INTRODUCTION

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1. INTRODUCTION

Water is one of the most crucial natural resources for the sustenance of mankind. Twenty-six countries are now classified as water deficient, and nearly 230 million people are affected with water shortages. While on the one hand there is prediction that by 2025, one quarter of the world's population will face severe water shortages (Seckler et al. 1999), on the other hand, economists like Biswas (1999) feel that, the current estimates of the future global water requirements are likely to prove far too high, and this would have to be revised significantly downwards during the next decade. The amount of water that is available for use at present is seriously underestimated because reuse and recycling of water are ignored; therefore, the estimates of groundwater availability need to be revised upwards. In addition, the technological advances are making costs of desalination and new non-conventional sources more and more attractive.

A dominant character of the Asian groundwater economy is its spontaneous, private, informal nature. While public investments in surface irrigation projects have built unwieldy irrigation bureaucracies, private investments in wells and tube wells have created agile, wealth-creating groundwater economies, which, by many accounts, are more productive than public irrigation systems (Shah et al., 2001). Indeed, while much public investment has been devoted to the creation of surface irrigation, the reality of Asia is that the bulk of its agrarian growth in recent decades has been energized by a rapid rise in groundwater irrigation through small pumps and wells financed mostly through private farmer investments (*ibid*).

These booming groundwater based agrarian economies in many parts of Asia are under serious threat of resource depletion and degradation. The problem is quite serious and a risk to food security in India and China, where up to 25 percent of the harvest is at risk due to falling water tables, according to recent IWMI research. The rate at which groundwater is being drawn in parts of Asia is far in excess of the rate of recharge. Groundwater depletion has both environmental and economic consequences. Yet, the groundwater economy of these regions have responded more to the short term economic opportunity in terms of the wealth it has created rather to a long term sustainable hydrologic opportunity in terms of the availability of the resource in question. Unrestricted open access has been the general rule even in the regions that have serious threat of either depletion or deterioration through over use (Shah et al., 2001).

To avoid the social and environmental chaos, therefore, there is a clear need for better management of the limited amount of available water. Water resources management generally fall into two main categories: those designed to support supply-side management approaches; and those designed to support demand-side management.

While supply-side management options are sometimes necessary and may be the only way to meet short term imperatives for economic development or provision of basic water services, they are quite expensive in monetary terms, technologically demanding to install and maintain, and may, alone, not serve the purpose of the environmental sustainability of water resources. This is especially true as the readily accessible and cheaper sources have become exploited. Worldwide, there is some action by way of a response to groundwater degradation; but largely it is supply-side oriented. There is precious little done to reduce demand for groundwater or approaches to economize its use.

Demand-side management entails the management of off stream demands of water and minimization of the impacts of land use and water use on water resources, through a mix of planning, regulatory and economic measures. Management, prevention and remediation of the impacts of land use on water resources require that all sectors recognize the biophysical and ecological links between land and water. The land-use decisions should be made with due consideration being given to their potential impacts on water resources. As noted in *Agenda 21*: "special attention should be paid to the demand for natural resources generated by unsustainable consumption and to the efficient use of those resources consistent with the goal of minimizing depletion and reducing pollution" (UNU, 2002)

It has been estimated that the increases in cropping intensity, in India, in the next decade and a half will exceed that in last three decades to meet agriculture demand and this would depend essentially on larger and improved water supply systems (Alagh, 2002). To resolve this issue a demand driven approach for water planning and policies has been suggested in recent policy discussions.

Groundwater in particular has been the prime source of development in irrigated agriculture. It constitutes about 89% of the freshwater on our planet. Groundwater systems are dynamic with groundwater movement continuously in slow motion from zones of recharge to areas of discharge. Tapping and using groundwater in a sustainable way is a formidable challenge that few developing countries and local communities have been able to meet. The most formidable challenge is to attain the sustainable use and management of groundwater in vast and growing regions where the resource is under threat.

1.1 Issues in groundwater management

This section covers the myriads of groundwater issues that are currently being debated at various forums. An attempt is made to highlight the issues in the context of sustainable management of this precious resource.

