNS			
Yield (tones/acre)	26	31	49
Market price (Rs/tonne)	500	650	800
Gross income	13000	20150	39200
Net return	-11172.7	-2482	10936
Cost/tonne	910.8	730	576
Net return/tonne	-429.7	-80	223
Net return without implicit cost	3483	10140	26570

Note: Figures in the parentheses are percentages to the total.

Crop productivity – indicator of sustainability

Due to the ‘poor’ quality water, agricultural productivity and labor employment in the affected area declined, and the environment deteriorated. The results pertaining to these aspects are presented in table 9.

With ‘poor’ quality water, the yield of paddy was 6.2 quintals while it was 16.5 quintals in ‘normal’ situation, a reduction of 62.4 per cent. The decline in the yield of sugarcane on ‘poor’ quality water situation was 47 per cent. The yield of banana was the highest (10 tones/acre) with ‘normal’ quality irrigation water and was the lowest (5.5 tone/acre) with poor quality water. In mulberry, the yield with ‘poor’ quality water was lower by 62 per cent compared with the normal water quality (Table 9).

Table 9: Impact on crop productivity

Crops	Water quality			Loss due to poor quality water (%)	Loss in GI (%)
	‘Poor’	‘Moderate’	‘Normal’		
Paddy (qtls/acre)	6.2	8.5	16.5	62.4	74.5
Sugarcane (tones/acre)	26	31	49	47	67
Banana (tones/acre)	5.5	6.3	10	45	45
Mulberry (tones /acre)	0.75	1.33	2	62.5	
Ragi (qtls/acre)	NA	NA	13	NA	NA
Tomato (tones/acre)	NA	NA	3.5	NA	NA
Bhendi (tones/acre)	NA	NA	3	NA	NA
Coconut (nuts/tree)	NA	NA	100	NA	NA

Note: NA- Not applicable as they were not grown in ‘poor’ and ‘moderate’ quality water.

Explicit and implicit loss due to poor quality water in paddy and sugarcane production

Barring paddy and sugarcane, the area under other field crops virtually disappeared in the affected area due to increase in the salts concentration in the water. An attempt has been made to estimate the yield loss and associated monetary loss at farm level as well as at regional level. The results are provided in the Table 10 and 11 for paddy and sugarcane respectively. At the farm level, the loss incurred due to the poor quality irrigation water was to the tune of 10.3 quintals per acre valued at around Rs. 8250 including the negative externality cost. Based on the farm level yield loss, the monetary loss incurred at the regional level has been estimated.

In each season, there has been loss of paddy output of 14085 quintals, from 1367 acres of command, resulting in a monitory loss of Rs. 70.42 lakhs in the entire command. The total by-product value lost on account of non-palatability of the fodder is around Rs. 20.5 lakhs. The total avertive expenditure/negative externality cost incurred in affected area to get the existing yield is Rs. 21.8 lakhs. Thus, the total loss of revenue in the command is of Rs. 112.7 lakhs.

Similarly, the loss of sugarcane output due to poor quality water problem has been worked out. At farm level, the sugarcane output loss due to the poor quality irrigation was 23 tonnes, worth Rs. 16476 including the avertive expenditure/ negative externality cost. Accordingly, the loss in the sugarcane productivity as well as the associated income loss at the regional level has been computed (Table 11).

Table 10: Estimated implicit and explicit loss of paddy output due to poor quality water

Particulars	Values
1.Productivty of paddy in good water (qtls/ac)	16.5
a. Productivity of paddy in poor quality water	6.2
Difference between normal and poor	10.3
b. Total area under paddy in the affected command area (acres)	1367.5
c. Total production loss in the command (qtls)	14085
d. Total monetary loss in the command (Rs in Lakhs)	70.42
2. Total byproduct value lost on account of non-palatability of the fodder (Lakhs)	20.5
Total avertive expenditure / negative externality cost incurred in affected area to get the existing yield (Lakhs)	21.8
Gross loss of revenue in the command (Lakhs)	112.7
a. Per acre Monetary loss of paddy in affected area	5150
Per acre Monetary loss of bye-product	1500
Per acre defensive expenditure incurred to get the existing yield	1600
Per acre total monetary loss at Farm level	8250

Table 11: Estimated implicit and explicit loss of sugarcane yield due to Poor quality water

Particulars	Values
1.Productivty of sugarcane in good water (tones/ac)	49
a. Productivity of sugarcane in poor quality water	26
Difference between normal and poor	23
b. Total area under sugarcane in the affected command area (acres)	1822.5
c. Total production loss in the command (tones)	41917.5
d. Total monetary loss in the command (Rs in lakhs)	256.5
Total avertive expenditure / negative externality cost incurred in affected area to get the existing yield (Lakhs)	43.7
Gross loss of revenue in the command (Lakhs)	300.2
a. Per acre Monetary loss of sugarcane in affected area	14076
Per acre defensive expenditure incurred to get the existing yield	2400
Per acre total monetary loss at Farm level	16476

At the regional level, the damage to the sugarcane yield was 41917.5 tones from an area of 1822.5 acres, resulting in a monetary loss of approximately Rs. 256.5 lakhs in the entire command. The avertive expenditure/ negative externality cost incurred in affected area to get the existing yield was Rs. 43.7 lakhs. Thus, the total loss of revenue in the command was Rs. 300.2 lakhs.

Influence of water quality on quality of farm produce

Poor quality groundwater used for irrigation affected the quality and quantity of farm produce (Table 12). The crops grown using 'poor' quality water fetched lower prices in the market and lacked demand in the local market when compared with normal produce. As paddy grown using 'poor' quality water had blackish tinge, the demand reduced as reflected in a 20 per cent lower price realized compared to 'normal' paddy. Similarly, the price of sugarcane was lower by 37 per cent compared to 'normal' crop since the sucrose recovery was four per cent unlike 'normal' sucrose recovery is eight per cent. As mulberry leaves cultivated using 'poor' quality water were of poor quality, the cocoons were of poor shape and low quality as the yarn reeled was weak. Therefore, such cocoons fetched 45 per cent lower price compared with the 'normal' cocoons. The reelers decided the price of cocoons by mere questioning regarding the place from where the cocoons were bought.

Table 12: Features of 'poor' quality produce due to use of 'poor' quality water

Crops	Type of damage	Output Price for affected produce	Output Price for ' normal' produce	Percent age loss
Paddy	Proportion of broken rice to the total rice is large when milled. Thus, rice recovery was 35 kg for every 100 kgs of paddy milled. Which is half of the 'normal'.	Rs. 400/qtl (Paddy price)	Rs. 500/qtl	20
Paddy straw	Paddy straw is discolored (turned blackish brown) and not palatable to livestock and hence straw is burnt.	Nil	Rs. 500/tonne	100
Sugarcane	Sugar recovery is around four per cent while; normal recovery is eight to ten per cent. Thus, sugarcane is not preferred in the sugar factories.	Rs. 500 /tonne	Rs. 800/tonne	37.5
Silk cocoons	Dull colored, weak filament, breaks frequently and low demand in market	55 Rs/Kg	100 Rs/Kg	45
Milk	Milk is mainly from local cows and the buffaloes, as improved cows do not survive in the area. The quality of milk is poor as it spilt soon.	0 (No sale)	11 Rs/lt	100
Coconut	Lack of demand in local markets due to poor quality of tender coconut (sour in taste)	1.50 Ps/nut	4 Rs/nut	62.5

In the area, there was lack of demand for milk, as milch animals were managed using the poor quality water and similar trend was noticed with respect to tender coconuts. This was due to the perception of the consumers and the fear of the people that the products are raised using polluted water and hence not good from the health point of view (Table 13). Thus, there are clear implications for regional food insecurity and welfare loss in the area due to the pollution of groundwater.

Impact on human and animal health

Changes in water quality due to contamination /pollution lead to undesirable changes in the ambient environment. These changes lead to the incidence of diseases and consequently impairment of physical activities due to continuous exposure to 'poor' quality water. An attempt however, was made to value the negative externalities of 'poor' quality water on human and livestock health by estimating the expenditures incurred on health by the affected. The expenditure includes, medical expenses due to poor quality water, loss of employment and associated earnings.

Table 13: Nature of ill effects and the associated costs on the human and livestock health

Particulars	Nature of problem	Additional cost on health/Year /family (Rs)
Human health	Allergic dermatitis/ other skin and fungal infection. Gastrointestinal infection.	2616
Animal Health	Dehydration, Skin infection, Continuous exposure to the water during agricultural operations observed edema	1368

Poor' quality water due to pollution posed a multitude of health problems like allergic dermatitis, skin irritation and gastrointestinal problems. This has increased health expenditure to the tune of Rs. 2,616 per year per family. Bullocks, cows and buffaloes were facing the problem of dehydration, skin irritation and hair dropping due to dependence on polluted water for drinking and washing the livestock with the same water. In this regard the annual expenditure towards medical related problems of livestock formed Rs. 1,368.

Loss in labour wages

The value lost due to difference in the employment generated between 'normal' and 'affected' area was Rs. 2,000 per farm labor for two-crop seasons. The annual health cost per farm labor per year was Rs. 327 and thus the total loss was around Rs. 2327 (Table 14).

Table 14: Loss in wages per farm labor for two crop seasons per year

Particulars	Poor quality water	Good quality water
Total employment generated (Man days)	120	160
Loss in working days (Man days)	40	
Wage income lost due to illness (Rs)	2000	
Health cost/labor (Rs)	327	
Total Value lost (Rs)	2327	

Effect on ecology and environment

Due to 'poor' quality water use, soil structure and texture had deteriorated, poor drainage of the soil, and agricultural productivity declined drastically (Table 15).

Table 15: Ecological and environmental effects of groundwater pollution (According to perception of the farmers)

Particulars	Effects
Soil structure and texture	Hardening of the soil
Water holding capacity (poor drainage)	Slow infiltration (takes > 15 days)
Fertility of the soil	High nitrate content resulting in profuse vegetative growth and excessive weeds. Contaminated water leads to deposition of heavy metals in the soil, increasing soil toxicity.
Agricultural productivity	Low. Paddy 6.2 qtls/acre and sugarcane 26-tones/ acre.
Land value	Farmers expressed that; they can seldom sell their land. Thus the land value is almost negligible. But for normal soils in the area the land value is Rs. 1,20,000
Bird population	Completely reduced (Crane population)
Fish population	Thirty sample farmers have 25 dug wells and five bore wells. Fish population has declined markedly in the dug wells.
Drinking water	Women are forced to fetch potable quality water from 1 or 2 km, as the drinking water becomes polluted water.

Regarding the fertility status, soil was rich with high organic and nitrate content that led to profuse vegetative growth and excess weed problem (Srikanthimathi, 1990). Incessant use of polluted water was led to accumulation of heavy metal loading in the soil (siddramappa et al 1997). Further, there is no demand for the affected land. The drinking water wells were polluted and consequently abandoned. Regarding other ecological changes, crane population disappeared and fish population in the dug wells dwindled due to water pollution.

Estimation of transaction cost in fetching potable water

Most of the drinking water wells in the area are contaminated with sewage water rendering it unsuitable for potable purpose. As a result, women are forced to walk long distance to fetch potable water for domestic use. This involved transaction cost (Table 16).

Transaction cost, here, comprises the number of women days lost due to procuring potable water from a distance due to the water quality problem in the area. The estimated transaction cost was Rs. 2,533 per year per household. Thus, this amount reflected the cost of potable water inflicted on each household due to the contamination of groundwater in the area.

The yield loss per acre of paddy was 10.3 quintals and that in sugarcane was 23 tones. The loss of gross income from paddy and sugarcane was Rs 7270 and Rs 26200 respectively. Employment loss due to poor quality water was 40 man-days. Around Rs. 62,000 was the loss due to decline in the land value. Thirty four percent of the cropping intensity was lost due to poor quality water (Table 17).

Table 16: Estimation of Transaction cost in fetching potable water

Particulars	**'Poor'**	**'Moderate'**	**'Normal'**
1.Average distance traveled to fetch good quality drinking water (in kms)	1.5	1	0
2.Average time spent on fetching good quality water/day (Hrs)	2	1 1/2	1/4
3.Estimated number of women days spent in fetching potable water/yr	91.25	59.25	6.8
4.The imputed cost of labour lost (in Rs)	2737.5	1777.5	204
5. Transaction cost (the net of poor and normal)	2533.5	1438.5	-

Table 17: Economic losses arising due to poor quality water

Particulars	Water quality		Loss due to poor Quality water
Productivity	Normal	Poor	
a) Paddy (qtl/Ac)	16.6	6.2	10.4
b) Sugarcane (tons/ acre)	49.0	26	23
Gross Income per acre			
a) Paddy	9750	2480	7270
b) Sugarcane	39200	13000	26200
Employment generated (man days / year)	90	50	40
Land value (Rs. / Acre)	120000	58000	62000
Cropping intensity (%)	186	152	34

Efficiency of paddy and sugarcane production

The total volume of water applied per acre of paddy under 'poor' quality water was 65 inches and there is no difference in good quality (64) water situation. In moderately affected water situation, it is 52 inches. Yield of paddy per acre-inch of water is 9.4 kgs with 'poor' quality water, 16 kgs with moderate quality water and 28 kgs with 'normal' quality water indicating direct relationship between the quality of water and productivity (Table 18)

Table 18: Productivity of Paddy and sugarcane per acre-inch of water

Crop	Quality of water	Inches of water used per acre	Output per acre- inch of water
Paddy (kgs)	'Poor'	65	9.4
	'Moderate'	52	16
	'Normal'	64	28
Sugarcane (tones)	'Poor'	87	0.29
	'Moderate'	71	0.43
	'Normal'	85	0.57

In the case of sugarcane, the total volume of water applied per acre was comparatively high in 'poor' quality water situation (87) than on 'moderate' (71) and 'normal' quality (85) water situation. Sugarcane yield obtained per acre-inch of water is very less with 'poor' quality water irrigation (0.29 tones), when compared with 'moderate' (0.43 tones) and 'normal' quality water irrigation (0.57 tones).

