Irrigation Water Management for Food Security in India: The Forgotten Realities

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India's water crisis is often perceived to have been perpetuated by the widening gap between the utilizable water resources and the aggregate demand for water in agriculture and other sectors in certain regions; and the spatial and temporal variations in water resources endowments. As a result, many scholars argue for technological and policy interventions that aim at increasing agricultural productivity and production in water-rich regions, and export of food grains from those regions to water-scarce regions. In the process, the constraint induced by poor availability of arable land had been by and large ignored leave alone the issue of poor agricultural growth in those regions.

Traditionally, reservoirs are built and water scarce regions within and across basins are provided water to mitigate water crisis. Over the past 3-4 decades, widespread exploitation of groundwater had helped overcome the natural disadvantage India has, particularly because it could happen in arid and semi arid regions which are poorly endowed in both surface and groundwater. But, this resource has, for long, begun to show alarmingly declining trends in many arid and semi arid regions. But, some scholars believe that the continued exploitation of groundwater could sustain the boom in well irrigation in water-rich regions, and help avert the water crisis due to growing food insecurity.

The paper takes a hard look at two of the key factors that drive agricultural growth and food production in India viz., access to arable land and water resources, with particular reference to their regional variations, in order to make a qualitative assessment of the magnitude of food security and water management challenge posed by the country. The paper then takes a critical look at the recent official assessments of groundwater exploitation in India. This is done by comparing those estimates with the actual negative physical, social and economic consequences of over-exploitation evident from different pockets.

Based on the above sets of analysis, the paper argues that the real food security and water management challenge lies in the fact that there are regional differences in water resource endowments in the country. Further, water demands that juxtapose with high demands in regions of natural water shortage and low demands in regions of water abundance; and serious resource depletion problems in the naturally water-scarce regions are of common occurrence. Subsequently, the potential impacts of ongoing groundwater crisis in certain regions on the country's food security are analyzed.

The paper concludes that sustainability of well irrigation in the agriculturally prosperous regions of the country can be achieved through judicious and careful investments in surface water projects that encourage direct irrigation and replenishment of over-exploited aquifers. The other strategies include: improving the efficiency of utilization of green water or the rainwater held in the soil profile; reducing the soil water depletion, through reduction in the amount of residual moisture held in soils after harvesting; and reducing the consumptive use of water through shift to low water consuming crops that are economically more efficient.

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I. Introduction

India's water crisis is often perceived to have been perpetuated by two factors. First is the widening gap between the utilizable water resources and the aggregate demand for water in agriculture and other sectors in certain regions. Second is the spatial and temporal variation in water resources endowments. As a result, many scholars argue for technological and policy interventions that aim at increasing agricultural productivity and production in water-rich regions, and export of food from those regions to water-scarce regions, instead of looking at viable solutions. In the process, the constraint induced by poor availability of arable land had been by and large ignored leave alone the issue of poor agricultural growth in those regions.

Over the past 3-4 decades, widespread exploitation of groundwater had helped overcome the natural disadvantage India has, particularly because it could happen in arid and semi arid regions which are poorly endowed in both surface and groundwater (Kumar, 2007). But, this resource has, for long, begun to show declining trends in many arid and semi arid regions, which are also agriculturally prosperous, with increasing number of blocks and districts falling in the "over-exploited" and "dark" category, while surface water resources in those regions have already been "over-appropriated" and over-allocated (Kumar 2007; Kumar and Singh, 2008). Yet, some scholars believe that the continued exploitation of groundwater could sustain the boom in well irrigation in water-rich regions, and help avert the water crisis due to growing food insecurity.

The purpose of this paper is to: challenge some of the misplaced notions of food security challenges posed by the country; by examining how far water becomes a constraint in achieving food security in different regions; analyze the potential future impacts of problems on nation's future food security; and suggest some broad strategies for achieving long term sustainable water use and food security. The analysis takes into account the natural variations in land and water resources endowments across regions and the problems in resource availability caused by its over-exploitation. Given the fact that a major share of the water demand comes from production of food and agricultural produce, the paper argues that India's food crisis is as much a crisis of land and ecology in some region as the crisis of water scarcity in agriculturally prosperous regions, induced by poor resource endowments, and over-exploitation.

II. India's Water Resource Scenario

i) Water-scarce and water-rich regions

From an anthropogenic perspective, water-scarce regions are those where the demand for water for various human uses far exceeds the total water available from the natural system, or the technology to access it is economically unviable. This includes the surface water, water stored in the aquifers, and that held in the soil profile. Water scarcity can also be felt when the resources are available in plenty in the natural system in a particular region, but adequate financial resources to access it are not available with the populations living in there. The former is called physical scarcity, and the latter economic scarcity. North Gujarat in India and Israel are ideal examples of physical scarcity, whereas Ethiopia in eastern Africa and Bihar in eastern India are ideal examples of economic scarcity of water. In this article we are concerned with regions facing physical scarcity of water.

Physical scarcity of water occurs in regions which experiences low to medium rainfalls and high evaporation rates. Most parts of Western, North-western Central and Peninsular India fall under this category. They have low to medium rainfalls (see Map 1), and high potential evaporation rates (see Map 2). The mean annual rainfall ranges from less than

300 mm to 1000mm, where as the PE ranges from less than 1500 in some pockets in the north east to more than 3500 in some pockets in Gujarat and Maharashtra.

We would explain the process which determine the supplies and demand for water, which in turn induces water scarcity in those regions, in the subsequent section. As regards natural water supplies, the runoff available from rainfall precipitation and groundwater recharge from a unit land area in such regions is generally low. This is because runoff is the amount in excess of the soil moisture storage and infiltration. Since evaporation rates are high, soil moisture generated from precipitation gets depleted during the rainfall itself, increasing infiltration of water which fulfills the soil moisture deficit. This leaves much less chance for water to runoff (see Kumar *et al.*, 2006 for detailed discussion).

As regards the demand for water, crop evapo-transpiration mainly determines the requirement of water for agriculture, as agriculture is the largest source of water demand for human uses in all major river basins in India.

Table 1 gives the reference evapo-transpiration against the effective renewable water resources from surface runoff and replenishable groundwater.[2] It shows that for all the five basins, annual reference evapo-transpiration is many times more than effective renewable water resources. But, what is available for crop production includes the soil moisture storage as well. But since the soil moisture storage is a small fraction of the rainfall even in very high rainfall regimes, the potential evapo-transpiration (PET) for the entire year would be much higher than the sum of soil moisture storage--which is a fraction of rainfall--, and effective renewable water resources.

Now, the actual demand for water could be much higher than this, as what is actually cultivated might not be what the demand as water scarcity might force communities to reduce the area under cultivation. The demand can only go up as the population in these regions continue to grow.

In that case, the imbalance between effective water availability and water demand for agricultural uses is very high for all the five basins. In addition to the agricultural water, there are demands for water from other sectors such as domestic and industrial uses. But, for the time being, we can ignore this. This gap between demand and renewable supplies can be reduced if we have very little arable land, and very large amount of land serving as natural catchments for supplying runoff water. But, unfortunately, the amount of virgin catchment left out in water-scarce regions of India is very small. It varies from 58.6% in case of Pennar basin to 28% in case of Sabarmati basin.

As a matter of fact, increasingly the rich upper catchments of river basins and watersheds are being put to crop production due to growing population pressure. This has two major negative impacts on available renewable water resources. *First*: it captures a share of the runoff generated from the area, and therefore reduces the available surface water supplies. *Second*: increase in cultivated land increases the water requirement for irrigation. This way, large regions in India are facing shortage of water to meet the existing demands. The recent report on groundwater resource assessment and irrigation potential in India clearly shows that the regions facing problems of groundwater over-exploitation are mostly in Gujarat, Rajasthan, Maharashtra, MP, AP, TN and parts of Karnataka, and coincide with the naturally water-scarce regions (GOI, 2005).

Table 1: Average Reference Evapo-transpiration Against Mean Annual Rainfall in Selected River Basins in Water-Scarce Regions

Sr. No	Name of the Basin	Mean Annual Rainfall (mm)	Average Annual Water	Effective Annual Water	Reference Evapo-

[2] For a basin, if only a small fraction of the drainage area is under cultivation, then effective renewable water availability per unit of cultivated land would be more, and vice versa.