1.1.1 *Depletion of groundwater*

The irrigation development in India over the last several decades has been characterized by the growth in use of Groundwater. This growth in groundwater use was fuelled by advancement in the technology of drilling and lifting groundwater from deep strata, the rural electrification programme, expansion in rural credit for groundwater extraction infrastructures, advent of new high yielding varieties on agricultural production front and the rising agricultural product prices (Vaidyanathan, 1996). Studies report of the evidences of progressive decline in groundwater tables in several parts of the country (Parihar et al., 1990; Bhatia, 1992; Shah, 1993; Dhawan, 1995; Janakaranjan, 1996). Despite the fact that questions have been raised on the reliability of the basis for judging particular regions as over exploited (Vaidyanathan, 1996), the statistics show an increased numbers of grey and dark blocks (Centre for water policy, 2005). On the one hand there are statistics of over-exploitation, the statistics of groundwater exploitation compiled by the Central Groundwater Board (CGWB) reveal that bulk of our groundwater potential is till untapped. This mixed state of affairs is indicative of the lack of firmness in information with regard to groundwater data base (Dhawan, 1989). Nevertheless, the progressive deepening of wells puts small farmers at a disadvantage because they can least afford to invest on deepening of wells and can ill afford purchasing water from the sellers, particularly in areas where this is scarce.

1.1.2 *Inefficiency in groundwater pumping*

When groundwater withdrawals exceed recharge, the resource will be mined over time until either supplies are exhausted or the marginal cost of pumping additional water becomes prohibitive. The first implication of this is that a marginal user cost is associated with mining groundwater, reflecting the opportunity cost associated with the unavailability in the future of any unit of water used in the present. An efficient allocation considers this user cost, which effectively signals the *in situ* scarcity of the resource and is called the resource's scarcity rent. Hence, efficient pricing of a resource that exhibits natural supply constraints incorporates both marginal cost of extraction and scarcity rent.

Scarcity rents must be imposed on current users. In absence of clear groundwater ownership rights, scarcity rents are usually unrecognized and are difficult to estimate. The situation of no scarcity rents results in the price of groundwater being too low and groundwater extraction being above the socially optimal level. Further, in the absence of optimal dynamic management of common-pool groundwater resources, or, alternatively, in the presence of a competitive extraction regime, ignoring scarcity rents results in inefficient pricing and misallocation of the resource.

1.1.3 *Externalities of groundwater extraction*

A number of studies of groundwater extraction have analyzed the externalities imposed by users on each other. Ground water is exploited by a group of independent pump owners, all withdrawing from a common aquifer to maximize their profit. This implies that externalities are pervasive in the exploitation of a ground water stock, which can be perceived to be a common property resource. The fact that there is a finite stock means that each unit of ground water that is extracted by one farmer will have little incentive to save water for future use as other farmers have the same access to the stock. Hence, each pump owner will extract large amount of ground water affecting the other pump owner. This is called stock externality.

Further, the pumping cost is dependent on the water level, which means that as the ground water stock is depleted, extraction cost rises because water level goes down. The individual farmer usually does not consider the effect of its pumping on other farmer's cost. This is called pumping cost externality.

In view of the uncertainty of rainfall and, thus, ground water recharge, the ground water stock plays a stabilizing role by reducing the variability of available water and thus that of income of farmer. A large ground water stock protects all farmers from income risk, so that each unit of water left in the ground has risk reducing value. The farmer, in ground water extraction, fails to consider the buffer role of left over stock for other ground water users and causes risk externality. In addition, excessive pollution of ground water from waste treatment effluent of plants and factories, urban and agricultural run off cause environmental externalities.

1.1.4 *Energy–irrigation nexus:*

The groundwater boom in the Asian sub continent has been caused by the government support to tube wells and subsidies to electricity supplied by state-owned electricity utilities to farmers. The energy–irrigation nexus that has emerged as a result has encouraged waste of groundwater. However, "hidden in this nexus is a unique opportunity for groundwater managers to influence the working of the colossal anarchy that is India's groundwater socio-ecology. Even while subsidizing electricity, many state governments have begun restricting power supply to agriculture to cut their losses." (Kumar et al., 2004) This can be a powerful tool for groundwater demand management in livelihood supporting socio-ecologies to create tradable poverty rights in groundwater (Deb Roy and Shah, 2002). There are examples, where state government had to resort to electricity supply management as an instrument to management of the groundwater (Scot et al., 2003).

1.2 Groundwater management remedies

Gravity of these issues notwithstanding, there has been attempts, technological and policy interventions, to tackle them. Following section describes in brief the remedies undertaken to address the problem of water resource management in general and groundwater management in particular. These solutions, nevertheless, are not without their share of debates raised by the scholars.