Gross income function for paddy and sugarcane

Gross income function was estimated to capture the influence of water quality and productivity on gross income in normal and affected area (Tables 19 & 20). Dummy variable is used to differentiate the water quality.

Table 19: Income function for paddy

Sl. No	Particulars	Coefficients	t stat
1	Intercept	2047.45	2.99
2	Water used (Acre inches)	-9.27*	-2.92
3	Productivity (qtls/acre)	424.83*	11.59
4	Dummy for water quality (Poor quality = 1, normal =0)	-1710.14*	-4.70

Note: R^2= 0.97
*- Indicates significance at 5 percent level
Pooled data (Affected and normal)

Almost 97 per cent of the total variation in gross income was explained by quantity and quality of water and the productivity of paddy. All the three regression coefficients have registered statistical significance. The coefficient for quality of water has turned out to be negative depicting the fact that the gross income from paddy in poor quality area is relatively less when compared to normal area. The regression coefficient for water used in acre inches is negative (-9.27) indicating for every one acre inch of water used, the gross income reduced by 9.27 units. A very substantial reduction in output value due to poor quality of water is evident by the significant regression co-efficient for water quality.

Table 20: Income function for sugarcane

Sl. No	Particulars	Coefficients	t stat
1	Intercept	8528.10	8.16
2	Water used (Acre inches)	3.23	1.01
3	Productivity (qtls/acre)	620.38*	31.63
4	Dummy for water quality (poor quality = 1, normal =0)	-12284.3*	-29.39

*Note: R^2= 0.99, *- Indicates significance at 5 percent level, Pooled data (Affected and normal)*

In case of sugarcane, the gross income was influenced by only productivity as indicated by the coefficient. The regression coefficient for water used was insignificant. However, the dummy variable was negative and significant indicating the influence of water quality on the gross income.

Equity – Percent area affected across size classes

For marginal farmers, the percentage of area affected was 100 per cent. Thus, marginal farmers are worst hit due to ground water pollution. The percentage of area affected due to poor quality water was 58 per cent and 61.5 per cent in the case of small and large farmers respectively (Table 21).

Table 21: Average holding size and percentage of area affected across size classes in study area

Categories	Average holding size (Acres)	Extent of area affected (Acres)	Percentage of area affected
Marginal farmers	2.00	2.00	100.00
Small farmers	3.80	2.20	58.00
Large farmers	11.70	7.20	61.50
Total	17.50	11.40	65.00

Net return and net benefit cost ratio of paddy and sugarcane among the different classes of farmers

The benefit cost ratio was negative for all three classes of farmers. The ratio varied from -0.63 to –0.5 across all the farmers indicating the uniform impact of the brunt of the damage borned by the farmers. In sugarcane, the benefit cost ratio was -0.22 for large farmers, which was less compared to marginal (-0.32) and small farmers (-0.35) (Table 22).

Table 22: Net return and net benefit cost ratio of paddy and sugarcane across classes of farmers

Farmers	Expenditure	Gross returns	Net returns	B: C Ratio
	Paddy			
Marginal farmers	8041	3951	-4092	-0.50
Small farmers	8051	3227	-4824	-0.60
Large farmers	8680	3176	-5504	-0.63
	Sugarcane			
Marginal farmers	23412	15865	-7546	-0.32
Small farmers	22722	14648	-8174	-0.35
Large farmers	23038	17820	-5218	-0.22

Net return per acre-inch of water used

The net return per acre-inch of water used for paddy and sugarcane was calculated to estimate the effect of poor quality water and presented in Table 23..

Table 23: Net returns per acre inch of water across different categories of farmers

Size group	Acre inches of water used	Out put per acre inch (qtl/tonne)	Net return per care inch
Paddy			
Marginal farmers	63	13	- 66
Small farmers	65	11	-75
Large farmers	64	12	- 86
Sugarcane			
Marginal farmers	84.8	0.35	- 88.9
Small farmers	85.4	0.31	- 95.7
Large farmers	87.1	0.37	- 59.9

Water used per acre of paddy was uniform for all the three classes of farmers. The loss in net returns per acre-inch of water was low for marginal farmer (Rs. -65) compared to small (RS. -74) and large (Rs. -86) farmers. In sugarcane, there was no much difference with respect to water used, but the loss in net returns per acre-inches of water used was on the lower scale for large farmers (Rs. -59.9) compared to marginal (Rs.-88.9) and large (Rs.-95.7) farmers

Sustainability

The productivity differential between 'poor 'quality and 'normal' is an indicator of sustainability as this is the effect of use of poor quality water over time the results are presented in Table 24.

Table 24: Productivity trends of paddy and sugarcane under poor quality versus the normal groundwater

Particulars	Poor Quality		Good Quality	
	Paddy Q/acre	S Cane Tons/acre	Paddy Q/acre	S Cane Tons/acre
1991	11.58	38.9	19.42	51.72
1992	11.2	38	19.82	51.5
1993	10.6	38	19.86	52.8
1994	10.5	37.65	20.45	53
1995	9.8	36.8	20.82	53.5
1996	8.5	35	21	54
1997	7.82	31	21.62	54.8
1998	7.02	30.5	22	55
1999	7.2	29.35	22	55
2000	7	28.2	22.8	55
Mean	9.122	34.34	20.979	53.632
Percent Difference	56.51	35.97	---	---
CV (%)	19.88095	12.02745	5.303965	2.518815
Compound Growth rate (%)	-6.28*	-3.8*	1.7*	0.80*

** Indicates significance at 5 per cent level.*

Source: Agricultural office, Bidadi.

There was 56 per cent and 36 per cent difference in productivity under poor quality regime in paddy and sugarcane crops compared to 'normal' condition. The stability of yields measured in terms of coefficient of variation also was of higher degree in 'poor' quality compared to 'normal'.

Sustainability index

The components of sustainability index are, impact on resources, impact on production system, impact on human /animal health. After giving the respective weightage for each farmer, sustainability index was formulated. About 50 per cent of the farmers were in less sustainable group in the case of their resources (Water, soils and biomass). Around 43 per cent of the farmers were in less sustainable category. Effect of poor quality water on human/animal health was higher when compared to resources and productivity, about 63 per cent of the farmers were in unsustainable group (Table 25).

Table 25: Sustainability index

Impact on resources		
	Average score	% Of farmers
Less sustainable	0.45	50
Moderately sustainable	0.85	23.3
Sustainable	1.05	26.7
Impact on production system:		
Less sustainable	0.45	43.3
Moderately sustainable	0.65	30
Sustainable	1.0	26.7
Impact on Human/Animal health		
Less sustainable	0.45	63.3
Moderately sustainable	0.65	23.3
Sustainable	0.85	13.3
Overall Sustainability Index		
Less sustainable	0.45	52.3
Moderately sustainable	0.65	13.3
Sustainable	0.96	34.4

Land degradation ratio

An effective indicator to measure the environmental damage is the ratio of current irrigable area to initial irrigable area. The land degradation ratio measures the extent of irrigated area lost due to groundwater degradation (Table 26).

About 18.5 per cent of the cultivable area in the region is lost, as it is unsuitable for growing crops unless remedial measures were taken up. In the case of the ragi about 100 per cent of the area under cultivation was lost due to poor quality water use. It is interesting to note that most of the vegetable crops lost their area share to sugarcane and paddy, as these two crops are tolerant to salts.

Table 26: Land degradation ratio

(Area in acres)

Particulars	Before pollution	After pollution	Area lost/Added	Percentage
1. Cultivable Gross Area	318	259	59	18.5(-)
2. Total Area under Ragi cultivation	39	0	39	100(-)
3. Total Area under Bhendi cultivation	42	0	42	100(-)
4. Total Area under Tomato cultivation	39	0	39	100(-)
5. Total Area under Paddy cultivation	84.5	107	22.5	26.6(+)
6. Total Area under Sugarcane cultivation.	84.5	113	28.5	33.7(+)
7. Total Area under Banana cultivation.	29	39	10	34.4(+)

Alternative options to ameliorate the poor quality water

The possible measures to reduce the ill effects of 'poor' water quality include use of organic manure, gypsum, drainage, additional seed and use of local amendments like coir pith.

Expenditure on surface drainage

Farmers did not invest in drainage system recommended on scientific basis since, the drainage involved huge capital investment. However, majority of the large farmers provided surface drainage using the labour component on a rudimentary basis. The labour cost incurred to provide drainage was around Rs 400, and maintenance was around 150, together formed around Rs. 550 (Table 27)

Table 27: Per acre expenditure on surface drainage

Particulars	Units
No of labours employed	8
Wage rate /man day (Rs)	50
Total wage bill	400
Maintenance cost /year	150
Total cost (Rs)	550

Additional cost for providing surface drainage per acre was Rs 550 and the gross return derived from this practice was around Rs 1037. Thus, the net gain accrued on account of surface drainage was Rs. 487.50, which is remunerative (Table 28).

Table 28: **Economics of providing surface drainage for paddy cultivation**

Debit			Credit
a) Increase in cost			a) Decrease in costs
			Nil
i. Cost of surface drainage	(Rs)	400	
ii. Maintenance cost	(Rs)	150	
b) Decrease in returns		Nil	b) Increase in returns
			i. Paddy yield 2.5 qtls @ Rs 415/qtl = 1037.5
A) Total (a+b) (Rs) 550			Total (a+b) (Rs) 1037.5
Net gain (B-A) = Rs.487.5			

Treatment of polluted water

The Bangalore Water Supply and Sewage Board (BWSSB) has proposed the wastewater treatment plant in the Vrishibhavathi command, which is likely to be commissioned. Based on the estimates given by the BWSSB for treating polluted water, the treatment costs were worked out (Table 29).

The treated water could be effectively utilized for crop husbandry as well as other domestic purposes. The estimated capital outlay on the treatment plant is approximately Rs.50 crores, of which, around 40 percent accounted towards civil structures and the remaining towards the mechanical components. Upon amortization, the fixed capital share constituted around Rs.2.56 crores while the operation and maintenance expenditure comes to Rs. 0.714 crores. Thus, on an average, the cost incurred to treat one million liter of wastewater is Rs.1285. The cost of supplying one acre-inch is Rs. 130, which is two and half times higher than the present cost of well irrigation in the study area. According to a research study conducted in Eastern Dry Zone of Karnataka State, the cost of irrigation per acre-inch of water comes to Rs. 107/-. This clearly indicates that the farmers can afford to the treated water for irrigating their agricultural lands in this region. They need to pay Rs.130 per acre-inch as cost of amelioration. Considering the marginal value product of groundwater as Rs. 196 per acre-inch of water it is economical to use treated water at Rs. 130 per acre-inch.

Table 29: Cost of treating wastewater of Vrishibhavathi valley

Sl. No.	Particulars	Amount
1	Cost on civil structures	Rs. 20 crore
2	Amortized cost of civil structure (life span of 80 years; discount rate 04 per cent)	Rs. 0.8362crores
3	Cost of mechanical components	Rs. 30 crores
4.	Amortized cost of mechanical components (life span of 30 years; discount rate 04 per cent)	Rs. 1.7349 crores
5	Operating and maintenance cost	Rs. 0.7140crores
	Total cost to treat 25550 ML/Y	Rs.3.2851 crores
6	Cost per one million liter	Rs. 1285/-
7	Cost per kilo liter	Rs. 1.285
8	Cost per acre inch	Rs. 130/-

Replacement cost or cost of damage

Once the groundwater aquifers are polluted, it is difficult to treat and purify groundwater on a large scale especially for crop production. Therefore the cost of replacement has to be borne by the farmer as a negative externality (Table-30). Hence, the option available for farmers is to invest on a well in a normal area where groundwater pollution is not a problem. This proposition is viable only when the farmer has land in the non-affected area. Secondly, farmers can purchase water from others. In this method, the cost that would be required to mitigate the problem and replace a damaged asset is the cost of developing the alternative source. According to the current estimates to drill one well and to own three acres of land in normal area it would cost around Rs. 3.6 lakhs.