				Resources[1] mm)	Resource[2] (mm)	transpiration[3] (mm)	
		Upper	Lower			Upper	Lower
1	Narmada basin	1352.00	792.00	444.70	937.60	1639.00	2127.00
2	Sabarmati basin	643.00	821.00	222.84	309.61	1263.00	1788.80
3	Cauvery basin	3283.00	1337.00	316.15	682.80	1586.90	1852.90
4	Pennar basin	900.00	567.00	193.90	467.80	1783.00	1888.00
5	Krishna basin	2100.00	1029.00	249.16	489.15	1637.00	1785.90

Sources: [1]The average annual water resources was estimated by taking the sum of annual utilizable runoff (GOI, 1999: Table 3.6) and the dynamic groundwater resources from natural recharge in these basins (GOI, 1999: Table 3.9) and dividing by the geographical area of the basin.

[2]The effective renewable water resources were estimated by dividing the average renewable water resources for the basin by the fraction of total cultivated land to the total basin drainage area. The basin-wise total cultivated land considered was for the year 1993-94 (GOI, 1999: Annexure 3.2, pp 422).

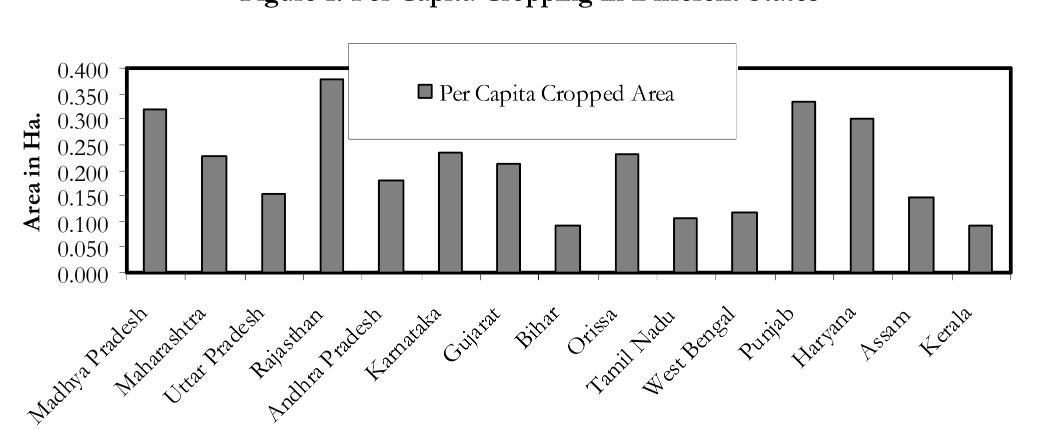
[3]Reference evapo-transpiration values were estimated using meteorological data from FAO CROPWAT model, except for Pennar basin and upper Krishna. For Pennar and upper Krishna, the data were obtained from IWMI climate atlas.

Now, physically water-rich regions are those which experience medium to high rainfalls and low evaporation. Hence, going by Map 1 and Map 2, eastern India, eastern part of central India, western Ghats and north east fall under this category. Traditionally, demand for water in a region is derived from its food demand, plus the demand for domestic, municipal and industrial production purposes. This approach becomes valid so long as there is sufficient amount of land available for production of food at the aggregate level, and therefore would work for a country-level water demand projections. But, for a region with has limited land resources, the demand for food will not get translated into water demand. Examples are Bihar and Kerala. Their water demands would be driven by the total amount of arable land, and the number of times with which it can be put to use in a year, rather than the total food demand. The reason is that there isn't much land available for utilizing the amount of water needed to produce this food, though is available in plenty in these regions.

The aggregate demand for water in agriculture in these regions is a function of the land available for cultivation; the type of crops grown in these regions; and the durations for which these crops occupy the land within a year. If we assume the same cropping pattern for comparison, reference evapo-transpiration can be a good basis for comparison. Since certain part of the crop water demand will eventually be met by rainfall, the difference between ET_0 and P can be the deciding factor for net irrigation water demand. Since we do not have proper estimates of effective rainfall that is directly available to crops, we are only considering the ET0 values for crop water demand estimation.

Analysis shows that the per capita cultivated land is much higher in regions that are physically "water-scarce" and very low in regions that are "water-rich" (Figure 1). For

Figure 1: Per Capita Cropping in Different States



instance, the per capita cultivated land in Bihar and Kerala is 0.09ha (naturally water-rich), followed by 0.15ha in UP, whereas it is 0.38ha in Rajasthan, 0.334 in Punjab, and 0.233ha in Karnataka (Kumar, 2003).

Now, ET_0 will be much lower in water-rich regions as compared to physically water-scarce regions, as there is inverse spatial relationship between ET_0 and precipitation existing across India[3]. This is evident from a quick analysis of reference evapo-transpiration and precipitation figures of selected locations in India starting from naturally water-scarce regions of Peninsular India covering Andhra Pradesh, Karnataka and Tamil Nadu to the water-rich regions of west Bengal, Bihar and eastern UP. The cumulative effect is that the agricultural water demand would be much lower in physically water-rich regions. On the other hand, the renewable water resource availability per capita is very high in these regions as these regions have enormous amount of dynamic groundwater, groundwater stock and surface water resources (GOI, 1999).

Superimposing the data on overall natural water supplies and demand for water for agriculture in different regions of India, it becomes clear that the effective renewable water availability would far exceed the demand for water in physically water-rich regions. Table 2 shows the per capita effective renewable water availability obtained by dividing the annual renewable water availability by the population and per capita water demand derived from ET_0, and net cultivated land in several locations in three major water-rich basins. The figures of per capita water demand are for agriculture, and were estimated by multiplying the net cultivable area by ET_0. Hence, the physically water-rich regions are also water-abundant. These three basins encompass nearly 36% of India's population today. Hence, more than 1/3[rd] of India's population lives in basins that are water surplus.

Table 2: Per capita Renewable Water Resources and Per Capita Water Demand in Agriculture in Three River Basins

Sr. No	Name of the basin	Average Annual Rainfall in the basin		Average Renewable Water Resources (m^3/capita)	Effective Renewable Water Resource (m^3/capita)	Mean Annual Reference Evapo-transpiration (mm)		Water Demand for Agriculture (m^3/capita/annum)
		Upper	Lower			Upper	Lower	
1	Ganga	1675	1449	1081.56	1476.60	710.00	1397.00	1387.66
2	Brahmaputra			1649.86	2288.10	1064.00	1205.00	2413.62
3	Meghna							

Source: authors' own estimates based on ET0 values estimated from FAO CROPWAT, and population and renewable water availability figure obtained from GOI, 1999.

Note: i] In estimating the renewable water resources, only the utilizable water resources are considered. The remaining part is un-utilizable because of the topography existing in these basins, and the peak flows. This un-utilized part can be treated as the flows available for ecosystems downstream after diversions.

ii] The net cropped area figures considered for each basin are for 2050, as per the projections provided in the National Commission on Integrated Water Resources Development (GOI, 1999): Annexure 3.2, pp 422. They are higher than the actual cultivated area in these basins at present. This leaves the chances of under-estimation of water demand for agriculture in our methodology

3 A glance at the Map 1 and Map 2 would reveal that as the rainfall increases, the potential evaporation reduces. It is to be noted that reference ET is a function of PE.

iii] The total static groundwater resources in the two basins was estimated to be 21,774 and 28,841 MCM, respectively (source: GOI, 1999: Table 3.11: pp 46).

If we assume that a small fraction ($1/100^{th}$) of the static groundwater from the three basins would be available for utilization, the total amount of utilizable water resources in these basins (1,694.4 and 2,576.5 m^3/capita per annum) would be much higher than the water demand in agriculture. One could argue that withdrawal of groundwater at level exceeding the annual recharge from these alluvial basins could cause environmental damage as it would cause reduction in stream flows during lean seasons, an alternative argument could be that the over-draft itself could increase the rate of recharge to groundwater from the stream flows, thereby making available the non-utilizable surface flows in the two basins for future utilization.

III. The Groundwater Story

i) Drivers of groundwater intensive use

We have already seen that there is major mismatch between water supply and water demand for agriculture in India. Eastern India extending over Bihar and eastern UP, which is part of the Gangetic alluvium, is abundant in both surface water and groundwater. This region is underlain by one of the richest aquifers in the world, having huge static groundwater reserves (GOI, 1999: Table 3.11, pp 46). But, this region continues to be a net importer of food grain (Amarasinghe *et al*., 2004), and is agriculturally very backward (Evenson *et al*., 1999). The productivity levels for main cereals such as wheat and paddy are lowest in this region. While there is scope for improving the productivity of main cereal crops such as wheat and paddy which are major crops in this region[4] through enhancing farmers' access to well irrigation by means of massive electrification and pump subsidies, there are serious limits to which this can contribute to enhancing the food grain production in the country, and making this region food self sufficient.