1.2.1 *Water conservation*

This implies improving the availability of water through augmentation by means of storage of water in surface reservoirs, tanks, soil and groundwater zone. Since agriculture accounts for about 69% of all water withdrawn (Kumar et al., 2004), the greatest potential for conservation lies in increasing irrigation efficiencies. An important supplement to conservation is to minimize the wastage of water. Dhawan (1989) has referred to four aspects of such wastage of irrigation water at farmer's level. One, escape of water to drains during the course of its transit from the outlet to the field; two, wastage arising out of recourse to field-to-field irrigation in absence of field channels connecting individual field to the canal outlet; third, surface runoff of irrigation water because of lack of field leveling and fourth, over irrigation. These wastages need to be curbed for efficient utilization of water for its sustainable use in perpetuity.

1.2.2 *Watershed management*

Watershed management establishes a workable and efficient framework for the integrated use, regulation and development of land and water resources in a watershed for socio-economic growth. The water harvesting and storage technology have, in the past, been successful in arresting groundwater fall and have also served the water needs of agricultural production. Whilst moves by the Government of India since 1995 have been made towards creating common guidelines in the form of a framework for watershed development, there are concerns that legislative measures in place to protect and manage India's water resources are hindered by the lack of an integrated framework for watershed management, 'looseness' in departmental co-ordination and supply rather than demand side mechanisms (Wilson et al., 2003).

1.2.3 *Conjunctive use of surface and groundwater*

Conjunctive irrigation has come to connote private groundwater development within public canal commands. Water logging problem can be kept under control if conjunctive use of water is adopted. Indian canal system is not only leaky but also inefficient in meeting timely water needs of the farmers. A major portion of supplied water through canal gets seeped into ground, which can be recovered through private well within canal command. Such approach would not only achieve vertical drainage in the surface irrigation works but also enable canal irrigators to be benefited in demand-determined water scheduling instead of supply-determined scheduling (Dhawan, 1989). The conjunctive water use for irrigation is quite relevant in the context of problem areas encountering water logging and salinity related management issues.

1.2.4 *Inter-basin transfers /water export to recharge aquifer*

It is being debated at several forums that groundwater depletion can be countered by importing surface water. The areas deficit in surface water sources can not only be well served by the areas with surplus surface water but also could help recharge the groundwater. A key consideration behind India's proposed mega-scheme to link its northern rivers with peninsular rivers too is to counter groundwater depletion in western and southern India. Gujarat's own Sardar Sarovar Project envisages carrying the stored water in dam to areas in North and Kuchchh.

1.3 Water: National and State Scenario

In India, about 90% of the total use of water is accounted for by irrigation and this includes the hydro-electric power, also used for pumping groundwater. About 40% of the irrigated agriculture is served by the groundwater. In addition to its role in enhancing irrigation potential, groundwater has also become imperative to better serve the production goal of the agriculture sector, besides the supplementary role of horizontal drainage in the area served by the canal network. In arid and semi-arid regions, groundwater has also come to play a crucial role of buffer during periods of drought, when this tends to be the only source to hedge against the risk of crop failure.

1.3.1 *Water resources of India*

India receives annual precipitation of about 4000 km^3. The total average annual flow per year for the Indian rivers is estimated as 1953 km^3. The total annual replenishable groundwater resources are assessed as 432 km^3. The annual utilizable surface water and groundwater resources of India are estimated as 690 km^3 and 396 km^3. The ultimate irrigation potential of India has been estimated as 140 Mha. Out of this, 76 Mha would come from surface water and 64 Mha from groundwater sources. The estimates indicate that by the year 2025, the water requirement for irrigation would be 561 km^3 for low-demand scenario and 611 km^3 for high-demand scenario. These requirements are likely to further increase to 628 km^3 for low-demand scenario and 807 km^3 for high-demand scenario by 2050.

1.3.2 *Water resources of Gujarat*

Gujarat has just 2.28% of India's water resources and 6.39% of country's geographical area. The average per-capita availability of water (876 m^3) reflects the water scarcity in the state criteria of 1000 m^3, the variation being 407 m^3 in the north Gujarat region to 1378 m^3 in South and Central Gujarat. The state has an average annual rainfall of 80 cm with a high coefficient of variance over time and space, and as a result droughts are frequent. Out of 185 rivers, the state has only eight perennial rivers and all of them are located in southern part. Around 80% of the state's surface water resources are concentrated in central and southern Gujarat, whereas the remaining three-quarters of the state have only 20% (Fig. 1.1). Groundwater has contributed to more than 80% of irrigation in the state (Figure 1.2). At the ultimate irrigation potential of 6.85 million ha, 43% of it will be from groundwater, 31% from surface water from the state basins and