Table 30: Replacement cost / cost of damage

Sl no	Particulars	Amount
1	Investment on new well in the normal area and purchase of 3 acres land (lakhs)	Rs. 3.6
2	Cost of irrigation per acre in normal area	Rs. 871
3	Purchasing water from neighbors for paddy (Value of ¼ of the crop produce = ¼ * 16* 456)	Rs. 1824
4	Purchasing treated water for paddy production. (Valued at Rs 130/acre inch x 40 acre inches)	Rs. 5200

Willingness to pay for good quality irrigation water

The results of OLS estimation for good quality irrigation water are given in the Table 31. The results indicate that paddy yield; price of the paddy, human health and land value had a positive relation with WTP for good quality irrigation water. Human health has high impact as indicated by the coefficient. If the cost on health increases by 1 percent, then the willingness to pay increases by 7 percent. It is significant at 5 percent level (t* 2.4). WTP estimated at average value of independent variables was Rs. 785 per acre/year for irrigation water, which was closer to the actual average value.

Table 31:Willingness to pay according to the income groups

Annual income of the respondents (Rs.)	No of farmers	Average WTP (Rs.)
Income range 1000-10000	26	815.6
Income range 10000-20000	10	1230
Income range 20000-30000	4	675

Willingness to pay according to the income group

Changes in environmental quality have significant effect on human health. This health impact in monetary terms can be determined in terms of willingness to pay of the individuals for the improved quality of water in order to minimize the ill effects on the health. Accordingly, the willingness to pay has been estimated according to the income group for clean water for agricultural and domestic use. The results are provided in the Table 32.

Table 32: OLS Estimates for willingness to pay for good quality drinking water

	Coefficients	t Stat
Intercept	-38.72	-0.66
Age	1.91	1.55
Education	7.71	2.40
Income	0.0028	1.21
WTP estimated at average value (Rs)	128.43	

The average willingness to pay was Rs. 815.6 in case of income group of the farmers ranging from Rs.1000 to Rs.10, 000, it is Rs.1230 in case of the income ranging from Rs.10, 000 to Rs.20, 000 and it is Rs. 675 in case of income range between Rs. 20,000 to Rs. 30,000.

Table 33 gives the OLS estimation for clean drinking water. The results given in the table shows that variables like age, education and income have a positive impact on their willingness to pay for drinking water. All the variables are significant at 5 per cent level. As the age increases, the willingness to pay increase by 1.9 per cent, as the education increases the WTP increases by 7.7 per cent and as the income increases WTP increases marginally (0.0028 %). The WTP estimated at average value of independent variables was Rs. 128 per year, which is on par with the actual average obtained.

Table 33: OLS Estimates of Willingness to pay for good quality irrigation water

Parameter	Coefficients	t Stat
Intercept	-1407.738	-1.031
Paddy yield	87.058	0.974
Price /qtl	1.379	0.384
Animal health cost	-0.047	-0.303
Human health cost	0.387	2.436
Land value	0.002	0.151
WTP estimated at average value(Rs)	785.00	

V DISCUSSION

GROUNDWATER DEPLETION

The results of the study are discussed on the following themes as detailed below.

Socio-economic indicators

The family size is uniform without much variation across different water regimes. But, the working family members on the farm are only one third of their family size indicating high dependency ratio. More than 80 percent of the respondents are literate in all the three situations. The average age of the respondents indicate that they are in the middle age and are capable of taking strategic decisions in organization and managing the farm. The land holding size was slightly bigger in the case of groundwater alone situation and tank irrigated with groundwater supplement (8 acres) as against canal irrigated with groundwater (6.7 acres). The farm size is a decisive factor that influences capital investments on groundwater development through wells. This is in accordance with the study by Neelakantaiah (1991) who reported that the education level, farm size and availability of credit have strongly influenced the level of investment on ground water development (Table 3).

Overall, across different water management regimes around 60 to 70 per cent of the total arable land was under irrigation. With respect to average irrigated area, there was no striking difference between groundwater alone situation versus canal +groundwater situation however, there was a difference of 13 per cent as compared with tank + groundwater situation. This slight difference was due to the fact that perennial orchards like coconut and arecanut occupied the major chunk in the cropping pattern in the case of groundwater and canal water regime while in the case of tank irrigated regime, the cropping pattern is diversified. Also, the slight difference in gross and net irrigated area in groundwater regime is due to scarcity of water, but in case of canal it is due to availability of canal water in particular period of time and absence of groundwater irrigation facility to that land. With respect to groundwater + tank regime, the difference is owing to availability of tank water for a particular period and availability of groundwater to the same land in other periods. The share of off-farm income constitutes around 20-25 per cent of the total income in three situations. The main source of off farm income is through tractor leasing.

Cropping pattern

The cropping pattern is mainly dominated by commercial perennial coconut plantation in groundwater régime and groundwater + canal regime. Where as in the case of tank irrigation more than 50 percent of the area is allocated to the short duration field crops. The assured surface water supply for one season through canal source enabled conjunctive use (groundwater + canal, groundwater + tank), which in turn facilitated to allocate more area under paddy in summer season. The crop diversity is comparatively better in the tank irrigated area compared to groundwater and canal irrigated situation. By and large the cropping pattern on the dry land occupied by the staple food crop ragi (*Elusina coracana*) in all the three regimes. Pulses are complementing the ragi in groundwater and canal irrigated situation, while maize and groundnut crops are prominent in groundwater + tank regimes. A large chunk of cropped area is under perennial orchards that include coconut and arecanut. These are cash crops in the area having a distinct comparative advantage over other crops because of specific natural endowments contributing for quality of the produce, good market infrastructure, relative management ease and cost effectiveness in production. These factors have been instrumental for specialization in coconut plantations (Table 4).

Frequency distribution of wells across different water regimes

Over 80 per cent of the farmers in the groundwater regime owned more than one borewell (Table 5). Out of this, 40 percent of them have more than 4 borewells. In both conjunctive use regimes nearly 72 per cent of the farmers possess only one borewell. Thus, the profile of distribution of wells across different water regimes clearly indicates that the well density is very high in the groundwater regime than in conjunctive use (Fig 7). In the groundwater regime, where there is no other source of surface irrigation there is a keen competition among the farmers for the exploitation of groundwater resource as evident by the number of wells owned by each farmer.

The study area is a typical hard-rock belt where the recharge rate is low not matching with abstraction rate leading to overdraft. In addition, well failure rate is quite high hence the sprawl of wells across all the directions in their attempt to get successful wells in the groundwater regime. The failure of wells in conjunctive use is uncommon as there is a hydrological synergy between surface water and groundwater leading to better recharge of groundwater that enabled consistent well yield over time. This corroborates with the study of Palanisami and Easter (1991) that positive relationship between tank storage and well yield exist in conjunctive use regimes. It is also in accordance with the study by Dhawan and Satyasai (1988) indicating that the volume of canal water that seeped through the canals to the ground water table in Punjab, formed about 50 per cent. The related recharge from rainfall to the total recharge, the component of canal seepage works out to 66 per cent.

Working and failed wells in different water regimes

Of the total borewells in the groundwater regime, only 46 per cent of the bore wells were productive yielding water. Dug-wells are completely un-fructuous and only 14 percent of the dug-cum-borewells were working. On the contrary, all the borewells and dug-cum borewells are productive in the conjunctive use. Even more than 60 per cent of the dug-wells are functional. This clearly reflects the positive externality in terms of increased groundwater recharge in the conjunctive use. The well density per unit area was 0.5 in groundwater regime, which is very high as compared to conjunctive use regime of 0.2. Higher number of bore wells per unit area in groundwater regime indicates high well failure rates and consequently more investments on borewells (Table 6).

Well density

Well density is one of the indicators to measure the sustainability. In over exploited area, there was overcrowding of wells without regard to isolation distance between well to well. As a result, the surrounding shallow depth wells productivity decreased sharply and gradually dried up leading to colossal loss of investments. In the area the well density is very high reflecting the un-sustainability of the groundwater resource. Though the well density in terms of increased number of wells indicates wider access, the resource needed to own a well and pump are constrained the physical access to groundwater for small and marginal farmers considering high capital cost (Table 6).

Average depth and life of the irrigation wells in different water regime

The pattern of groundwater development has been marked by three distinct phases in the sole groundwater irrigated regime. The 1st phase stretched from 1965 to 1985 characterized by the traditional dug-wells with a depth of 25’ to 40’ with a productive life span of around 11 years (Table 7). The extraction mechanism was by centrifugal pumpsets. The second phase was marked by dug-cum-borewells with a depth ranging between 90-150 ft depth. After 1990s groundwater situation began to deteriorate due to rapid spread of deeper bore-wells and decline in the community management of tanks. Further, due to degradation of irrigation tanks in the area, most of the dug-wells and dug-cum- borewells dried up. With the gradual failure of dug-wells and dug-cum-borewells, deeper borewells triggered and spearheaded in the third phase. The rapid strides in borewell technology both for exploration and extraction enabled farmers to go for deeper borewells. The average well life has gradually dwarfed to 3 years from 15 years; as a result, farmers are frantically investing on additional deep borewells and chasing the limited groundwater with a huge cost. Further, the inter well spacing between wells is completely ignored causing cumulative well interference problems leading to well failure. The government policy intervention of subsidized electricity on flat rate basis also contributed to the over development of groundwater. Thus, the explosive groundwater development led to overexploitation of the groundwater tilting towards unsustainable development reflecting scarcity of groundwater. The story is entirely different in the case of conjunctive use regime. The earlier failed dug-wells are currently working. The borewells are functional yielding adequate water. The average life of wells is longer. Investment on additional wells is not apparent. The longer life period of dug wells and working condition of dug-cum borewells and continuous working condition of the borewells in conjunctive use regimes has supported the studies of Palanisami and Easter (1991) and Dhawan and Satyasai (1998).

Investment details of irrigation wells in different water use regime

As evident from the table 8 the magnitude of investments on wells and well improvements escalated over time in case of groundwater regime than in conjunctive use regime (Fig 8). This is mainly because of secular lowering of water table in the area. In order to capture the fugitive resource competitive deepening and drilling of additional bore wells has led to increased investments as well as operating expenditure. In spite of huge investments on drilling wells, farmers have been experiencing scarcity of groundwater. This clearly reflects the physical limits to the resource since groundwater is a depletable resource in the hard-rock area. In the process of competitive race for groundwater development, the poor farmers access to groundwater both physical and economic is restricted in view of heavy lumpy investments. The average productive age of the bore well shrunk from 7 to 3 years. As a result, farmers continue to invest on supply augmenting mechanisms in order to restore the irrigated farming. Thus, the perennial overhead nature of the investments has been virtually turned into short run investments. In the neo-classical economic sense, the overheads are bye gone, still because of the shorter life span of wells one need to consider these overheads in estimating irrigation cost. Thus the hypothesis 'the overexploitation of groundwater has increased the scale of investments' was supported by the results.

Implicit cost of Energy in lifting groundwater

Proper pricing of any resource is quintessential in order to ensure the most efficient use of the resource. In case of groundwater irrigation, marginal cost of pumping is zero not reflecting the real extraction cost. As a result, there is a tendency to operate the substandard pumps where efficiency is low, leading to colossal waste of energy. In addition, there is a tendency to operate pumps of the wells yielding less than 800 GPH since electricity charge is virtually free, even though these wells are considered to be failed according to NABARD. As clear from the **Fig** 9, the distortion between what farmers presently pays for electricity charges for lifting groundwater and the implicit cost borne by the society because of electricity subsidy is widening causing a concern (Table 9). As, a result, the electricity boards are running under loss and not in a position to supply adequate and quality power to the agriculture sector. It is without doubt that the electricity pricing on a pro-rata is a major problem considering the logistical difficulties however under pricing of electricity has become political economic issue too. The hypothesis stating that the implicit cost has increased due to the overexploitation of groundwater is tenable.

Groundwater irrigation cost

The pricing of groundwater to reflect its scarcity value of water is of considerable policy interest in order to promote efficient use of water and sustainability of the resource. With respect to groundwater, the cost is based on access and delivery. The cost of groundwater extraction comprised the amortized cost of lumpy capital investment on the well and the variable extraction cost. In Karnataka, for well irrigation the electricity is highly subsidized. However, a flat tariff of Rs. 300 per HP per year has been levied since April 1997. Thus, the variable extraction cost is only the repairs and maintenance cost. In groundwater alone regime, the amortized annual groundwater irrigation cost per well is twice that of conjunctive use wells. There has been upward trend in the annual maintenance and repairs cost. The electricity charges due to change in the pump capacity is also on higher side. As against this, in the case of conjunctive use regime, the annual cost of groundwater irrigation and the cost per acre-inch of water has been dampened due to positive interaction effects of recharge (Fig 10). The irrigation cost in case of groundwater regime is one of the costliest inputs compared to surface irrigation among an array of other inputs involved in the production. Yet, groundwater irrigation is profitable in coconut production as the return per unit of water is Rs.590.3 (table 10) after internalizing all the costs in the production. Thus, the physical scarcity in terms of decreased water yield from the wells and economic scarcity in terms of increased irrigation cost per acre-inch are evident in the case of groundwater regime.