This limit mainly comes from poor land availability due to very high pressure on land; very little additional land that can be brought under irrigation; high degree of land fragmentation; poor public investments in rural infrastructure including irrigation and electricity; ecological constraints due to floods; and overall lack of institutional and policy reforms in agriculture sector.

Very small sized holding and low crop yields reduce the capacity of farmers from generating surpluses, and use the same for investing in high yielding variety seeds and irrigation that can support it. Very high land fragmentation forces farmers to depend on water buyers rather than investing in their own irrigation infrastructure, which would be economically inefficient due to poor utilization of the potential created (Kishore, 2004). With very low level of electrification, water buyers pay prohibitive prices for the water which is purchased from well owners, reducing the net returns from farming (Kumar, 2007). The low total factor productivity (TFP) growth in this region (Evenson *et al*., 1999) could perhaps be due to this.

On the other hand, the farmers in the semi arid and arid regions of Punjab, Haryana, Gujarat, Andhra Pradesh and Tamil Nadu have been rather quick in adopting green revolution technologies, with modern high yielding varieties and farm mechanization, as large

[4] For example, in U.P., which has the largest area under wheat, yields could be increased by 50 per cent; in Bihar, by over 100 per cent. Similarly, rice yields in Chattisgarh could be raised 150 per cent on un-irrigated land and 169 per cent on irrigated land.

public investment in irrigation infrastructure supported this[5]. Availability of sufficient amount of arable land enabled the farmers' quicker adoption of modern high yielding varieties, as they could produce enough surpluses from irrigating them. The subsequent years witnessed the rapid growth in wells and well irrigation, with the traditional varieties being replaced by modern high yielding varieties even in the non-command areas. These high-yielding varieties were also water-sensitive crops, having less drought resistance. Rapid rural electrification, followed by heavily subsidized electricity for groundwater pumping and institutional financing for wells and pump sets helped sustain intensive irrigation of water-intensive crops, which otherwise would be unviable if full economic costs of production and supply is passed on to the farmers. This has led to over-exploitation of groundwater in these regions. The lack of institutional regimes governing the use of groundwater such as well-defined ownership rights in groundwater, or effective regulations.

The much lower per capita net cultivated area and the lowest productivity levels for cereals such as wheat and paddy essentially means that the water rich regions have severe food shortage, making these regions have to depend on imports from the water-scarce regions that have forward agriculture, with both high crop yields and high per capita cultivated land (see Figure 1). This is another factor that drives intensive well irrigation in these regions, as the regional imbalances in food production, and the concern of national food self sufficiency ensures market support for the food produced in these regions through good procurement prices.

ii) Groundwater exploitation

The first set of alarms about groundwater over-exploitation were raised almost three decades ago (Kumar and Singh, 2008). Over the years, several new regions have been classified as falling under "over-exploited" category. Punjab is one such region--where many blocks were shown as experiencing falling water table conditions. There has been a lot of whistle blowing about the impending groundwater crisis in many arid and semi arid regions based on anecdotal evidences from some of these regions on groundwater level trends.

But, if one goes by the official estimates of groundwater development in 2005 from CGWB, only 23.1 M ham out of the 43.2 M ham of renewable groundwater in the country is currently utilized (GOI, 2005). Again, if one goes by the most recent disaggregated data, only 15 per cent of the groundwater basins in the country are over-exploited; 7% critically exploited. Nearly 62 per cent of the groundwater basins are still "safe" for further exploitation (GOI, 2005). Interestingly, as per the official statistics, Punjab is one of the states where over-exploitation is most serious, next only to Rajasthan and is followed by Delhi and Gujarat. The number of over-exploited districts in the hard rock areas of Andhra Pradesh, Tamil Nadu and Saurashtra in Gujarat, where high incidence of well failures is reported, is very low (see Map 3).

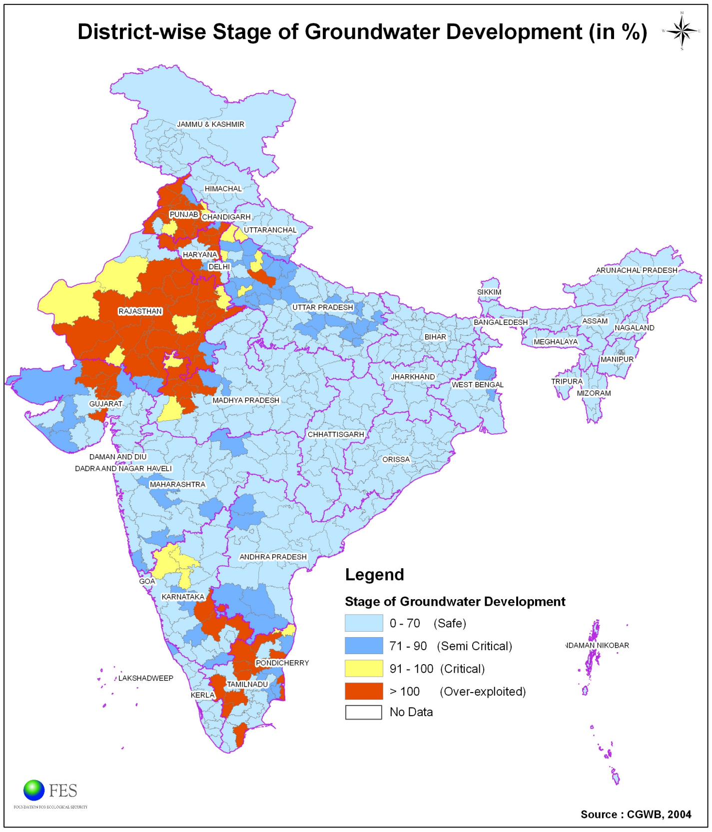
Therefore, such doomsday prophecies have not been based on rational assessment of the scenario using data on hydrological changes and hydrodynamics. Collin and Margat (1992) have argued that this is an unconscious or incited over-reaction to a given situation, while Custodio and Llamas (1997) and Llamas (1992a) assert that this is the result of deeply entrenched "*hydromyths*". Custodio (2000) further opines that the groundwater developers take the opposite position, which focus on "beneficial use" and use the concepts of safe yield, or rational exploitation and the economics side of sustainable development to present their viewpoints. This is not to say that groundwater over-exploitation is not a cause for

[5] During the sixties and seventies, Maharashtra, Gujarat, Andhra Pradesh and Tamil Nadu made colossal investments in large irrigation systems, whereas Punjab and Haryana had made investments in irrigation way back in the 50's. Irrigation systems were already in place in Punjab and Haryana before green revolution technologies were introduced.

concern in India. In the subsequent section, we would examine how far these "doomsday prophecies" are correct.

Analyzing Water Level Trends

Groundwater level trends are a net effect of several changes taking place in the resource conditions owing to recharge from precipitation, return flows from irrigated fields, seepage from water carriers (canals, channels etc.), abstraction or groundwater draft, lateral flows (either inflow or outflow) or outflows into the natural streams (Todd, 2003: pp218-229). In a region, where long term levels of groundwater pumping are less than the average annual recharge, the groundwater levels can experience short-term declining trends as a result of drastic increase in groundwater pumping owing to monsoon failure. But, such a phenomenon does not represent the long-term trends. It is important to note here that semi arid regions in our country also experience significant inter-annual variability in rainfall (source: based on Pisharoty, 1990; Kumar *et al.*, 2006). Further, it is not correct to attribute all changes in groundwater conditions to hydrological stressed induced by human action.



In a region where groundwater outflows into the surface streams are quite large due to the peculiar geo-hydrological environment, even if the net annual groundwater draft is far less than the net recharge, water levels can decline on an annual basis, as illustrated through a study of surface-water groundwater interactions in Narmada river basin in India. In such situations, increasing draft over time can actually reduce the rate of decline in water levels on a long time horizon (Kumar *et al.*, 2005). In fact, this is the situation prevailing in many river basins of Central India, such as Mahi, Tapi, Krishna, Mahanadi and Godavari. Such situations also prevail in the western Ghats and north-eastern hilly regions. This means in such areas, integrating environmental considerations such as maintaining lean season flows in rivers would limit the safe abstraction rates, to levels much lower than what is permissible on the basis of renewable recharge. Hence, in such regions, estimating the base flows would be very crucial in arriving at the net utilizable recharge, and therefore the actual stage of development of groundwater. We have already seen that the groundwater outflows are not properly accounted for in the estimates of the net recharge. Due to this reason, the estimates would show a much lower stage of development than what the region is experiencing.