26% from inter-state allocations (Agriculture & Cooperation Department, 2000). There has been a consistently increasing trend of groundwater utilization for irrigation purposes, which is reflected in the spectacular increase in the number of irrigation wells and tube wells in different parts of the state (Figures 1.3 and 1.4). The state has had to pay heavily in terms of severe depletion of utilizable groundwater resources all over the state. Due to the typical water-intensive crop varieties and less awareness/experience of the real value of water, the so-called water-surplus regions of south and central Gujarat have also experienced a severe loss of utilizable groundwater as compared to water-scarce regions. In 1984, 88.5% sub-districts of the state had less than 70% groundwater development. In 1997 these sub-districts were reduced to 51.9%, with a corresponding increase in over-exploited (OE) sub-districts from 0.55% in 1984 to 16.4% in 1999. Continuous lowering of the groundwater table has resulted in an alarming increase in the number of defunct wells, 1.9-fold over a period of 25 years (1970–71 to 1996–97). (Gupta, 2004)

1.3.2.1 *Emerging scenario*

The water scarcity problem has assumed serious dimensions. At this rate, in the next 25 years, even during a normal monsoon the state would face a shortage of around 7000 MCM. Not only the groundwater table is depleting progressively in many parts, but also the quality of drinking water has become a serious concern for Gujarat. According to the Central Ground Water Board (CGWB), in North Gujarat including Ahmedabad, water tables are falling at an alarming rate of over 7 ft every year as a result of overexploitation (Vyas, 2001). Agriculture consuming the major part, in such a scenario, the issue of agricultural crop production in general, and in arid and semi-arid context in particular, warrants serious debate and policy interventions to serve the inhabitants of these areas.

1.4 Contribution of the study and objectives

Studies on groundwater use have attempted several issues ranging from economics of tube well irrigation to management of groundwater stock in hard rock areas. As such the examination of issue of groundwater extraction at farm level and its relation with cropping systems practiced particularly at catchment level has not been much explored. Moreover interventions from both supply and demand side would only be meaningful in the context of a geohydrological unit, which is catchment/ watershed. Only a few studies have looked into the issues of groundwater extraction and its relationship with the crops and cropping system practiced in the watershed at varying rainfall scenarios. Such an attempt would develop an understanding about the extraction pattern for groundwater, which would, in turn, help plan demand-side management of water in the catchment before planning for augmenting the water resource to meet the requirement. Towards this end, the present study would contribute by examining the pattern of groundwater extraction vis-à-vis the cropping systems, identify crops and crop combinations in terms of their water extraction level and examine their water productivity, inter-season as well as intra-season. A rational use of irrigation water in crop, particularly the groundwater would be attempted based on economic theory to draw implications for resource sustainability. Finally, a deterministic control approach in quadratic linear problem framework would be applied to examine the response of groundwater system to different groundwater extraction scenarios to draw implications for groundwater availability.

The objectives can be listed as,

a) To examine the pattern of groundwater extraction vis-à-vis the cropping systems;

b) To identify crops and crop combinations in terms of their water extraction level;

c) To examine inter-season as well as intra-season water productivity; and

d) To optimize groundwater use by examining response of groundwater table to different extraction scenarios.

1.5 Limitations of the study

The present study is conducted in a watershed with a given hydrological setting. To that extent, the relevance and application of the findings have a limited scope. Nevertheless, the issues addressed might help understand the intricacies in the management of this natural resource in areas with similar geo-hydrologic and socio-economic realities. The spatial and temporal data on production relationship and groundwater extraction pertain to a limited period of three to four years. A longer period time series data would have better served the purpose of understanding the inter-relationships of cropping system and groundwater extraction in the well command. However, the non-availability of data base related to groundwater extraction and use puts a constraint on examination of this issue.

Towards that end, building such a data base with as many variables as deem fit to understand the socio-economics of groundwater system at watershed level in different regions would be the future line of action.

1.6 Organization of manuscript

Chapter II gives the general review of literature, followed by design of study in chapter III. Chapter IV describes the relationship of groundwater extraction and water table depth in the watershed with the crops and cropping systems practiced in the tube well command. This is followed by crop system discrimination and clustering of crop groups based on groundwater extraction in chapters V and VI, respectively. Chapter VII gives crop water productivity; inter season as well as intra season drawing implications for groundwater saving in crop use. Finally, chapter VIII describes the optimization framework and draws implications of groundwater extraction for the groundwater table. Finally, the summary and conclusion of the manuscript is given in chapter IX.