Economics of different crops across different regimes:

a. Cost of Paddy cultivation

There has not been much difference in the inputs cost excluding irrigation cost across groundwater and conjunctive use regimes. However, there has been remarkable difference in the irrigation cost with respect to groundwater regime accounting 71 percent of the total cost. The yield of paddy was highest in conjunctive regime with the use of tank water (25 quintals) since water was not a constraint. The net income received was negative (Rs.-4753) in groundwater regime and it was Rs.5953.78 and Rs.4256.51 in groundwater + canal water and groundwater + tank water regime, respectively. The higher benefit cost ratio of 2.12 in ground water + canal regime implied higher profitability of paddy production in conjunctive use regime where surface water is supplemented with ground water. The negative income and low benefit cost ratio in ground water regime implied loss in paddy cultivation where the cost of irrigation was high (Rs.10818.12 per acre) for paddy crop. The results show that the cultivation of paddy in conjunctive use regime is profitable (Table 11).

b. Coconut plantation

Farmers in the study area are suffering heavy loss in coconut cultivation due to unscrupulous development of groundwater leading to water scarcity for irrigating the gardens coupled with mites menace. As a result, there has been steep fall in the net returns from the plantations. The net income received per acre by the farmers in groundwater regime was less (Rs.5313.84) than other two regimes where surface water is supplemented with groundwater (Table 12). The low benefit–cost ratio of 1.89 in this regime than that of conjunctive use regimes revealed the fact that the economics of coconut plantation is profitable in the conjunctive use regimes.

c. Mixed plantation

Establishment of arecanut crop in coconut plantations in groundwater area is a recent trend observed in the study area. Where as the coconut-areca mixed cropping is quite common feature in conjunctive use regime. Input cost in all the three regimes are similar and it is to a tune of Rs. 4600 to 4900 per acre (Table 13). The major item of cost difference exists with respect to very crucial and vital input 'water'. The per acre irrigation cost is high in groundwater regime (accounts to about 54.14% of the total cost) than in conjunctive use. The B : C ratio is the indicator of returns per rupee invested, which is high in conjunctive use pattern rather than in overdraft region. This fall in returns in overdraft region is attributed to two important reasons. Firstly, the average expenditure on irrigation in case of groundwater is high that swells the cost of cultivation (which takes away sizeable portion in the gross returns) while all other costs remains same in comparison to conjunctive use. The second reason is water scarcity for irrigating the garden coupled with mites menace found in recent times. Since these plantations are new and susceptible to the pests, there has been a considerable yield variability and yield loss. The cost benefit analysis clearly indicates that the economic performance of the coconut-areca cultivation is more feasible in conjunctive use pattern than in over-exploited area.

Implications of groundwater depletion

Some of the physical indicators reflecting the scarcity of groundwater associated with unscrupulous groundwater development (Table 15) include; increased depth of water table (from 80’ to 496’) (Fig 11), decreasing groundwater discharge (from 3500 to just 800 gallons/hr) over time, increased irrigation pump capacity (5 to 7.5 HP), gradual well failures, depth of placement of pump from the top are increasing over the year indicating the decrease in water table due to over exploitation of groundwater (Table 14). Thus, the physical sustainability of the groundwater over the years was decreasing in the overexploited area. This supports the hypothesis that as the degree of overexploitation increases, physical sustainability decreases. The gradual failure of wells and initial failure of wells in the region indicates the increased investment on additional wells over time. The increased investment on drilling (Fig 12) and over head cost, higher deepening cost of the failed borewells, investment on additional wells due to failure of previous wells, increased expenditure on pump repairs, increased cost of pump replacement are the indicators of economic scarcity of ground water. The steep increase in implicit and explicit cost of deeper well irrigation severely affect the fresh water supply to villages and many surface water bodies gradually dried up affecting the surrounding ecology. If the same trend continues in the groundwater development in the overexploited area it may lead to irreversibility in future. This is indicative of the extent of damage to the irrigated agriculture in particular and regional food security in general. The existence of these physical and economic scarcity of ground water in the study area are in accordance with the study by Arun (1994), that farmers responded to well failure by drilling additional wells. Nagaraj (1994) in his study found that farmers invested Rs.23,000 on additional wells to combat the well failure. Shyamasunder (1997) found that the deepening of additional well as one of the coping mechanism to combat with well failure. Ramaswamy *et.al.* (1999) pointed out the consequences of the excess ground water extraction, increasing pumping hours, increasing in draft power of electric motors, failure of new wells, decrease in life of wells, yield variability and change in the quality of water.

In the early stage of groundwater development large farmers had captured as much as the resource they can due to their higher economic accessibility. This is a serious equity issue, which left the small and marginal farmers in lurch in the race of reaping the benefits of irrigated agriculture. The imbalance in access due to excess of draft by the large farmers caused depletion in the stock, which led to irreversible damage in hard rock areas. This has resulted in reduced access even to the potential farmers. In the process of groundwater development due to heavy investments on wells physical and economic access to the small and marginal farmers has been restricted. The implications from this study are that at first this mismatch across the farmer groups regarding economic and physical access generates social inequity. Secondly a serious and potential threat to the resource conservation and thirdly leads to the environmental hazards like deterioration in water quality consequently affecting the flora and fauna. Currently in over exploited area getting water in the open wells is like finding an oasis in the desert. The euphoria of unabated borewell drilling activity is creating both intra and inter-generational inequity.

Negative externality cost

The additional investments on deepening, drilling deeper wells subsequent to failure of existing wells, investments on coping mechanisms reflects the forced investments of well owners in order to stay with the original use of water level. This forced investment inflicted by the action of all the well owners in a given aquifer represents the negative externality costs. It is a case of reciprocal externality, where each one is imposing a cost on the other in the process of deepening / drilling deeper wells. The well owner whose extraction of water causes draw down of water table in nearby wells bear only private cost of additional withdrawal. Part of the additional pumping is inflicted on his neighbor whose condition of pumping is adversely affected. Under these circumstances, the additional cost of pumping by the individual user is less than the social additional cost. In response to groundwater depletion and associated scarcity of groundwater farmers have taken up host of coping mechanisms thus the cost of coping mechanisms represents yet another dimension of negative externality. Thus, there is a divergence between private cost and the social cost in groundwater overexploitation suffering the society in the long run.

Food security:

Status of paddy production before and after scarcity period

Paddy, which is a water intensive crop exhibited interesting trends in its area and production status during the previous to scarcity and after scarcity period in the groundwater irrigation regime. It is quite evident that the number of farmers cultivating paddy dropped drastically, about 70 to 80 per cent during kharif and rabi and about 30 per cent during summer. These percentages by themselves are misleading, as one would expect more drop out during summer than in kharif as water predicament is heightened during the summer. It is therefore essential to report the actual number of respondents who cultivated paddy during the two periods. From the table 15 it is marked that out of 19 farmers who produced paddy during previous to scarcity period only five are cultivating now again this may or may not include farmers from the first period and also there can be some new entry as well. These are only indicative of present situation of number of farmers cultivating paddy against their number in some reference year. Similarly, the area and production details are to be examined carefully before coming to any comprehensive inference. The average area under the crop has come down from 1.38 acres earlier to 1995 while it was 0.5 acres during acute water shortage period during kharif. What is more appealing from the table is that there is decline in number of farmers growing paddy, area under and ultimately production. These are more relevant from the policy angle that the secular decline in the water yield has resulted in change in cropping pattern in the initial phase and finally leading to food insecurity at various levels. From the table 16 it can be known that the CGR of area under food crops has shown deceleration where as a remarkable growth in area under non-food crops was recorded at both the taluk and district level. This shows that the demand for groundwater is exacerbating causing further strain on this fragile resource. In the study area farmers are not in a position to maintain irrigation to the existing gardens due to which there has been phenomenal loss of net returns. This reiterates the fact that the micro-level indications of food insecurity are reflected even at the macro level. This calls for serious concern to check further deterioration of the situation. Thus, both food security and commercial security has been affected. Recently, the price crash for coconut and arecanut put the farmers in disarray whether to retain the gardens or replace them.

Irrigation efficiency across different regimes

The net income obtained per acre of gross irrigated area after accounting most of the explicit and irrigation cost was found to be highest in case groundwater + tank regime farmers (Rs. 16090.40), while the farmers in the groundwater regime realized lowest net income of Rs 8029.56 per acre of gross irrigated (Fig 13). The highest net income in the groundwater + tank regime was due to more gross cropped area and availability of the tank water to grow paddy crop in summer and in the same land they use to grow the other commercial crops like maize, groundnut red gram using groundwater through borewells (table 17). In case of groundwater regime farmers are not able to grow other commercial crops except maintaining coconut gardens due to shortage of water. Since the irrigation cost per acre was highest, the income from the gross irrigated area was reduced to a greater extent. The income received per acre-inch of water by farmers in the different categories of the farmers also followed the same order as the net income obtained. The income received per acre-inch of water used in groundwater + tank regime (Rs.700.80) was highest followed by groundwater + canal (Rs.577.89)and groundwater regime (Rs.495.96) (Fig 14). The above result supported by other studies stated that higher income could be obtained by conjunctive use of water and there will be recharge of wells and less failure of wells in conjunctive use regimes (Palanisami and Easter (1991), Dhawan and Satyasai (1988), Palanisami and Balasubramanian (1998).

Water use efficiency of different crops

Irrigation efficiency is a subjective measure of water used and transformed into produce; it includes both agronomic and economic efficiency. Groundwater being a scarce resource and abstracted nearly 70 portion of it for agriculture production it has to be judiciously used for attaining maximum benefits. The prominent crops in the irrigated region of the study area are coconut and paddy. Growing paddy is not desirable in areas where groundwater overdraft is a serious problem since paddy demands more water than other crops. However, water use efficiency of paddy in terms of the output per acre-inch of water used in groundwater regime (0.5 qtl) indicated that the farmers in the groundwater regime produced more of paddy per unit of water than that of groundwater + canal (0.35 qtl) and groundwater + tank regime (0.43qtl). Due to scarcity of groundwater, farmers were scrupulous in managing and using the water. The higher output per acre-inch of water in groundwater regime reflected higher water use efficiency. This is mainly due to scarcity of groundwater that motivated the farmers to use the water more efficiently. Thus, the hypothesis of groundwater scarcity induced efficiency is justifiable.

In case of the coconut plantation, the output per acre was 42 quintals per acre with groundwater regime, which is lesser than groundwater + canal regime (48 qtls) and higher than groundwater + tank regime and the water used per quintal of output follow the same order (Table 18). The decline in yield per unit of water from coconut plantation in groundwater regime can be attributed to two reasons. Firstly, mites attack which is very prominent in the area and secondly due to shortage of water.

In case of mixed plantation of coconut and arecanut the higher yield of coconut per acre-inch of water was observed in case of groundwater + canal regime (0.22 qtl) and that of arecanut in groundwater regime (0.11 qtl). Thus, in case of groundwater regime where the water is a scarce resource for the production of crops the farmers used it judiciously. It was observed that the farmers in this area have often face the problem of water shortage to irrigate their coconut plantation and resorting only protective irrigations to save the crop. Notwithstanding the scarcity problem of water, in terms of agronomic efficiency, groundwater regime is better than conjunctive use regime. It has been reported that irrigation efficiency of the canal irrigation system as whole is considered to be 30-40 per cent while in case of groundwater it is around 50 –65 percent (Veeman, 1978).

Economic efficiency of water

In all the regimes, the net income per acre obtained by cultivating paddy, coconut and mixed plantation (coconut & arecanut) were highest in conjunctive water use regimes. The net income of paddy and coconut were highest in groundwater + canal regime (Rs 6003.78 & Rs 12190.04 respectively). The higher net income per acre of mixed plantation was observed in groundwater + tank regime. The lesser net returns in case of groundwater alone regime used for all the crops was due to the higher irrigation cost that the farmer has to incur in the production. Thus, the higher irrigation cost in the groundwater regime contributed to lower net returns.

Marginal value product of water

The marginal value product of water for paddy was highest in groundwater + tank regime (Rs 197.97 per acre- inch per acre) and was least in case of groundwater + canal regime (Rs.161.90). In case of coconut, the marginal value product of water was high in groundwater alone use regime followed by groundwater + canal and groundwater + tank regime (Table 19). The higher marginal value product for coconut in the groundwater regime indicated that the water use efficiency in this regime was higher. The economic efficiency in terms of value marginal product of water is equal to marginal factor cost indicates that the VMP is greater than irrigation cost in all the cases reflecting that the farmers are using water efficiently.

As long as the marginal extraction cost is less than the marginal benefit from each unit of water, the users continue to extract more and more water from the aquifers causing overdraft. When marginal cost of water exceeds the marginal benefits, then the users would cut profligate use of water and adopt conservation measures. Thus, marginal pricing of water is vital not only to promote efficiency in use but also in conservation. Considering the sizeable investments on wells, the positive MVP is justified. Based on the MVP of water, at least introduction of electricity pricing for pumping groundwater would promote more investments on efficient irrigation technologies and conservation.