Groundwater Balance for Assessing Over-draft

Ideally, in a region where lateral flows and outflows from groundwater systems are insignificant, groundwater "over-draft" can take place if the total evapo-transpirative demand for water (ET) per unit area is more than the total effective rainfall, i.e., the portion of the rainfall remaining in situ after runoff losses, and the amount of water imported from outside for unit area. In many semi-arid to arid regions of India, cropping is intensive demanding irrigation water during winter and summer months. The ET demands for crop are much higher in comparison to the effective rainfall. The deficit has to be met either from either local or imported surface water or groundwater pumping. Hence, the change in groundwater storage would be the imbalance between the total of recharge from rainfall and return flows from irrigation, and groundwater draft. In semi arid and arid regions, natural recharge from precipitation are generally very low. In an area with intensive surface irrigation, a negative balance in groundwater indicates high levels of over-draft or deficit in effective rainfall in meeting the ET requirements.

Punjab is a classical example. The region is intensively cultivated and irrigated. Most of Punjab is falling in semi arid to arid climate. Both these factors make ET per unit area very high. Again effective rainfall is low. The water levels are falling throughout Punjab at a rate of 0.3 metre per annum (Hira and Khera, 2000). Let us examine the groundwater balance in an ideal situation like in Punjab. The change in groundwater storage (Δ_s) could be written as:

$$R_{rech} + RF_1 - NGD$$

But, $NGD = ET + \Delta_{Dep} - (S_I + P_e - RF_I)$

$$\Delta_s = R_{rech} + RF_1 - \{ET + \Delta_{Dep} - [S_I + P_e - RF_I]\}$$

$$\Delta_s = R_{rech} + S_I + P_e - ET - \Delta_{Dep}$$

Here, R_{rech} is rainfall recharge; RF_I is irrigation return flow; NGD is the net groundwater draft; Δ_{Dep} is the total of water depleted from the soil during the fallow period and the water stored in the soil profile below the root zone; S_I is the surface irrigation water applied; and P_e is effective rainfall.

Going by the above groundwater balance equation, if S_I is removed, then the change in groundwater storage would become negative if the entire land is cultivated, which is the condition in almost throughout Punjab. This is because rainfall (P) is less than ET requirement, and as a result, P_e +Recharge also, as P_e + Recharge would always be less than the total rainfall (P). Hence, surface irrigation's role in maintaining groundwater balance is more than that of the return flows from it, and equals the actual amount of surface water applied. This also means that if water levels are falling even with canal irrigation inputs, then the storage depletion and drop in water levels without exogenous water inputs would be much larger.

Geological Conditions

Under what geological conditions drops in water levels occur is also important in assessing the extent of groundwater over-draft conditions. Many semi arid and arid areas in the country fall under hard rock conditions. Examples are Peninsular India except the western Ghat region, Saurashtra in Gujarat, western parts of MP, almost the entire Maharashtra and most parts of Orissa (see the Map). In these regions, the specific yield of aquifers is very small--0.01 to 0.03. Large seasonal drops in water levels are a widespread phenomenon in these areas. During monsoon, sharp rise in water levels is observed and after the monsoon rains, water levels start receding. Many open wells get dried up during summer. Often the drop in water levels between pre and post monsoon is in the range of 5-6 metre. So, one should make a clear distinction between seasonal depletion and annual depletion.

Further, in hard rock areas, a unit volume of groundwater pumped from the aquifer results in up to 12-13 times the annual drawdown that occurs in alluvial areas for the same amount of over-draft. A fall in water level of one metre in alluvial Punjab should be a cause for much greater concern than a one metre fall in water levels in hard rock areas of Tamil Nadu, or Saurashtra or Karnataka given the fact that the specific yield of alluvium in Punjab is in the range of 0.13-0.20. This will be evident from the data on recharge-abstraction balance for two distinct regions. This is not to say that magnitude of water level drop is not important. In fact, a sharp fall in water level would also have serious implications for the investment required for pumping groundwater, and also efficiency with which groundwater could be abstracted. Hence, what is more important is at what rate water levels fall on a long term basis.

Integrating Negative Consequences of Over-exploitation in Assessing Groundwater Development?

As Custodio (2000) notes, the concept of "groundwater over-development" or aquifer over-exploitation is complex linked to various "undesirable consequences" which are physical, social, economic, ecological, environmental, and ethical in nature. Therefore, an assessment of groundwater over-development involves complex considerations that are hydrological, hydro-dynamic, economic, social and ethical in nature. However, some of the most important ones are: groundwater stock available in a region; water level trends; net groundwater outflows against inflows; the economics of groundwater intensive use, particularly irrigation which takes lion's share of the groundwater in most semi arid and arid areas; the criticality of groundwater in the regional hydro-ecological regime; ethical aspects and social impacts of groundwater use. Let us examine how the use of these complex considerations in assessing groundwater over-draft would change the groundwater scenario in India.

First of all, as regards the groundwater stock, a region with huge amount of static groundwater resources may experience over-draft conditions, with resultant steady decline in water levels. The region which can be cited is alluvial plains of the Ganges, whose groundwater stock is many times more than the average annual replenishment (source: based on GOI, 1999: Table). In such regions assessing over-draft conditions purely in terms of average annual pumping and recharge may not make sense. In such regions, the long-term sustainability goal in groundwater use can be realized even if one decides to deplete certain portion of the static groundwater resources along with the renewable portion, annually (Custodio, 2000). Limiting groundwater use to renewable resources, with the aim of benefiting future generations, can mean foregoing large present benefits.

As regards the influence of water level trends, a region may not experience over-draft when pumping is compared against recharge. But, partial well failures could be an area of concern due to the seasonal drops in water levels. Such steep seasonal drops in water levels are characteristic of hard rock areas. For instance, historical data of water levels in 11 watersheds falling in Mulla-Mutha-Pawana shows levels of groundwater development below 20 per cent in eight watersheds. But fluctuations in water levels between post and pre monsoon were very high in many wells. For instance, in an observation well in watershed no. BM-42 in Dhanori village in Haweli taluka of Pune district shows a decline of 6.40 metres during the period from October 1991 to May 1992. Again, during the period from September 1996 to May 1997, a decline in water level of 6.35 metres was observed in water levels in the same well. In several years, the drop in water levels during the same period (between October and May) is in the range of 2.75 metres to 3.75 metres (source: Groundwater Survey and Development Agency, Pune Regional Office, Pune, 2001).

As per official estimates many such regions are still categorized as white and grey", though these areas face severe groundwater scarcity during summer (Kumar *et al*., 2001). Table 2 shows the data on wells which have failed, and well which are not in use, available from minor irrigation census of 2001 for 12 Indian States. The total number failed wells include both wells which have "permanently gone dry" and wells which are "temporarily not in use". The second category essentially refers to wells which are seasonal, due to seasonal depletion of groundwater. The data shows that the states which are mostly underlain by hard rock formations, both the percentage of wells that have failed and which are not in use are high. For instance, in Orissa, even as per 2005 official data, the stage of groundwater development was only 18% (GOI, 2005). But, a large percentage of dug wells (21.5%), and a much large percentage of deep tube wells (51.8%) have failed. In terms of numbers, a total of more than 79518 dug wells had failed in Orissa by 2001. Likewise, a significant percentage of open wells (17.3%) in AP have failed by 2000-01, though the level of groundwater development in the state was only 45% even as per 2005 estimates (GOI, 2005). The number of wells, which have failed, is also very large (204761). Similar trend is found in Tamil Nadu and Madhya Pradesh as well.

Table 2: Well Failures in Different Categories from Eight Major Indian States (2001)

Sr. No	Name of the State	Percentage of Wells which have failed/(Not in Use)		
		Dug wells	Shallow Tube well	Deep Tube well
1	Andhra Pradesh	17.3/20.20	2.4/2.9	1.6/2.2
2	Bihar	18.0/32.50	2.7/4.8	36.7/44.9
3	Gujarat	19.3/22.0	12.0/14.2	8.5/12.0
4	Madhya Pradesh	16.2/18.0	14.7/15.1	13.9/16.2
5	Maharashtra	9.30/10.9	4.3/7.9	10.7/13.6
6	Orissa	21.0/25.0	16.5/19.3	51.8/62.8
7	Punjab	0.0/0.0	0.0/0.0	1.2/1.6
8	Rajasthan	24.9/27.9	3.3/3.5	7.4/7.8
9	Tamil Nadu	20.0/22.1	7.5/8.1	19.7/20.4
10	Uttar Pradesh	4.4/9.50	0.80/1.2	3.7/5.0
11	West Bengal	6.30/10.3	3.5/4.4	9.8/12.2

Source: Authors' own analysis based on Minor Irrigation Census data 2001

Note: the figures in brackets show the percentage of wells which are currently not in use due to several reasons.