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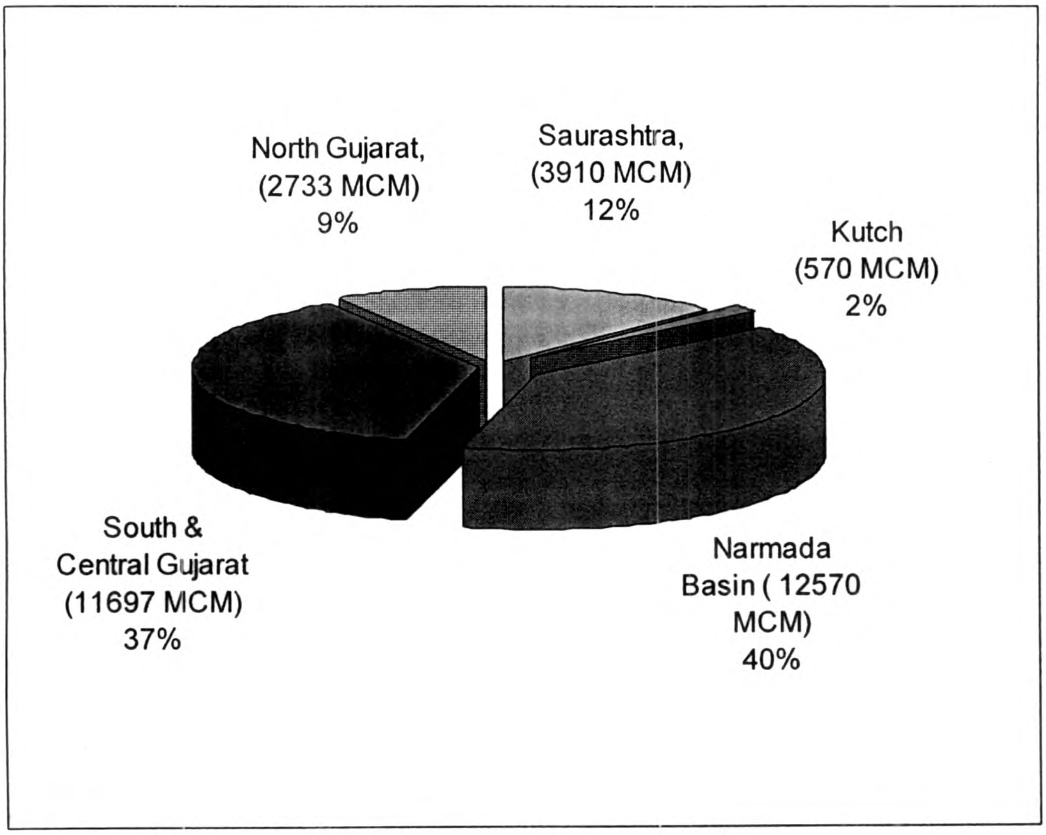

Fig.1.1. Utilizable surface water (31,500 MCM) in Gujarat (Source, Gupta, 2003)

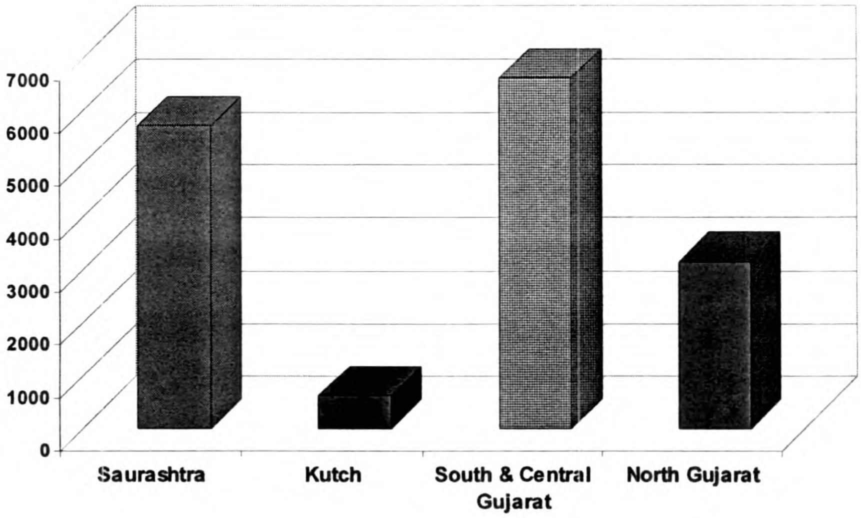

Fig.1.2. Utilizable groundwater (16,105 MCM) in Gujarat (Source: Vyas, 2001)