Equity issue in groundwater regime - wells owned and area operated by different size groups

The fact that over 80 per cent of the wells were owned by the medium and large farmers itself implies the extent of inequity persisting in groundwater development and use. It is very interesting to note that about 88 per cent of the irrigated area in the groundwater regime were operated by medium and large farmers. The remaining 12 per cent was operated by the small farmers (table 20) (Fig 15). This skewed distribution of wells and lopsided irrigated area in the regime revealed the fact that only the resource rich farmers can have access to the groundwater in the areas where the groundwater is scarce (Fig 16). Groundwater development especially in the overexploited areas has distinct equity implications. Small and marginal farmers find it extremely difficult to make risky investments in well irrigation without financial assistance from the commercial banks. Since, lending is completely closed in overexploited area small farmers cannot dream to have access to groundwater. Thus, the results obtained in the study approve the hypothesis that the overexploitation of groundwater has differential impacts across different categories of the farmers in terms of well failures and investments. The results further strengthened with the findings of Joshi and Tyagi (1991) who reported that continuous decline in water table, small and less resource endowed farmers would be deprived of the groundwater. The large and better-endowed farmers would be in a position to install deep tube well and dictate the terms for irrigation water to small farmers. Equity is one of the basic concepts of sustainable development (Cai et.al., 2001). There are two dimensions in the equity. The first one pertains to temporal equity and the second one relates to spatial. Temporal equity emanated mainly because of resource depletion over time, which constrained the resource poor to compete with large farmers to chase the water from the deep borewells involving huge lumpy investments. The spatial equity is mainly in terms of lack of physical access to the resource by the poor in the hard rock areas where groundwater mining is a problem. Thus, in over-exploited area, temporal and spatial inequity is persisting.

Cost of irrigation across different categories of the farmers in groundwater regime

The results revealed that the cost of groundwater irrigation per acre per year decreased with increase in land holdings. The groundwater irrigation cost was highest for small farmers (Rs.5531.11), which was more than double the irrigation cost for large farmers (Rs. 3403.76). This inequality in cost of groundwater irrigation across different categories of the farmers was mainly due to the lower irrigable area with higher investment. Small farmer has to incur the same amount of investment on borewell as that of a large farmer but a large farmer can irrigate more area by virtue of his large size of holding and enjoy the fruits of scale economies. The fact that the small farmer incurred irrigation cost of Rs. 259.95 per acre-inch as against Rs 240.93 in case of large farmers (Table 21) proves that there is a dis-economy in water use by virtue of their smallholdings (Fig 17). Small farmers use groundwater more intensively while large farmers use more extensively spreading less water on more area because of their large size holdings.

Equity in income distribution and water extraction across different categories of the farmers

The distribution of income and extraction of water from the aquifer across water use regimes gives the indication of equity in the region. In order to assess the equity, most often used measure is Gini ratio. A value approaching to one indicates inequity while a value closer to zero designates fairness in distribution. From the table 22 it is apparent that the incomes of the small farmers are more skewed than that of large and medium farmers (Fig 18), where as the imbalance in water extraction is not apparent.

Equity in income distribution and water extraction across different water use regimes

The inequity in income distribution was more in groundwater regime than in the conjunctive use regime (Fig 19). This implies that income inequalities are relatively higher in groundwater regime than in the conjunctive use pattern(Table 23). This may be due to the frequent well failure and loss in yield due to stress caused by inadequate irrigation. The inequality in income distribution in groundwater regime can also be attributed to the inequity in water extraction in the regime (Fig 20).

Conjunctive use - returns to supplementary irrigation

Under conjunctive use in case of canal irrigation, water is available only after Jan 15th for summer season. Water is let 5 days in a week with a gap of 2 days. Normally farmers irrigate once in two days. Nevertheless, the tail end region is prone to shortage of water quite often. In case of tank, depending on the availability of water in the tank, farmer’s take a decision whether to grow paddy or not. In this case also the tail end farmers face the predicament of water shortage frequently. Thus, well irrigation is vital in the tail end area.

Wherever feasible, conjunctive use of both surface and groundwater ensures not only better utilization of the resource but also promotes sustainable use of water resources. By and large, in case of canal and tank irrigation the cropping pattern is dominated by paddy. Even though there is access to surface irrigation but quite often there is uncertainty about the adequate amount of water at right time. At this juncture, supplemental groundwater irrigation is crucial for saving the crop. In canal-irrigated area, there is always delay in letting the water, hence most of the farmers raise paddy nursery by using groundwater so that they can transplant the paddy when the water is delivered. In both canal and tank irrigated area, on an average farmers provided 6-7 supplemental groundwater irrigations in the tail end area depending on the delay in the availability of surface water. Farmers without wells in the tail end area tend to under-irrigate resulting yield loss. The difference in the yield of paddy with supplemental irrigation and without supplemental irrigation was estimated. Accordingly, the return to supplemental irrigation is computed. By giving supplemental irrigation farmers have realized the full benefits. As compared to groundwater irrigation, farmers in the conjunctive use regime realized 23 per cent higher yields and earned around Rs. 2000 more income per acre of paddy. The return to supplemental irrigation is to the tune of Rs.218.17 in groundwater + canal regime and Rs.270.41 in groundwater +tank regime(table 24).

Impacts of conjunctive use of water

Though the surface irrigation is very expensive to the government, it is a welfare policy of the state to provide irrigation. Practically it may not possible to extend the canal irrigation to the groundwater-exploited areas, it certainly rejuvenates the groundwater status to the greater extent. The recharge of the groundwater occurs through seepage from canal as well as from the tanks. The groundwater recharge could be experienced both in terms of physical as well as economical. Increased well life, negligible well failure, increase in the water yield of the wells and higher crop diversity are some of the main physical impacts of the conjunctive use in the groundwater + canal and groundwater + tank areas. The economical impacts are in terms of negligible or even no investment on the coping mechanisms like drilling additional well, deepening of the well and adoption of the drip system. The farmers will have the advantage of lower irrigation cost and higher income from their irrigated lands (Table 25). Thus, the conjunctive use of surface and groundwater had a positive effect on sustainability of the groundwater promoting intra and intergeneration equity. The individuals investing on wells and undermining the traditional community management of tank system is apparent. Thus, there is a greater need for restoration of irrigation tanks for recharging wells. The results of the study supports the hypothesis on conjunctive use of water that conjunctive use of groundwater and surface water improves groundwater recharge, which in turn enhances the sustainability.

Cost of Coping Mechanisms

The farmers of the study area have been facing the predicament of extreme scarcity of groundwater for irrigating coconut gardens. In response to scarcity, farmers have resorted to different coping mechanisms to deal with the scarcity of water in order to sustain the yield of the crop. The host of coping mechanisms *inter alia* include investing on an additional well, improvement of the existing well (deepening or well inside the well), water transfer, adoption of resource cost saving technology, buying of water from others and so on.

Equity effects in the adoption of coping mechanisms

Most of the coping mechanisms meant to mitigate the groundwater scarcity entailed sizeable investments. The small and marginal farmers are constrained to adopt these measures due to their poor capital base. As a result, around 20 per cent of their gross income was lost. In the groundwater regime, scarcity of groundwater forced them to adopt some of the coping mechanisms. Some of the farmers devised their own indigenous drip system, which is cost effective. The farmers have been striving to give protective irrigation to the coconut plantation to alleviate the moisture stress so that there will not be drastic fall in the productivity. Most of the large farmers adopted the coping mechanisms on a large scale compared to small holders. All the large farmers in the area gone for additional well due to the failure of previous well. While around 50 per cent of the small and medium farmers could venture in drilling additional wells. This clearly indicates the inability of the small farmers to invest on capital-intensive coping mechanisms. Compared to small farmers, the transfer of water from the source (far off place) to the garden was adopted by all large farmers. Majority of the small farmers adopted the coping mechanisms like indigenous drip system and purchase of water from neighboring farmers due to their shallow resource base. Thus, the overall scenario with respect to adoption of coping mechanisms revealed that all farmers are actively involved in adopting coping strategies, however, small farmers adopted less capital intensive coping mechanisms while large farmers adopted capital intensive measures. The results supported from another study by Shyamsunder (1997) that farmers to cope with well failure go for change in cropping pattern in favour of less intensive crop, go for deepening of well and drill additional well.

Drilling an additional well being one of the capital-intensive coping mechanisms adopted by the large farmers. The field observation during the data collection confirms that most of the small farmers who had gone for additional well, mobilized capital from their kith and kin since institutional finance is not coming fourth. The adoption of different conservation practices by different categories of the farmers in the groundwater overexploited area supports the hypothesis that the overexploitation of groundwater has differential impact on different categories of the farmers in terms of the conservation measures. The results of the coping mechanisms adopted are in conformity with the study by Joshi and Tyagi (1991) who reported that continuous fall in the water table the small and less resource endowed farmers was deprived off the groundwater. Shyamsunder (1997) in his study reported that to cope with well failure farmers shifted cropping pattern in favour of less water intensive crops, deepened wells and drilled additional well.

Conservation vs. Depletion

The difference between conservation and depletion is that conservation does not mean nonuse or wise use, but it pertains to when of use of a resource. Hence, conservation is a deferred use while the depletion is the present use. The objective of conservation is not to achieve equality of opportunity but to compensate for the distortions due to unequal opportunity (Ciriacy-Wantrup, 1968). In hard-rock area where groundwater resource tenure is indefinite, it is the self-interest of every well owner to extract as much as water from the aquifer and put to use as fastest as possible to recover their capital outlay. The individuals are motivated to expand the rate of pumping from the existing wells or investing on well improvements/ additional wells. The end result is, increasing irrigation cost and negative externalities.

The negative externalities in well irrigation especially in the overexploited area is manifested in terms of increased investments on drilling deeper wells, colossal investment loss due to cumulative well failures, increased investments on coping mechanisms and so on. These externalities are inflicted on others as well as on their own. In this way farmer’s myopic investments on well irrigation resulted in depletion of the resource and generated reciprocal externalities. Realizing the gravity of the groundwater situation and risk involved in betting investments on wells, some of the farmers refrained from investing on wells instead invested on water saving devices like drip irrigation. On an average, the drip system requires an investment, which is half the investment of additional well. The associated benefits include about 44 per cent saving in water, additional improvement in yield to the tune of 20 per cent and highest water use efficiency. In case of drip with the existing bore-well with the existing yield of the well one can maintain the garden for a longer period while in case of additional well it is not possible. Using the drip irrigation system can prolong the life of the well. The economic measures of IRR, NPW and BCR amply indicated that the investment on drip is economically feasible. Though, in both the cases the investment is feasible, from the viewpoint of conservation of the resource for present and future development drip irrigation is most desirable. The results amply support the hypotheses formulated on the coping mechanism viz. i) the investments on coping mechanisms are economically viable, ii) drip irrigation as a viable alternative not only results in minimization of irrigation costs but also augments the output value and iii) drip irrigation is more viable than investment on additional well or deepening of well.

The results of this study is in conformity with the study by Anand (1994) indicating drip irrigation requires only 54% of total water required under flood irrigation and this increases water use efficiency by 2.5 times as compared to flood irrigation. Ramanathan (1994) reports that drip irrigation is a sustainable alternative in dark zones with indiscriminate groundwater mining in India indicating water saving of 30% to 50% compared to conventional irrigation. The study by Nagaraj (1996) indicated that by using drip irrigation for coconut around 40 per cent of the ground water could be saved.

Policies of Groundwater Regulations

The policies like subsidized power, subsidized minor irrigation (well) loans, land reform policy of excluding groundwater irrigation from land ceiling all promoted groundwater exploitation over time. According to the NABARD, the credit for well drilling increased by six folds, while there has been steep fall in the repayment of well loans. This is an indicative that farmers fail to repay the loans due to fall in the water table and subsequent failure of wells. Though NABARD has put spacing regulations for drilling wells but it is applicable only to the borrowers of loan from institutional finance for well drilling. But this rule is not tenable to the farmers who can contribute their own funds for well drilling. In addition to credit facility, provision of subsidized electricity also stimulated investments on wells. Thus, these policies enabled farmers to invest massive amount on well irrigation and large-scale conversion of dry land into irrigated land leading to lopsided extraction of groundwater in relation to recharge. This would be at the cost of inter temporal, inter spatial and inter-generational misallocation of groundwater. The difference in consumption of electricity in some of the states is depicted in figure 21. After shifting from prorate policy to flat rate charges during the year 1982, the power consumption of I-P sets is almost doubled. According to the Karnataka Power Transmission Corporation Limited, currently, agricultural pump sets consume over 35 percent of the total power generated in the state. But, in terms of the revenue received for power sold to I-P sets is very paltry and hence poor quality power supply. The subsidized power enabled farmers to venture more investments on well irrigation and thus depleting the resource affecting the sustainable use of groundwater. However, this policy helped small farmers to participate in the groundwater irrigation thus promoting equity. Thus, these policies failed to improve efficiency and sustainability in groundwater development and use. The policy options should aim at motivation of the farmers to pay electricity charges on pro-rate basis, adoption of efficiency measures such as shift to less water intensive crops and alternative irrigation technologies. This would increase the total benefits both to society and farmers.