Similarly, the current district-wise assessment of groundwater development does not take into account the long-term trends, as the latest methodology suggests. A region might have experienced long term decline or rise in water levels; but a few years of abnormal precipitation (either drought years or wet years), may change the trends in the short run. Hence, assessment of over-draft conditions should integrate hydro-dynamics, i.e., the way groundwater levels behave.

Another dimension of groundwater over-exploitation is economic. The cost of production of water should not exceed the benefits derived from its use, or the cost of provision of water from alternative sources. Drops in water levels beyond certain limit cause negative economic consequences, by raising the cost of abstraction of unit volume of water, not only in irrigation but also in other sectors like municipal uses. Though there could be plenty of water in the aquifers, the fixed cost and variable costs of abstraction of water could be prohibitively high. In alluvial north and central Gujarat and arid Rajasthan, groundwater irrigation is viable due to heavy electricity subsidies. An analysis by Kumar *et al.* (2001) in Sabarmati river basin of north-central Gujarat showed that groundwater irrigation would be economically unviable if the full cost of energy used for pumping groundwater is borne by the farmers.

In many hard rock areas underlain by basalt and granite, the highly weathered zones in the geological formations, which yield water, have small vertical extent-up to 30 m. When the regional groundwater level drops below this zone, farmers would be forced to dig bore wells tapping the zone with poor weathering. The reason is tapping groundwater from strata below this depth using open wells would be not only technically infeasible, but also economically unviable. These bore wells have poor yields, unlike the deep tube wells in alluvial areas such as north Gujarat, alluvial Punjab, Uttar Pradesh and Haryana. For instance, analysis of census data (Table 3) show that as high as 40 per cent of the nearly 85,601 deep bore wells (that are in use) in AP were not able to utilize their potential due to poor discharge. The figure was nearly 19.1% for Rajasthan, which had sedimentary and hard rock aquifers. The figure was 59.9 per cent for Maharashtra, which has basalt formations. One could see that the percentage of deep tube wells which suffer from poor discharge was very low in alluvial areas of Punjab (0.30%) and West Bengal (0.30%). While the number is very high for alluvial Bihar, the total number (430) is negligible.

Table 3: Percentage of Dug Wells and Deep Tube Wells Suffering from Poor Discharge in Selected Indian States

Sr. No	Name of the State	No. & Percentage of Wells in Use Which Face Discharge Constraints	
		No. of Deep Tube Wells	% of Deep Tube Wells
1	Andhra Pradesh	34216	40.0
2	Bihar	430	12.6
3	Gujarat	20282	24.5
4	Madhya Pradesh	17841	58.5
5	Maharashtra	39958	59.9
6	Orissa	132	7.7
7	Punjab	10	0.10
8	Rajasthan	10010	19.1
9	Tamil Nadu	22838	34.1
10	Uttar Pradesh	3110	9.3
11	West Bengal	15	0.30

Source: authors' own analysis based on Minor Irrigation Census data 2001

Withdrawal of groundwater from these bore wells creates excessive draw-downs as specific yield and transmissivity values of these hard rock formations are very low. Due to excessive draw-downs and high well interference, well failures become widespread. Therefore, before a farmer hits water in a successful bore well, he/she would have sunk money in many failed bore wells. Due to this reason, the actual cost of abstraction of groundwater becomes very high. The command area of wells is also on the downward trend. For instance, in the case of five districts falling in the basaltic area of Narmada river basin in

MP, the average command area of energized wells were found to be declining almost consistently from 1974 till 2000 (see Table 4). In Betul district, the average area irrigated by a well reduced from 6.97 ha to 2.18 ha during the 26 year period. In Chhindwara, it reduced from 4.56 ha to 2.75 ha. So investment for well construction, compounded by reduction in command area reduces the overall economics of well irrigation. But, this aspect has been captured in the criteria for assessment of over-exploitation. As per the official data, these five districts are still in the white category, and safe for further exploitation (GOI, 2005).

Table 4: Reduction in Average Command Area of Wells over Time in Narmada Basin, MP

Name of District Falling in Narmada Basin	Average Area Irrigated by a Well in Ha					
	1974-75	1980-81	1985-86	1991-92	1995-96	2000-01
Balaghat	4.50	2.25	2.35	2.57	1.73	1.96
Chhindwara	4.56	2.58	2.26	1.42	1.50	1.75
Shahdol	2.04	0.18	0.50	0.70	0.99	0.47
Jhabua	2.93	1.87	0.89	1.20	1.26	0.57
Betul	6.97	3.37	3.02	1.98	2.06	2.18

Source: Authors' own estimates based on primary data as provided in Kumar (2007)

Interestingly, the economics of groundwater use is not a function of depth to water table alone, as often perceived. Even in areas with shallow water table conditions the cost of abstraction could be enormously high due to high cost of energy. In Bihar, due to poor rural electrification, farmers are forced to use diesel and kerosene pumps for lifting water from wells. Though the depth to water table is nearly 15-20 feet, it costs them Rs.50 per hour for pumping water with an output of nearly 15 litres per second. The unit variable cost comes to Rs. $1/m^3$ of water. This is higher than the variable cost farmers incur in north Gujarat (Rs.$0.50/m^3$) for pumping out water from a depth of 400-500 feet.

The economics of groundwater use is not static. Economic viability of groundwater abstraction can change under two circumstances: 1] opportunities for using the pumped water for more productive uses emerge with changing times; and 2] the cost of abstraction of groundwater changes due to improvements in pumping technologies, or changing cost of energy for pumping groundwater. With massive rural electrification, cost of groundwater abstraction in Bihar could come down to negligibly low levels. On the other hand, adoption of new high yielding varieties or high valued crops can increase the gross returns from farming.

Social consequences of groundwater use are equally important. One serious issue associated with groundwater intensive use is that it excludes resource poor farmers from directly accessing the resource when water levels start falling. Equity in access to resource (aquifer) should be an important consideration in assessing the degree of over-exploitation of aquifers. In many areas, it is only the rich farmers, who are able to pump groundwater, owing to astronomical rise in cost of digging/drilling wells, and they enjoy unlimited access to the resource. While the well owners of Mehsana incur an implicit cost of nearly Rs.$0.5/m^3$ of water[6], they charge to the tune of Rs.$1.5/m^3$ to Rs. $2/m^3$ from the buyers. Similar trends were found in Kolar district, in which case the well owners charge up to Rs. $6.5/m^3$ of water (source: based on Deepak *et al.*, 2005), against a close to zero marginal cost of pumping groundwater. In many areas, groundwater intensive use leads to water quality deterioration, causing scarcity of safe water for drinking. In such situations, the draft does not necessarily

[6] This is based on the capital investment of 10 lac rupees amortized over the life of the tube well (12 years), the annual operation and maintenance costs of Rs. 50,000 and the average volume of 2.5 lac cubic metre of water pumped during a year at a rate of $100m^3$/hour.

exceed the recharge. Examples are Saurashtra and Chennai coast, alluvial north and central Gujarat, Gangetic alluvium of West Bengal. While the issue is of salinity in coastal Saurashtra and Chennai, it is arsenic content in deep aquifers in West Bengal (Kumar and Shah, 2004).

Groundwater over-use, like the use of other natural resources involves ethical considerations (Custodio, 2000). The ethical considerations concerning water use mainly revolve around the distribution of benefits and costs of water use and risks associated with it (Llamas and Priscoli, 2000). The extent to which wasteful use practices are involved in major sectors of water use and the degree to which water abstraction practices reduce the opportunities of users--neighbouring farmer, individual himself, and others--, are the major issues to be investigated (Kumar, Singh and Singh, 2001). In a water-scarce region, physically and economically inefficient uses should be discouraged. But, in reality, even in regions where acute scarcity of groundwater exists, farmers use traditional irrigation methods that are wasteful; and allocate water to economically inefficient uses (source: based on Kumar, 2005; Deepak *et al*., 2005). In hard rock areas, competitive drilling by powerful farmers causes reduction in yield of neighbouring wells due to well interference, depriving resource-poor farmers (Janakarajan, 2002; Deepak *et al*., 2005).