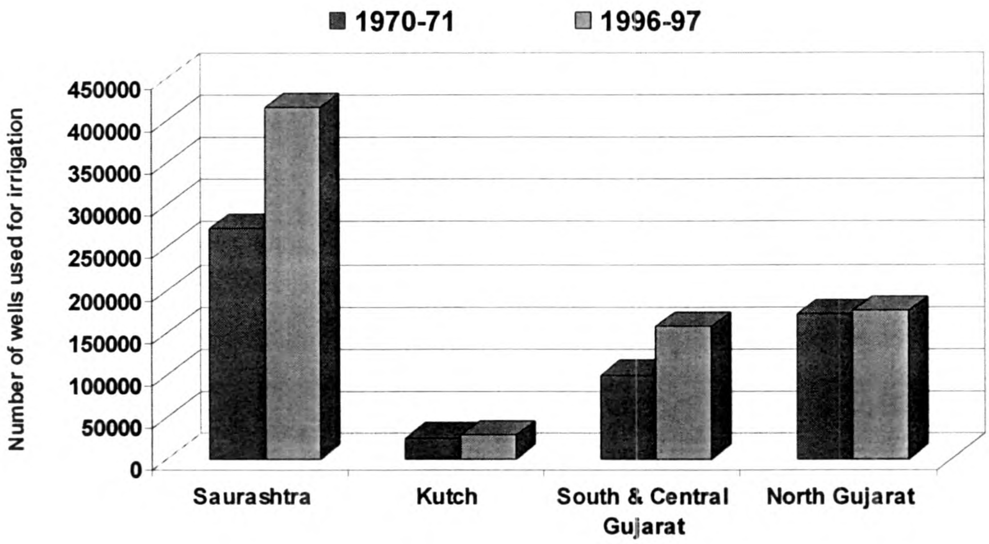

Fig.1.3. Number of wells used for irrigation. (Source: Gupta, 2004)

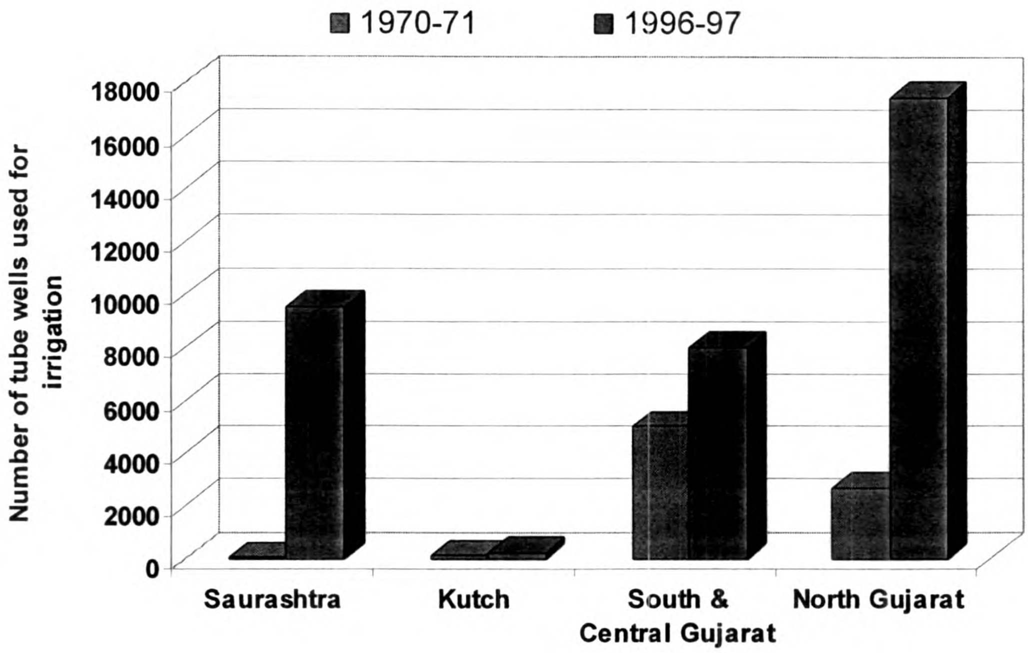

Fig.1.4. Number of tube wells used for irrigation. (Source: Gupta, 2004)