GROUNDWATER QUALITY

Socio- economic indicators

Family size was relatively larger with more number of dependents in the affected farms compared to the normal condition. The productivity of family labor in agriculture was falling due to impairment of environment in the area on account of polluted surface and groundwater. Since, agricultural incomes were affected due to poor water quality, some of the farmers worked in the surrounding industries earning an income to the tune of Rs. 19,800 per annum. Education is one of the key factors, which brings about desirable changes in the farmers outlook towards modern input intensive agriculture. The literacy rate is fairly good in the affected farms in contrast to control. This facilitated better management of resources in the affected area for coping with the predicament of poor water quality. With respect to the age of the respondents, a majority of the farmers were middle aged to make sound decisions and take risks taking in decision-making relating to investments on the farm. The average land holding size in affected area was twice the holding size in normal condition. But the per capita arable land was the same in both the situations. The share of area in well command was higher in the normal area than the affected areas (Fig 22). The gross irrigated area was however uniform in both the areas.

The affected farmers realized a gross income of Rs. 10,425 from dryland horticulture, mainly from coconut and mango. Ragi was grown as an inter-crop in mango and coconut plantations. In 'control' gross income derived from dryland agriculture was almost half the share in the affected area, as these farmers allocated smaller area for ragi with coconut as intercrop. A majority of large farmers are concentrated in the affected area than in control area. In the affected area, land productivity is falling due to application of poor quality irrigation water for growing sugarcane and paddy. The negative impacts include water logging, salinity and hardening of soil further constraining cultivation of crops. Farmers expressed disinterest in agriculture in the affected area, a disturbing note.

Cropping pattern and cropping intensity

In the affected area, options to diversify crops are restricted by poor water quality. A decade ago farmers were cultivating a variety of crops in the affected area. Presently (2002), only paddy and sugarcane crops are cultivated on a large scale. Paddy varieties like Mangala, Rasi, IR-30864 and CO-62175 of sugarcane only thrived in poor quality water with high salt concentration (Table-2). Other crops could not thrive under well irrigation due to poor water quality. Due to high salt concentration (EC >1) in groundwater, upon frequent irrigation to vegetables; maize and oilseeds were wilting.

Thus, the cropping diversity virtually withered away in the affected area compared to the normal. In control, in addition to paddy and sugarcane vegetables are also being grown. Thus, crop diversity was higher in the control. Even though market access favored cultivation of vegetables in the area, farmers were forced to cultivate salt tolerant paddy and sugarcane crops. In spite of access to irrigation, the cropping intensity with poor quality water situation was lower (152%) than the normal situation (186%), due to the poor quality of groundwater in the area.

Details of sample well particulars in the affected area

The drinking water wells were totally abandoned in the area causing hardship for women who were fetching potable water. Another interesting observation is that the depth to water table in both the areas has been same over the years due to constant recharge of aquifers by poor water quality (Table 3 and **Fig** 23)). In the area well failures are also minimal. The groundwater recharge is good matching the rate of extraction with the recharge rate. Thus, the groundwater quantity is not the constraint but the quality degradation is the major issue. This has imposed externalities on the current and future generation, as poor groundwater quality takes a long time horizon to rectify. This has implications on intra and intergenerational equity.

Profile of well investments

At 2001 prices, of the total investment on dug-well, the cost of construction accounted for 75.5 per cent compared to the bore well (28.5%) because dug wells involve labour intensive earth excavation and stone riveting to prevent well caving in. Cost of digging and stone lining involves a sizeable investment. In case of borewell, due to increased investment on submersible pump set, cable wire, pipes and other accessories the cost of extraction was higher than the dugwell (Table 4 & 5). Cost on exploration was towards citing productive water points for drilling a well, which was around Rs. 500 irrespective of dugwell or borewell. Notwithstanding the pollution problem in the area, there has not been substantial difference with respect to well investments between normal and affected area as water table is within 100-150 ft.

Annual cost of irrigation

The annual cost of irrigation includes the amortized cost of well investment plus the operation and maintenance cost and the flat rate electricity charges based on the horsepower of the pump. Electricity charges are subsidized in the rural areas for pumping groundwater. Presently, farmers pay electricity charges at Rs. 300/hp/annum. Therefore, the marginal cost of groundwater extraction is zero. With respect to the annual cost of irrigation, there was uniformity due to constant recharge and approachable water table both in affected and normal area (Table 6). One of the critical factors that influence the cost of borewell irrigation is the depth of the borewell. In most parts of the Eastern Dry Zone, the water table has been falling resulting in increased drilling depths from 300 to 500 ft in the last decade. But, in the study area depth to water table has been uniform, ranging between 100 and 150 ft in 'affected' and 'normal' area. This is due to the Vrishabavathi flowing sewage water polluting the aquifer (Pic-1). Hence, there was no appreciable difference in the irrigation cost between affected and normal. The use of polluted water however, imposed additional maintenance cost on pumset due to corrosion (Pic- 2**).** This problem was not evident in control. In the groundwater scarcity areas of Eastern Dry Zone, the irrigation cost is around Rs. 107 per acre-inch (Chandrakanth and Adya 1998). Thus, even though, the cost of groundwater here matches, the externality due to poor quality manifests both in terms of cost of prevention of quick corrosion and ameliorating of degraded land.

Cost of production of paddy and sugarcane

The cost of production of both paddy (Rs. 9181) and sugarcane (Rs. 19064) were high in case of good quality water compared with poor quality (Table 7,8 and **fig** 24). This is because the quantity of inputs used was low under poor quality water, which reduced the cost of production. However, the use of human and animal labour was high due to extra ploughing and weeding in the affected area. With continuous irrigation of polluted water, hardening of the soil due to accumulation of salts and heavy metals was common. This required extra ploughing in land preparation. Further, high concentration of nitrate and salt content in the polluted water promoted exuberant weed growth and macrophytes. This increased the quantity of human labour for effective weeding. Similar results were reported by Agrawal, (1999). Thus, the hypothesis that the cost of production is higher in poor quality water is not rejected. However, the cost of production plus cost of extrnalities was larger in poor quality area than the normal quality area.

Without adequate land preparation and effective timely weeding, farmers would loose the returns substantially. Even to realize a threshold yield in the affected area extra expenditure of Rs.1600 was required due to presence of negative externality. Considering all the variable costs, the output value is not adequate to get any positive surplus value in the case of affected area. On an average, farmers incurred a loss of Rs.1009 per every quintal of paddy produced under poor quality water whereas under normal conditions farmers realized a net return of Rs. 34.5. This shows that both under normal and affected area paddy production were not economical under groundwater irrigation. Nevertheless, farmers are growing paddy under normal conditions for food security whereas in the case of affected area there was no other option except growing paddy, as it is tolerant to salts. The rationality of continuing to grow paddy despite the negative net returns is that there is a break-even after excluding the implicit cost of owned inputs. In addition, farmers derived off farm income to the tune of Rs.19, 800. This serves as a buffer to continue in the production. The productivity of paddy was also low in the control area because of two prominent reasons. Firstly, the soils are sandy loams hence percolation loss was high not able to maintain required amount of water.

Secondly, farmers were not able to maintain the minimum water requirement on the paddy plots due to vagaries of electricity to pump groundwater. In the case of sugarcane too, the farmers incurred a loss of is Rs. 429 for every tonne of sugarcane produced as against a net surplus of Rs. 223 per every tonne under normal conditions. Thus, the net returns were negative for both sugarcane and paddy in the affected area .The magnitude of loss was high in paddy compared to sugarcane. Thus, cumulative loss with respect to paddy and sugarcane per acre amounts to Rs. 17,000 is attributed to the transaction cost of water contamination, the negative externality on the producers by the urban sewage.

Impacts of poor quality water on crop productivity

One of the important on-farm effects of poor quality groundwater irrigation was declining yield of crops. The productivity of both paddy and sugarcane have declined in the area .The yield of paddy declined by 62 per cent and the sugarcane yield declined by 47 per cent in the affected farms compared to normal farms. This is indicated by the macro level time series data at the Hobli level on crop productivity. Some of the farmers in the affected area grew crops like banana and mulberry, the yield of these crops also declined (Table 9 and **Fig** 25). The field irrigated with polluted water is loaded with heavy metals like ferrous and manganese causing hardening of the soil. Due to chemical degradation of soils, the crop choice was restricted with poor quality water. If polluted water is irrigated to grow vegetables, oil seeds, maize and pulses the symptoms of wilting and finally crop loss were apparent, as these crops are sensitive to salts (Pic- 3 & 4). These problems occurred because the well water in the affected area has EC>1ds/mt and pH>8.5 indicating high salt concentration. Studies by siddramappa and Nair (1997), Andani Gowda *et al* (2000) and Department of Mines and Geology (1994) have reported the above said water quality parameters in the sample area.

Impact of water quality on paddy and sugarcane productivity

Low paddy yield of 6.2 qtls/acre are realized resulting in negative net returns after accounting all the explicit and some of the implicit costs. The poor performance of crop production was due to poor quality water, which in turn created external effects on the soil properties. The water as well as soils contained higher EC and pH with heavy metal loading. The high organic content in the soil led to profuse vegetative growth associated with poor yields in paddy. The results obtained by Datta and Dayal (2000) are similar to these findings. Paddy straw was not palatable as it was discolored. No income was derived from the straw, as it was burnt (Table 10 & 11). In sugarcane, negative returns were relatively low as compared to paddy. Further, the sugar recovery was poor because of excess nitrogen content in the water that led to the rich vegetative growth. Kirkhan (1986) also observed a similar phenomenon. The cumulative loss from both paddy and sugarcane on a regional scale was sizable.

Impact on product image

The farm produce produced using 'poor' quality water commanded a low profile consequently fetching low price. The product image as perceived by the respondents is summarized in the Table 12. The price of paddy was 20 percent lower than the price of paddy in the normal area. The quality of the paddy produced using poor quality water was reflected in poor milling ratio. The conversion ratio of paddy to rice when milled was 35 per cent of paddy as against 65 per cent in 'normal'. The proportion of broken rice was more in affected farms than 'normal'. Further, the quality of the straw was unfit for livestock consumption and hence there was no value for this byproduct (Pic- 5). It was observed that upon feeding the poor quality straw animals fell sick. This indirectly affected the performance of livestock due to shortage of fodder.

The sugar factories in the proximity did not readily accept the produce due to low sucrose content of four per cent, (4 %), leading to low sugar recovery. Added to this, high nitrogen content in the water as well as in the soil induced more vegetative growth resulting in low sugar recovery. Kirkhan (1986) reported similar results. The sugarcane tops, which usually serve as an excellent source of cattle feed, were not fed to the cattle due to their ill effects on the health of the animals.

The mulberry grown using polluted water when fed to silk worms resulted in dull colored silk cocoons. The filament strength was weak with poor reelability. The cocoons were seldom preferred in the local market and fetched relatively low price of Rs. 55/kg as compared to the normal (110/kg).

The performance of livestock in the villages was dismal, due to shortage of quality fodder. Improved milch animals were not preferred in the affected area owing to risk involved in maintaining them in view of polluted water and shortage of quality fodder. The effects of 'poor' quality water on milk from the local cows are bad odour and quick spilt. As cows were fed with green fodder grown with polluted water, these problems accentuated. In addition, cows drank the polluted well water. Thus, both crop productivity and livestock productivity were affected. The demand for the tender coconuts was severely affected due to sour taste not relished by the consumers.

Impact on Human and Animal Health

The polluted water disturbed the production potential of the crops and caused deleterious effects on human health. The ill effect on the human health is provided in the Table 13. Human health effects were *inter alia* allergic dermatitis, skin rashes, skin irritation and gastrointestinal problems. Farmers directly exposed to polluted water while working on these farms got affected. Skin irritation was the most common suffering when farmers working in the field during the cultivation practices, followed by gastrointestinal problems. The additional expenditure on health care per annum increased steeply for affected farmers. The bullocks, cows and buffaloes faced the problem of dehydration, skin irritation and edema. This is due to three important reasons; 1) drinking polluted water as there was no clean water supply for the livestock

2) washing with the same water and 3) continuous exposure to the polluted water during work in the field. Dehydration in cattle due to the feeding green fodder grown with polluted water. Thus, the transaction cost on animal and human health increased sharply (Table 13). The transaction cost is due to groundwater contamination. In future the economic consequences will be severe and may lead to migration and liquidation of their assets.

Impact on labor employment

Ill effects of 'poor' quality water on human health were the major cause for the loss in labour employment. On an average, a farm worker lost 40 mandays of employment due to sickness. Thus the loss in wage earnings was Rs. 2000 and the additional expenditure on health care was Rs. 327 per farm worker. There was no wage rate difference for agricultural labours between normal and affected area. This is contrary to the hypothesis that labourers demand higher wage in polluted area than in the normal (Table 14).

Impact on ecology and environment

Ecosystem is a crucial environmental resource supporting human needs. In the polluted area, there was ecological disruption due to irrigation with polluted water (Table 15), indicates several ecological and environmental effects arisen due to use of poor quality water. Soil structure and water holding capacity were affected resulting in waterlogged condition (Pic- 6). Soil hardening on account of heavy metal loading has become an environmental problem. These effects on soil have reduced the crop productivity. Siddaramappa Nair (1998) identified heavy metal in the well water in the Vrishabavathi basin. Here heavy metals like copper, zinc, lead, nickel, cadmium and chromium were identified in the water from sample wells. In addition, farmers reported that over the years bird population has completely reduced, especially the crane population.