In sum, the current assessment of groundwater over-exploitation does not give a clear picture of actual intensity of over-exploitation in both absolute and relative terms. It tends to underestimate the magnitude of groundwater over-exploitation in India, which can be assessed from the negative social, economic and ecological consequences of over-development. From that perspective, many districts in MP, Andhra Pradesh, Tamil Nadu could be actually over-exploited, though the official figures show that they fall under "safe", "semi-critical" or "critical". The regions which have serious problems are: alluvial Punjab; both hard and alluvial areas of Gujarat; hard rock areas of Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh,

IV. Impact of Groundwater Over-exploitation on Agriculture and Food Security

The past one decade had witnessed a slow down in growth of agricultural GDP from 3.3 per cent during 1980-95 to 2 per cent during 1995-2003. This has been accompanied by a decline in food consumption per unit of population. The per capita net availability of food grains (a rough measure of consumption) in 2004-2006 was 7.*8* per cent lower than in 1994-1996. It was even lower than what existed in 1954-1956. The agricultural crisis has grave implications for the country's ability to feed itself. In order to maintain the per capita production level of 2001-2, food grains production should reach 240 million tonnes in 2010. Given that food grains production was only 219.3 million tonnes in 2007-8, this is highly unlikely.

As groundwater contributes more than 5% of India's GDP[7] (Kumar, 2007) and accounted for nearly 61.2% of the net irrigated area in the year 2000 (source: Ministry of Agriculture, Government of India), it is a truism that depletion will have long-term impacts on the country's economic growth and food security. But, the potential future impacts of groundwater over-exploitation in a particular region on India's food security depend on: the relative contribution of well irrigation in that region to India's food security; the degree of over-exploitation of groundwater in the region; and the degree of vulnerability of the region. Here, vulnerability is considered to be an inverse function of the groundwater stock available for mining and the amount of water import available from outside that help improve the

[7] Only the contribution from 15 major Indian states was considered for estimating the size of groundwater economy. The size of the groundwater economy was estimated at 113000 crore rupees.

condition of groundwater. From that point of view, alluvial Punjab can be considered less vulnerable, though the degree of over-exploitation is very high as per out criteria.

According to some estimates, groundwater accounts for nearly 80 per cent of the agriculture production from irrigated areas in the country. Its contribution to the nation's food basket is quite major. But, the relative contribution of groundwater to irrigated area varies widely from state to state. Table 5 provides the aggregate area and percentage area irrigated by groundwater in major Indian states. It clearly shows that in the semi arid and arid states, the aggregate area under well irrigation is very large. Also, the percentage contribution of groundwater to total irrigation is major.

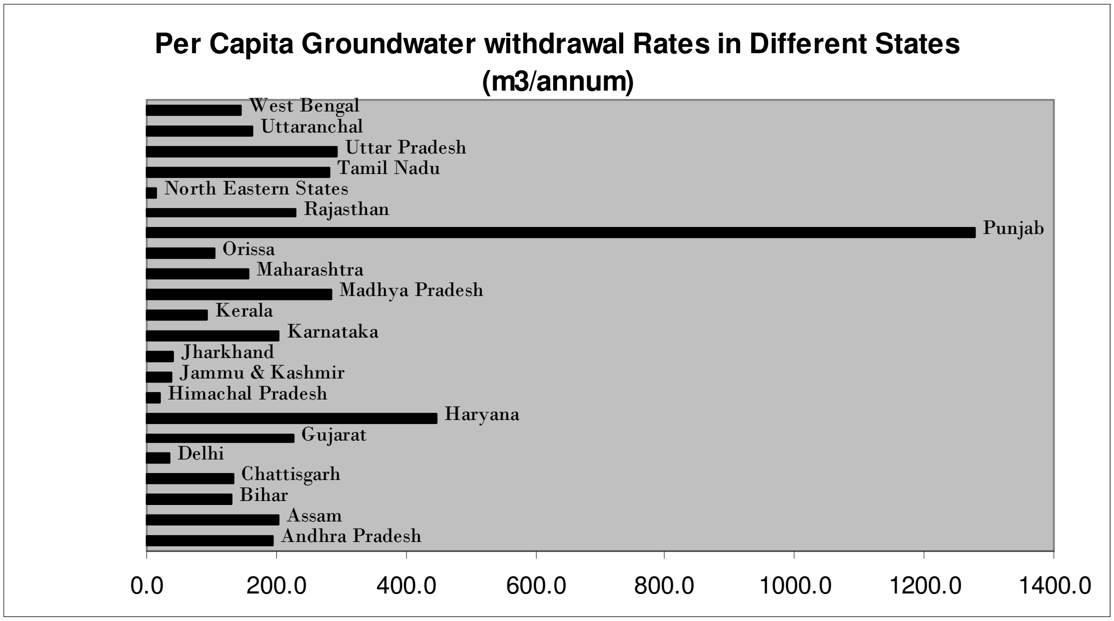
Table 5: Gross Irrigated Area and Well Irrigated Area for Major Indian States

Sr. No	Name of the State	Gross Irrigated Area	Gross groundwater Irrigated Area	Percentage Contribution of Groundwater
1	Andhra Pradesh	5.74	2.45	42.68
2	Gujarat	3.51	2.81	80.06
3	Haryana	5.22	2.57	49.23
4	Karnataka	3.17	1.19	37.54
5	Madhya Pradesh	4.59	3.10	67.54
6	Maharashtra	3.82	2.63	68.85
7	Orissa	2.39	0.62	25.94
8	Punjab	7.80	5.92	75.90
9	Rajasthan	6.60	4.30	65.15
10	Tamil Nadu	3.50	1.88	53.71
11	Uttar Pradesh	17.67	13.42	75.95
12	West Bengal	3.50	2.13	60.86

Source: Ministry of Agriculture, Government of India, 2000.

Now, the problems of groundwater depletion are encountered in both alluvial areas and hard rock areas. Examples are alluvial areas of Punjab, Haryana, and Gujarat mainland, and hard rock areas of Andhra Pradesh, Tamil Nadu, Karnataka and Saurashtra region of Gujarat. These regions also show much higher rates of withdrawal of groundwater in per capita terms when compared to some of the physically water-rich regions (Figure 2). This sharp difference could be attributed to the differences in per capita cropped land, and climatic conditions, which change the demand for water for crop growth. Punjab has the highest rate of withdrawal of groundwater with a per capita annual draft of nearly 1279.2 m^3, and north eastern States have the lowest (15.9 m^3). The rich groundwater endowment in the extensive alluvium extending over most parts of Punjab support intensive cultivation of the land with high water-intensive crops such as wheat and paddy in this region with arid and semi arid climatic conditions.

Within alluvial areas, over 80 per cent of the blocks in Punjab and Rajasthan, and over 60 per cent pf the blocks in Haryana are falling in either over-exploited or critical or semi-critical blocks (GOI, 2005). With secular decline in water levels, shallow wells dry up. As the investment for drilling tube wells reaches astronomical heights, the poor farmers lose out in the race of chasing water table. They are either forced to purchase water from the rich well owners at prohibitive prices or shift to rain-fed farming practices. For instance, the tube well owners of Mehsana in north Gujarat charge as high as Rs.70- Rs.100 for an hour of irrigation service. In the first case, the economics of farming itself is adversely affected due to the rise in cost of production, affecting the livelihood security. The water buyers show increasing tendency to grow cash crops that give much higher returns per unit of water



consumed, as they are confronted with high marginal cost of using water and have limited access to irrigation water in volumetric terms (Kumar, 2005).

It is important to note that the alluvial areas that fall under semi arid climate such as Punjab, Haryana, Rajasthan and north Gujarat are large exporters of agricultural commodities. While Punjab and Haryana exports cereals such as wheat and rice, Rajasthan exports wheat (Amarasinghe *et al.*, 2004), and north Gujarat is a net exporter of milk (Singh et al., 2004). Table 6 shows the aggregate and relative contribution of five Indian states falling under alluvial areas to India's wheat and rice production. It can be seen that a little more than 44 per cent of the total wheat production in the country comes from the three north Indian states, which are also known for severe problems groundwater over-draft. These states also contribute more than 20 per cent of India's rice production. Though the relative contribution is not high, it is important to remember that these are largely wheat-consuming states, and most of the production is available for export to the rice-consuming states in the south and east.

Table 6: Aggregate and Relative Contribution of States Falling in Semi Arid Alluvial Areas to India' Wheat and Rice Production (2000)

Sr. No	Name of the State	Wheat Production	Percentage Contribution	Rice Production[8]	Percentage Contribution

[8] Figures of raw rice production are for the year 2006.

1	Punjab	16.01	22.10	15.207	10.79
2	Rajasthan	6.36	8.78		
3	Haryana	9.79	13.51	5.057	3.63
	Total All Indian production	72.44		139.13	

Source: Ministry of Agriculture, Government of India.

Therefore, permanent depletion of groundwater in these regions would adversely affect national food production with area under well-irrigated crops reducing and farmers moving away from cereals to less water-consuming and high risk cash crops. The situation is likely to be more severe in states such as Rajasthan and Gujarat, where replenishment of groundwater in the over-exploited areas through import of surface water is extremely limited.

In the second case, crops become highly vulnerable to vagaries of monsoon with very high incidence of failure during droughts. High inter-annual variability in rainfall and frequent droughts are characteristic features of these low-medium rainfall regions (IRMA/UNICEF 2001; Kumar 2002). As a result, agriculture and rural economy become more and more vulnerable to droughts. The rich farmers are able to sustain tube well irrigation because of the flat rate mode of pricing electricity. Under the flat rate system, since the marginal cost of pumping is zero, the well-owning farmers can pump out excess water and provide irrigation services to the neighbouring farmers. By doing this, they can even earn profits, after recovering the high capital investment for well construction, and the high fixed operating costs.

Again, when groundwater resources deplete and the cost of well construction and pumping increases, the system of trading water provides greater economic opportunities to well owners having large holdings, and lesser opportunities to well owners having smaller holdings and water buyers. This is due to the fact that for a large farmer, the implicit unit cost of water is much lower as compared to small farmers. At the same time, a small farmer will not be able to raise the water charges to match with the implicit cost of pumping, as the prices are determined by the market forces (Kumar *et al.*, 2001).

Analysis has shown that in deep tube well areas of north Gujarat, if the State Electricity Boards start charging the full cost of electricity for pumping, irrigated production of many crops would be un-viable (IRMA/UNICEF, 2001; Kumar and Singh, 2001). This means that from a larger societal point of view, groundwater irrigation in such situations does not contribute to economic growth. On the other hand, it also has negative ecological impacts. The cumulative effect will be that the net social welfare would be negative.

In the case of hard rock areas, as seen in the earlier section, one of the immediate consequences of over-development has been the increase in incidence of well failures, and reduction in well yields. In such cases, the farmers are found to drill bore wells, to sustain access to irrigation water. As earlier analysis has shown, the bore wells have poor discharges, and the well owners find it hard to grow water-intensive crops such as paddy.

Here as well, the poor farmers, who do not have sufficient resources, lose out in the race. This has led to widespread emergence of groundwater markets, and rising price of well water. As hard rock areas have limited groundwater potential, water markets become monopolistic in nature (Janakarajan 2002; Deepak *et al.*, 2005; Kumar, 2007). Gradually, irrigated farming itself becomes un-viable for water buyers. Wherever farmers continue irrigation with purchased water, shifting to high valued crops has been a widespread phenomenon. Hard rock areas contribute to India's food security in a major way. For instance, nearly 51.5% of India's total rice production comes from the five states that are falling under hard rock category, and which are facing negative consequences of over-exploitation (Table 7). More importantly, Andhra Pradesh and Tamil Nadu, which are experiencing over-exploitation problems, account for 20.2 % of India's rice production. Hence, the impact of depletion in hard rock areas on food security would be remarkable.

Table 7: Contribution of States falling in Hard Rock Areas to India's Rice (Rough) Production in 2006

Sr. No	Name of the State	Rice Production (million ton)	Percentage Contribution to total production	Wheat Production (million ton)	Percentage Contribution
1	Andhra Pradesh	17.796	12.79	0.00	0.00
2	Chattisgarh	7.562	3.51	0.00	0.00
3	Karnataka	4.893	5.43	0.00	0.00
4	Madhya Pradesh	2.052	2.72	4.86	6.70
5	Maharashtra	3.794	7.38	1.18	1.62
6	Orissa	10.191	7.32	0.00	0.00
7	Tamil Nadu	10.263	12.79	0.00	0.00
	All India Total	139.13		72.44	

Source: Rough Rice Production (000 t) in India, by State, 1961-2006.

In nutshell the impact of groundwater depletion and resultant water scarcity would be multiple. First, it would reduce the contribution to the nation's grain pool as the states experiencing depletion, have significantly large well-irrigated areas, and are exporters of grains and agricultural commodities. Decline in food production could increase the food domestic food prices. Further, depletion would force the farmers, particularly water buyers, to grow high-valued crops with their well water that are often risky. As the prices of these high valued crops are sensitive to market fluctuations, the farmer households also become vulnerable to income losses. This would adversely affect their domestic food security.

V. Faulty Opinions Vs Harsh Realities

Given the significant contribution groundwater makes to India's agriculture production and food security, and the unique advantages of groundwater over surface water, researchers were pre-occupied with the questions of "how to sustain the groundwater boom" for quite a few years. The fact that aggregate level only a little more than 50% of the dynamic groundwater resources are exploited, had made at least some of them argue for intensive development of groundwater in regions that are yet to see the growth in well irrigation such as eastern India (see Mukherji, 2003; Shah, 2001). They argue that eastern India's agricultural stagnation can be turned around by improved access to well irrigation, given the region's rich endowment of groundwater. Further, informal water markets (pump rental markets) were suggested as institutional mechanisms to promote access equity in groundwater irrigation (Mukherjee, 2003; Shah, 2001).

Suggestions for flat rate pricing of electricity were made to promote water markets and reduce their monopoly power of well owners (Shah, 2001; Mukherjee, 2003). But, in water abundant eastern India, electric pump owners enjoy higher monopoly power over buyers in water trading (Kishore, 2004). The monopoly power comes from the poor transferability of water, and the very high transaction cost of obtaining power connections. Hence, power pricing policy will have very little impact on price of water. The impact would also be null and void, if significant number of well owners in the locality continues to use diesel engines for which the marginal cost of production of water is much higher. The high transaction cost involved in obtaining subsidies for purchase of diesel engines increases the monopoly power of diesel pump owners, in areas dominated by diesel engines. There is very little one can do to change the way well irrigators behave or water markets operate or reduce the monopoly power of well/pump owners, through changes in power pricing policies in eastern India. The real challenge lies in: a] making the process of securing electricity connections in farm sector easy; and b] accessing pump subsidies easy for poor small and marginal farmers (Kumar, 2007). Even if these issues are addressed, the constraint imposed by land availability in enhancing production cannot be ignored. In fact, the intensity of cultivation and irrigation are already considerably high in eastern India (GOI, 1999), and there are ecological constraints in further expansion of cultivated and irrigated areas.

Another important alternative suggested by many researchers to sustain the boom in well irrigation is water harvesting and artificial recharging of groundwater to arrest depletion (Shah *et al.*, 2003). There are many technologies and practices for recharging the aquifers. We have already seen that semi arid Punjab, Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu and Madhya Pradesh are the main states that are experiencing over-draft. Research has shown that the potential for artificial recharge in India is very low in these arid and semi arid regions. The reasons are: a] low to medium mean annual rainfalls and highly variable and erratic rainfall which reduces the overall runoff availability, runoff collection efficiency, and hence economic viability; b] the poor infiltration capacity of thin soils in hard rocks areas that constitute major chunk of India's semi arid regions, resulting in poor recharge rates (Muralidharan and Athawale, 1998); c] poor storage potential of hard rock aquifers underlying the areas; and d] high rates of evaporation from water bodies (Kumar *et al.*, 2006; Kumar *et al.*, 2008). But, past discussions on groundwater recharge has not considered factors such as hydrological opportunity and economic viability. Recent analysis shows that intensive water harvesting and recharge activities would have serious negative ecological consequences in arid and semi arid regions (Kumar *et al.*, 2006; Kumar *et al.*, 2008).