Similarly, the fish population in the wells was affected because of high Biological Oxygen Demand (BOD) by the polluted water. The aquatic ecology were affected due to reduction in crab and frog population in the wetlands. The alarming spread of weeds especially *basophylls* in all the cultivated plots was discernible (Pic- 7). Another effect was land degradation due to which land value declined drastically by 52 per cent. Reduction in the market value of land has severe equity implication for small and marginal farmers.

Estimation of transaction cost in fetching potable water

Transaction cost is the difference between the marginal social cost and the marginal private cost. The transaction cost comprises the number of women days lost while procuring potable water from far off wells due to water quality deterioration in the area (Pic- 8 &9). The transaction cost was high in 'poor' quality water area, because farmwomen have to walk one to one and half km to fetch clean water and the extra time spent was two hours per day. The estimated number of women-days in fetching potable water per year was 91 days valued Rs. 2533 at the current wage rate for farmwomen. In 'moderate' quality water situation, the time spent to fetch potable water was one and half per day, equivalent to 59.25 women-days in a year valued at Rs. 1777.5 (Fig 26). The transaction cost varied with the distance of location of clean wells. If clean water were available, farmers would have saved this cost. This loss in earnings due to their extra time devoted towards drawing clean water from far off wells is considered to be the transaction cost.

Estimating overall economic losses due to poor quality water

The economic loss due to poor quality water (Table 17) includes loss in value of paddy and sugarcane. The gross income was inadequate and did not even cover the variable cost. Hence, farmers realized negative net returns in paddy and sugarcane. In addition, there was loss of wage income to the tune of Rs. 2327due to employment lost on account of poor health. The health expenditure was more than their wage Income. Reduction in land value was another type of transaction cost. The fall in the land value was 60 per cent of the normal. There was 34 per cent loss in cropping intensity because, gross cropped area was reducing.

Efficiency of paddy and sugarcane production

One of the physical indicators to measure the efficiency of water use is the quantity of output per unit volume of water. Paddy used about 65 acre inches of water and yielded meager 9 Kgs per acre compared with normal where 64 kgs per acre inch of water have realized. In the case of both paddy and sugarcane, water use was higher in 'poor' when compared to 'moderate' and 'good' quality water. Output per acre-inch of water was also low, as farmers could not be efficient in the production of paddy and sugarcane (Table 18).

Gross income function for paddy and sugarcane

Income function was estimated to capture the influence of productivity, quantity and quality of water used on gross income. The model reveals that productivity, quantity and quality of water used significantly influence the gross income derived from paddy. While excess water used than the recommended quantity is responsible for reducing gross income in normal situation, where as both quantity and quality of water has influenced in reducing gross income in paddy crop in affected area. This argument gets its strength from the fact that the dummy variable used to indicate the quality of water is significant and negative. In case of sugarcane, the regression coefficient for water used was not statistically significant. On the other hand, the quality of water represented as dummy variable had significant and negative coefficient reflecting that the quality of water is crucial in improving gross income (Table 19 and 20).

Percentage of area affected across size class in the study area

Equity refers to equality, fairness and even-handed dealing. Equity in the context of groundwater pollution should address the issue such as who suffered the most; small, marginal and large farmers, landless laborers, women, and the public. How they suffered-include; loss in productivity, income, employment, wage income, increased expenditure on health and drinking water. About 65 per cent of the land was degraded due to application of poor quality of groundwater. The physical severity of the pollution effect was the same across all the farmers. This affected the small and marginal farmers more than large farmers, as their resource base is shallow (table 21).

Net returns and net benefit cost ratio of paddy and sugarcane

Net return per acre of paddy and sugarcane is calculated to examine the equity issues across different classes of farmers. As evident from the table 22 the net returns realized per acre of paddy was negative across different size groups. On an average, the marginal farmers realized a net return of Rs. 4,092 while small and large farmers realized Rs 4,800,and Rs. 5,000 respectively. Thus the loss in net returns per acre of paddy was marginally higher in case of large farmers. In case of sugarcane also all the three categories of farmers realized negative net returns. However, the magnitude of negative net returns per acre of sugarcane crop was higher with small and marginal farmers reflecting inequity. The net benefit cost ratio for paddy was negative for all the categories of farmers and the loss is more or less uniform. In the case of sugarcane, the net benefit cost ratio for large farmers was less (-0.22) compared to marginal (-0.32) and small (-0.35) farmers, reflecting the differential impacts of equity.

Net return per acre inch of water used

The net returns per acre-inch of water from paddy and sugarcane are negative for marginal, small and large farmers (Table 23). With respect to paddy, there is marginal variation in net return loss per acre-inch of water across all the farm groups. However, in case of sugarcane the net return loss per acre-inch of water is on the lower scale for large farmers (59.9) compared to marginal (88.9) and small (95.7) farmers. This is attributed to the fact that the large farmers ventured in ameliorative measures like surface drainage resulting in additional yield, whereas none of the small and marginal farmers could venture in ameliorative measures due to financial problems.

Sustainability in paddy and sugarcane productivity

Sustainability is a long-term concept and has been described as environmental stability (Bottrall 1981) and durability. It refers to the prevention or minimization of adverse physical changes. The rate of deterioration of an irrigation system is an indicator of sustainability. The intergenerational equity and well being of future generations are the key issues in the economics of sustainability.

In order to calculate the sustainability index the factors considered are; impact of poor quality water on resources, production system, human and animal health consequences. About 63 per cent of the farmers were less sustainable in human/ animal health category. In the case of resources and production system majority of the farmers fall under less sustainable category. The reason being over the years the quality of the water and the soil fertility is deteriorating. Consequently, the crop productivity is also declining (Fig 27). The productivity data has clearly indicated that the sustainability is falling over time due to water quality problems (Table 24 and 25).

Land Degradation Ratio

Land degradation ratio is one of the indicators of environmental damage. Entire area of Ragi (finger millet) was lost due to poor quality water. Vegetables too were losing their area share to sugarcane and paddy. The total amount of land being degraded and lost permanently accounted for 14 per cent of the total area under cultivation leading to the phenomenon of irreversibility (Table 26 and Fig 28).

Ameliorating strategies -expenditure towards drainage

In the first instance, the quality of irrigation water is poor and has aggravated the soil and drainage problems. In order to drain the water, farmers had to dig trenches around the field, which involved an additional expenditure of Rs. 550 per acre towards manual labour. Surface drainage facilitated quick infiltration of polluted water and ensuring aeration resulting in a positive impact on yield (Table 27). The adoption of drainage was apparent by large farmers due to their scale economy.

Assessment of benefits from drainage practice

The partial budgeting results indicated that there was a net gain by adopting drainage practice. Drainage practice involved an additional expenditure of Rs 550 per acre and resulted in incremental output of 2.5 quintals valued Rs. 1037. Upon deducting the additional expenditure from the incremental output value, farmers realized a net gain of Rs. 487. This coping mechanism is a partial solution for the drainage problem and not a total panacea for mitigating the quality of water (Table 28).

Cost of treating polluted water in the Vrishabavathi valley

The treatment cost incurred to clean the contaminants of the polluted water helps to realize better economic returns in the form of additional yield/ income. The other services like ecological services, biodiversity enhancement (increase in number and variety of crops grown) and environmental benefits if valued, would overweigh the costs incurred on purification. These costs are referred as avoided costs (Thomas, 2001) since such an investment would yield benefits in the form of damages being avoided but for treatment. The associated benefits by way of using treated water includes saving in negative externality cost, improved yield and reduction in the health costs. Besides, the intangible benefits include, the improvement in the soil properties, restoring the ecosystem and improvement in the product image and marketability.

In this study, an attempt was made to estimate the cost of treating the polluted water and supplying it to the users at its cost price. As evident from the Table 29 that the cost per acre-inch of treated water works out to be around Rs.130, which is five times more than the current level of cost incurred to irrigate one-acre of paddy through groundwater in the affected area (Rs.26.40) and twice that in the normal area (Rs. 52.40). The increased water processing cost is clearly an environmental problem. According to a research study conducted in the Eastern Dry Zone of Karnataka State, the cost per acre-inch of irrigated water comes to Rs. 107 (Chandrakanth and adya, 1998). This clearly indicates that the treated water cost is nearer to the actual costs incurred by the farmers towards providing groundwater irrigation. The price that they pay towards treatment can be considered as negative externality cost or cost of amelioration. The estimated willingness to pay per acre-inch of water for paddy and sugarcane in the affected area was found to be Rs. 13.80 and Rs. 10.37 respectively, which is ten times less than the estimated treatment cost. This calls for concerted efforts from the State to formulate suitable policy measures to protect the interests of farming community that apart sustaining the environmental utilities of public goods like water for future utilization. It is also quite true that the individual willingness to pay for protecting the aquifer contamination for future use is bleak since; aquifers protection has to be taken up the state in view of common property nature of the resource and hence the institutional role in protecting the quality of water is quintessential.

Replacement cost

Replacement cost is one of the valuation methods in natural resource economics widely used. In this method, the investment that would be required to replace or substitute a damaged asset is treated as the cost of damage. In case of groundwater pollution, the cost of protecting the groundwater aquifer can be estimated as the cost of developing alternative source of irrigation or investment on wells, which are free from quality problems. Replacement options that are available at farmers level would be to invest on the wells in a normal area where groundwater pollution is not a problem. This would be around Rs. 3.6 lakhs on a well plus the cost of the land. This option may not be plausible in view of massive investment. The other proposition would be drilling wells in the normal area and transferring the water to the existing plots. But this proposition too may not be viable considering the conveyance cost, which will be prohibitive. Secondly, farmers can purchase the water from others; this includes the cost of Rs.1824 per acre of crop paddy. If farmer go for purchasing treated water, this involves Rs. 5200 per acre of paddy (Table 30). In case of sugarcane this cost would be doubled.

Willingness to pay for good quality irrigation water

OLS estimates for WTP for good quality irrigation water (Table 33) indicated that, the productivity, land value and health cost are the factors, which influence positively WTP for good quality irrigation water. Specifically the expenditure on human health care has significant influence on WTP. Thus the farmers concern in the degradation of natural resource base and higher cost incurred on health care due to ill effects of poor quality has profound influence on the WTP. The estimated WTP at average value was Rs. 785 per acre, which was very near to the actual average value elicited from sample respondents.

Willingness to pay for clean water according to their income levels

The water pollution in a given area has a significant effect on the crop productivity as well as on the health of the individuals. These monetary impacts can be measured by the “willingness to pay” of the individual for the improved health and crop productivity. Considering the problem of groundwater pollution it is pertinent to estimate the willingness to pay for the clean water for the purpose of drinking as well as for agricultural use. As envisaged in the Table 32, the average Willingness to pay increased from the lower to middle income group compared to the high-income group. The WTP is high (Rs.1230) with the middle-income group of farmers whose income ranged from 10,000 to 20,000. On the contrary, the WTP is lower (675) with the higher income groups whose income varied from 20,000 to 30,000. This squarely implies that income is the main factor that decides their WTP in case of small and middle-income group. The farmers with high income are not willing to pay more since they have their own arrangements for getting clean water.

Willingness to pay for good quality drinking water

As evident from the Table-33 the age, education and income level have a positive relationship with WTP for drinking water. Education is the main factor, which influenced the people to pay since; education brings more awareness regarding the quality of water. It was expected that a person relatively having more number of years of formal education would be more concerned about the water quality. In the locality, majority of the people are not willing to invest on the water filters but instead they were in practice of using boiled water. The estimated willingness to pay at average value was Rs. 128 per year. This value was low considering the importance of drinking water. These results are contrary to the results obtained by Amarnath and Krishnamoorthy (1999). They have indicated that the proportion of farmers WTP was the highest in serious situation with 65.67 per cent and was the lowest in less serious situation with 24.39 per cent. The actual amount of WTP was Rs. 960, Rs. 804 and Rs. 984 for serious, moderate and less affected farmers.

VI - RECOMMENDATIONS

Groundwater quantity depletion

The depletion of groundwater is evident at different scales in Tumkur district, Karnataka State, posing threats to sustainability equity and efficiency. Given the current rate of groundwater development in the overexploited area of the study, the irrigated agriculture can hardly sustain. Added to this, groundwater resource status is also deteriorating leading to bankruptcy of the aquifers. The existing institutional arrangement only promoted overexploitation of aquifers and failed to generate adequate incentives for the adoption of efficient water use technologies. Thus, appropriate policy measures aimed at regulation and control of groundwater for the development of integrated groundwater and surface water system is the need of the hour.

Regulatory interventions

- Until recently, there was more focus on groundwater development. Currently, issues relating to groundwater management are becoming critically important. In the overexploited area, cutting across equity there is a need for institutional change to bring about groundwater regulations such as using permits for drilling wells, maintenance of inter-well space, optimum number of wells in a given area, use of efficient pump technologies and banning additional wells in over exploited area till the groundwater situation improves.

- State policies such as subsidized electricity for groundwater irrigation have adverse impact on groundwater development. Hence, appropriate pricing of electricity for groundwater reflecting its scarcity value serves as an instrument of groundwater regulation.

Demand side interventions

- Further, electricity pricing not only promotes water use efficiency through adoption of efficient irrigation technologies like drip system but also results in saving of sizable amount of water leading to conservation of the resource.
- In dark blocks, farmers have been facing the risk of loosing their investments phenomenally due to their myopic decision of investing on additional wells and encountering failures. In such areas, promotion of drip irrigation should be made mandatory to sustain groundwater irrigation
- The groundwater depletion is also attributed to cultivation of water intensive commercial crops on a large scale like coconut and arecanut in the area. Thus, there is a need for most efficient irrigation technologies to mitigate water scarcity.
- The marginal productivity of water is over Rs. 150 this could form the basis for deciding the electricity prices.

Supply side interventions

- Analytical results of the study clearly suggest that wherever surface water and groundwater coexisting there is synergic interaction effect of groundwater recharge, which has dampened negative externalities of overexploitation. Water has been efficiently managed from the wells located below the tank/canal area hence, examination of institutional and technical aspects of integrating surface and groundwater regime that alleviate overdraft problem need to be explored.
- Instead of drilling additional wells farmers need to be encouraged to form water users association for sustainable management of groundwater

- In over exploited areas, in order to bridge the gap between extraction and recharge, efforts should be made on community basis through people participation for construction of water harvesting structures and desilting the existing tanks so that groundwater supply can be augmented through recharge.

Institutional interventions

- The current pattern of groundwater extraction is the product of existing policies and institutions that failed to correct the distortion in groundwater development and use. Thus, to deal with the emerging problems of groundwater, the present policies have to be ammended keeping changes occurring in both quality and quantity of water resource.
- The problem of inequity existing in well irrigation could possibly be addressed by promoting group investments in well irrigation where sharing the cost and benefits among the farmers are imperative.
- Creating irrigation literacy through media, training and demonstrations about importance of water and its conservation for meeting the current and future needs is quintessential

Water Quality Issues

In the study area, poor groundwater quality is causing negative externality affecting agricultural production system, soil health, flora, fauna, health of human beings and livestock. The groundwater quality is a common pool resource problem and the polluters are not penalized for contaminating the resource. It is necessary to have an integrated approach in order to tackle groundwater pollution by monitor and abating including identification of the contaminants, sources and disposals, the type of pollution they generate, to mitigate the consequences of pollution. There is a market failure as well as policy failure to address the ‘poor’ water quality issues arising from pollution.

Policy options *inter alia* are:

1. Economic instruments

- Polluter pay principle should be used by imposing a tax on polluters, resulting revenue could be used to treat the water before letting to the river.
- Capital subsidy for treatment plants is to be provided to encourage abatement process. Further, green tax on polluting industries may be imposed in order to refrain from polluting water resource.

2. Regulations

- Pollution control Board should strictly monitor whether the polluters would adhere to the standards attained while letting the effluents to water bodies.

3. Technological

- Subsidy to be provided to farmers to use amendments to counter the pollution problem.
- Financial institutions to lend credit to the affected farmers to take pollution abatement.
- Crops and varieties other than paddy and sugarcane suitable to be grown under adverse water quality condition such as sweet flag (*Acorus calamus*) a medicinal plant, which thrives the polluted water could be explored.

4. Institutional/educational

- Inclusion of farmer representatives in the pollution control Board helps to seek viable solutions.
- There is a need for promoting linkage between farmers and extension workers to encourage the use appropriate technology for managing poor quality water.

- Recycling of wastewater for agriculture and industrial use need to be encouraged through private participation/ co-operatives.

Others interventions

- Resource degradation both in terms of quantity and quality could become a significant constraint for further food production. Other sources of growth, such as improved crop and water management/advances in biotechnology requiring less water for the crops will be required for sustaining food security in the future.

VII - REFERENCES

Agrawal, C.D, Kunkad, S. K and Malkhed, T., 1999, Diffuse agricultural nitrate pollution of groundwater in India. *Water Sciences Technology*, 39 (**3**): 67-75.

Amarnath, J.S. and Krishnamorthy, S., 1999, Externalities analysis and economic valuation of tannery pollution hazards in Vellore district. *Agricultural Economics Research Review*, 12 (**2**): 160-162.

Ananda, P, 1994, *Performance of Guava under Drip Irrigation*, M.Sc.(Agri) Thesis, University of Agricultural Sciences, Bangalore.

Anonymous, 1984, Royal Commission on Environmental Pollution. Tenth Report. *Tackling pollution, experience and prospects*. HMSO, London Public Health Laboratory service, London.

Anonymous, 1989, *Annual report*, All India Coordinated Research Project on Management of salt affected soils and use of saline water in agriculture, Agra, Bapatla and Dharwad centers.

Anonymous, 1995, *Resource management for upland areas in Southeast Asia* - An information kit for sustainability indicators, IIRR, Philippines.

Anonymous, 2000, *Karnataka at a Glance*, Director of Economics and Statistics Bangalore.

Anonymous, 2000, *Tumkur District at a Glance*, Director of Economics and Statistics, Bangalore.

Anonymous, 2001, *Potential Linked Plan of Tumkur District*, published by NABARD. Bangalore.

Arun, V., 1994, *Estimation and Internalization of Externalities in Groundwater Irrigation in Hard Rock Areas of Karnataka*, M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Bangalore.

Behera, Bhagirath and Ratna Reddy, V., 2002, Impact of industrial pollution on rural communities. *Economic and Political Weekly,* 37 (**3**); 257-265.

Benbrook, C.M. and Edwards, C.A., 1990, Societies stake in sustainable agriculture. *Proceedings of sustainable agriculture systems*, 67-68.

Bottrall, Anthony, 1981, *A comparative study of the management and organization of irrigation projects*, World Bank staff working paper No. 458, World Bank, Washington.

Cai, Ximing., Daene C. McKinney and Mark W. Rosegrant, 2001, *Sustainability Analysis for Irrigation Water Management: Concepts, Methodology and Application to the Aral Sea Region*, EPTD, Discussion Paper no.86, International Food Policy research Institute, Washington, D.C., U.S.A.

Central Groundwater Board, 1996, Hydro geological survey on fluoride pollution of groundwater in Balasiinghi/Singhipur areas, Bolagarh Block, Kurda District, Orissa. *BHU-JAL News*, 19-20.

Chandrakanth, M. G. and Adya Sushma., 1998, *Scarcity of groundwater for irrigation: Economics of coping mechanisms in hard rock area*. Technical Report, Published by University of Agricultural Sciences, Bangalore.

Chandrakanth, M.G., and Arun, v., 1997, Externalities in Groundwater Irrigation in Hard Rock Areas, *Indian Journal of Agricultural Economics*, 52(**4**): 761.

Chandrakanth, M. G. and Romm Jeff, 1990, Groundwater management in India – Institutional management regimes, *Natural Resources Journal*, 30: 485-501.

Chandrakanth, M. G., Sathish K. M. and Ananda, K. K., 1998, *Resource economics study of valuation of well interference externalities in Central Dry Zone of Karnataka*, Research Report under Ford foundation, New Delhi.

Ciaccio, L.L., 1997, *Water and water pollution handbook*, Vol.1. Marcel Dekker Inc., New York.

Ciriacy- Wantrup, S.V., 1968, *Resource Conservation: Economics and Policies*, Third ed., Division of Agricultural Economics, University of California, Berkeley.

Datta, K.K. and Dayal, B., 2000, Irrigation with poor quality water : An empirical study of input use, economic loss and coping strategies. *Indian Journal of Agricultural Economics*, 55(**1**) 26-37.

Dhawan, B.D. and, Satyasai, K.J.S., 1988, Economic Linkages Among Irrigation Sources: A study of Beneficial Role of Canal Seepage*, Indian Journal of Agricultural Economics*, 44(**2**): 669-674.

Dhawan, B.D., 1989, *Studies in Irrigation and Water Management*, First ed., Common Wealth Publishers, New Delhi.

Dhawan, B.D., 1991, Developing Groundwater Resources, *Economic and Political Weekly*, 26(**8**): 425-429.

Dhawan, B.D., 1993, Groundwater Depletion in Punjab, *Economic and Political Weekly*, 28: 2397-2400.

Gowda, Andani, Babu V. Suresh, Sreeramulu, K.R and Ravindrachary, 2000, Influence of sewage water irrigation on soil and plant microflora of mulberry. *Mysore Journal of Agricultural Sciences*, 34 (**1**): 297-301.

Gregor Mac James, Masirembu Simon, Williams Rick and Munikasu Christopher, 2000, *Estimating the economic value of water in Nambia*, The Paper Presented in Water Symposium: Sustainable Use of Water Resources; Maputo.

Joshi, P.K. and Tyagi, N.K., 1991, Sustainability of Existing Farming System in Punjab and Haryana - Some Issues on Groundwater use*, Indian Journal of Agricultural Ecvonomics*, 46(**3**): 412-421.

Kirkhan, M. B., 1986, Problems of using wastewater on vegetable crops. *Horticultural Science*, 21 (**1**): 24 –27.

Moench Marcus (1992), Drawing Down the Buffer - Science and Politics of Groundwater Management in India, *Economic and Political Weekly*, 28(**12**) A7-A14.

Moench, Marcus, 1994, Approaches to Groundwater Management: Control or Enable, *Economic and Political Weekly*, 30(**35**): A135-A146.

Moench, Marcus, 1995, Electricity prices – a tool for groundwater management in India, *VIKSAT* publication, Gujarat, India.

Moench, Marcus, 1995, Groundwater law – the growing debate, *VIKSAT* publication, Gujarat, India.

Nagaraj, N. and Chandrakanth, M. G., 1997, Intra- and Inter- Generational Equity Effects of Irrigation Well Failures: Farmers in Hard Rock Areas of India, *Economic and Political Weekly*, 32(**13**): A41-A44.

Nagaraj, N. and Chandrakanth, M.G., 1995, Low Yielding Irrigation wells in Peninsular India - An Economic Analysis*, Indian Journal of Agricultural Economics*, 50(**1**), 47-58.

Nagaraj, N., 1994, *Groundwater Irrigation from low yield Borewells in Hard Rock Areas of Karnataka - An Economic Analysis*, Ph.D. Thesis, University of Agricultural Sciences, Bangalore.

Nagaraj, N., Dorin, B. and Zerah, M. H., 1999, Institutional Management Regimes and Economic Instruments for Sustainable Use of Water – the French Model – Lessons for India, *Contributions CSH 99/2*, New Delhi.

Neelakantaiah, S., 1991, *A study on Investment in Groundwater Irrigation and Resource Use Efficiency in Doddaballapur Taluk of Bangalore Rural District, Karnataka*, M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Bangalore.

Palanisami, K. and Balasubramanian, R., 1998, Common Property and Private Prosperity: Tanks vs. Private wells in Tamil Nadu*, Indian Journal of Agricultural Economics*, 53(**4**): 600-613.

Palanisami, K. and Easter, K. William, 1991, Hydro-economic Interaction between Tank Storage and Groundwater Recharge, *Indian Journal of Agricultural Economics*, 46(**2**): 174-179.

Palaniswami, C. and Sreeramulu, U.S., 1994, Effects of continuous irrigation with paper factory effluents on soil properties. *Journal of Indian Society of Soil Science*, 42(**2**): 139-140.

Pearce, D.W. and Markandya, A., 1989, An economic perspective on sustainable development. *Journal of SID*. 2(**3**): 17-19.

Rajashekar, D. David, 1999, *Environmental impact assessment- concepts and methodologies for valuation of environmental costs and benefits*. Proceedings of UGC Regional seminar, New Delhi.

Ramanathan, S., 1994, Greening the Desert by Isreli Way- Is it Good Economics?, *Economics and Political Weekly*,29(9).

Ramaswamy *et al*. (1999) Coping Behavior to Growing Groundwater Scarcity in Tamil Nadu. (yet to be completed)

Saleth, R. M., 1991, Factors Affecting Farmers Decision to Buy Groundwater: Empirical Evidence from the Indo - Gangetic Region, *, Indian Journal of Agricultural Economics*, 46(**3**): 349-354.

Sathisha, K. M., 1997, *Resource Economic study of Valuation of Interference Externalities in Central Dry Zone of Karnataka*, M.Sc.(Agri) Thesis), University of Agricultural Sciences, Bangalore.

Shyamasundar, M.S., 1997, *Interplay of Markets, Externalities, Institutions and Equity in groundwater Development- An Economic Study in the Hard Rock Areas of Karnataka,* Ph.D. Thesis, University of Agricultural Economics, Bangalore.

Siddaramappa, B. and M.K.Nair, 1997, *Heavy metal pollution of soils of a watershed contaminated by sewage and industrial effluents from Bangalore urban area*. Report submitted to Karnataka State Council for Science and Technology, Government of Karnataka.

Titenberg, T., 1994, *Environmental economics and policy*. Harper Collins college Publishers, New York.

Veeman, Terrence G., (1978), Water Policy and Water Institution in Northern India: The Case of Groundwater Rights, *Natural Resource Journal*, 18(**3**): 569-587.

Vermillion D.L., 1999, *The participatory irrigation management programme in Andhra Pradesh, India: Current issues and the need for monitoring and evaluation*. Report submitted to Irrigation and CAD Department, Government of Andhra Pradesh, India.