Virtual water trade has been suggested as a means to deal with the groundwater crisis of water scarce regions by some environmentalists. The argument was that the ecologically fragile regions such as Punjab are producing water-intensive crops at the cost of resource use sustainability and energy use efficiency (Gulati, 2002), and instead food security can be achieved by encouraging water rich regions to produce surplus food for other regions. The proponents of this virtual water trade argument cite comparative advantage of eastern India in producing wheat and rice with much less amount of water. While it goes without saying that the water-scarce regions such as Punjab, Rajasthan, Gujarat, Maharashtra and Peninsular India need to make agricultural water use much more efficient, thereby reducing the pressure on their limited freshwater resources, this argument is far stretched. It has missed out the point that these water-rich regions lack sufficient amount of arable land that can be put to use for producing sufficient food for itself leave alone the issue of producing surplus for other regions; and that only the water-scarce regions are endowed with sufficient amount of this basic resource to produce surplus. Analysis shows that the virtual water trade is governed by access to arable land, and not renewable water resources. While access to arable land ensures some amount of water in the soil profile to grow crops, "water richness" does not ensure the amount of land to put that water to use (Kumar and Singh, 2005).

VI. Sustaining Groundwater Irrigation

In many semi arid and arid parts of the country, groundwater irrigation has expanded over the past many years (source: Minor Irrigation Census, 1995). Most of these regions are underlain by hard rock formations with poor groundwater potential. They include western and central Orissa, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Chattisgarh and most parts of Madhya Pradesh. Exceptions are Rajasthan and parts of Gujarat. Many parts of Rajasthan have sedimentary aquifers, whereas Gujarat has deep alluvium in large parts. Though according to official statistics groundwater development is still very low in these regions (GOI, 2005), it is based on average annual abstraction and recharge estimates. The annual water level trends are a net effect of many inflows into and outflows from the aquifer. These inflows and outflows determine the utilizable resources. But, this crucial variable is still not considered in the methodology for estimation of utilizable groundwater resources being adopted by Central Ground Water Board, and the concerned state government agencies.

The outflows into rivers and streams, which reduces the utilizable groundwater, are quite remarkable in upper catchment of many river basins that are underlain by hard rocks, and more so in western Ghats and hills of north east. As a result, official figures still put many of these areas as suitable for further exploitation. But, water levels have dropped remarkably in the recent decades in these areas. Hence, the chances of over-estimation of utilization potential of the resource could be high (Kumar, 2007).

Most of these hard rock regions are endowed with sufficient amount of arable land which can be brought under irrigated production. Many large and small cities also heavily depend on groundwater for municipal purposes. But, limited amount of utilizable groundwater would put a limit to further exploitation. In these regions, farmers have already moved from open dug wells to deep bore wells in search of water as shallow weathered formations get dried up very fast due to falling water levels. The deep bore wells are characterized by extremely low yields. Hundreds of thousands of open wells have gone out of use, though there are no exact statistics available on the investments that are going dead. Hence, the economic viability of tapping water from deeper hard rock strata is poor and therefore the opportunities for expanding well irrigated area are limited in these regions. But, these factors are not taken into account in the estimation of groundwater irrigation potential by Central and State agencies (Kumar, 2007).

In the recent past, groundwater irrigation has increased in sub-humid regions, including eastern Uttar Pradesh, Bihar, Assam and West Bengal. There is plenty of both dynamic and static groundwater in this deep alluvial region. These regions can support more wells. But, the issue is of availability of sufficient amount of arable land to expand the net sown area, as irrigation intensities are already very high. In Punjab and Haryana, the net sown area, the net irrigated area, and irrigation intensities are already at their peak, and groundwater contributes significantly to this. So is the case with UP and West Bengal. UP has the largest area under well irrigation among all Indian states (Kumar, 2007). In Bihar, the potential available for increasing irrigated area is very low due to several ecological factors, though there could be remarkable increase in net value product from agriculture due to reduction in cost of irrigation, and improvements in quality of irrigation particularly for water buyers (Kishore, 2004).

The water balance equation presented in the paper clearly shows that there are five major ways to sustain the groundwater economy. 1. Improve the surface irrigation in intensively irrigated areas, facing over-exploitation. 2. Improve the efficiency of utilization of green water or the rainwater held in the soil profile (P_e). 3. Reduce the soil water depletion, through reduction in the amount of residual moisture held in soils after harvesting. 4. Reduce the consumptive use of water (ET) through shift to low water consuming crops that are economically more efficient, i.e., crops that give higher net returns per every unit of water consumed (Rs/ET).

In some of the intensively irrigated areas, the scope for increasing the allocation of surface water for irrigation might exist. This needs to be explored. This deserves merit as the pockets which are receiving canal water are found to be having less number of administrative units falling under "over-exploited" and "critical" categories. Also, as the discussion in section 3 brought out, the magnitude of groundwater over-exploitation would have been much higher had the surface water not been available for irrigation in Punjab. Further, increase in efficiency of application of water through better reliability of water delivery, and control over water application could help reduce the amount of water depleted, and increase the consumptive use and productivity of water. But, in certain other cases, where there is plenty of surface water available for irrigation particularly during monsoon, applying excessive irrigation and the use of its return flows for recharging aquifers can be explored.

Improving the efficiency of use of soil water offers tremendous potential in medium and high rainfall areas in reducing the irrigation requirement of many crops. This can be done through advancing sowing of monsoon crops; conservation of available soil moisture, through evaporation prevention; and in situ water harvesting. Shifting to orchard crops and oil seeds can bring down the evapo-transpirative requirement of crops. But in regions like Punjab, where almost all the cultivated land is irrigated, it is important that such crops give same or higher return per every unit of land irrigated as well. The reason is that the scope for expanding the area under the crop won't be available in these regions unlike other semi arid and arid areas where the total irrigated land is a small fraction of the cultivated land.

But current mode of pricing followed in canal water is not volumetric in most states, and instead is based on crop area. Also, the power tariff policy followed by many states for farm sector is not economically efficient. Electricity is either supplied free or charged on the basis of connected load[9] (Kumar *et al.*, 2008). Under such conditions, the marginal costs of using water and electricity are close to zero, except when the supply of energy and water is extremely limited. Such conditions do not leave any incentive among farmers of these regions to adopt measures to improve the efficiency of water use in irrigation except those which also improve the returns per unit of land. Therefore, what is most important is to introduce reforms in water and energy sector, including volumetric pricing of canal water, and consumption based pricing of electricity used in groundwater.

VII. Conclusions

The real food security and water management challenge lies in the fact that the country is characterized by regional imbalances in water resource endowments and water demands that juxtapose with high demands in regions of natural water shortage and low demands in regions of water abundance. Since the low demand for water in water-rich regions is due to lack of sufficient arable land in these regions, the additional water required to meet the food deficit in this region eventually has to be found in water-scarce regions, which have good endowment of arable land. This puts additional pressure on the water-scarce regions for freshwater. Hence, food crisis is as much a crisis of land in water-rich regions, as crisis of water in semi arid and arid, water-scarce regions. Groundwater over-draft problems in the water-scarce regions increase the magnitude of the crisis.

Assessment of over-exploitation should involve complex considerations that are hydrological, hydro-dynamic, economic, social and ethical in nature that determines their undesirable consequences. Some of them are groundwater stock available in a region; water level fluctuations; economics of groundwater exploitation; and social impacts and ethics in groundwater use. The official assessments of groundwater development fail to integrate these complex considerations. In this paper, we have demonstrated that combining official statistics of groundwater development in the country, with information on detailed water balance, geology, water level fluctuations, and socio-economic, ecological and ethical aspects would cast an altogether different scenario of the degree of over-exploitation problems in India. In nutshell, groundwater over-exploitation problems in India are much serious than what official assessments indicate.

If unchecked, its impacts on national food security are likely to be severe as the regions that are experiencing over-draft are also regions producing surplus cereals that are

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[9] There are rare cases where unit charges are levied for electricity consumption in farm sector. Gujarat is one such case, where nearly 50% of the farm connections are metered.

exported to land-starved water-surplus regions. The alluvial areas of Punjab, Rajasthan and Haryana that experience secular decline in water levels are largest contributors to India's wheat stock. The hard rock regions of Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Chattisgarh and Karnataka are largest contributors to India's rice stock. The food security impacts would be multiple. First: depletion shrinks the area irrigated by wells, thereby causing the irrigated area under cereals. Second: when water becomes scarce, and cost of irrigation water rises, the farmers move away from traditional cereal crops that give low returns per unit of water and adopt cash crops that are high risk. This also can lead to decline in food production and national food security. All these could lead to rising prices of cereals, jeopardizing the ability of poor people to purchase food. As the prices of the high valued crops are highly sensitive to market fluctuations, the farmer households can also become vulnerable to income losses, thereby getting exposed to food insecurity.

Several of the ideas being pursued or discussed as solution to groundwater over-exploitation problems are fanciful, need to be replaced by serious scientific research to explore the physically and economically viability and the actual potential of the following key strategies at the macro level 1. Improve the surface irrigation in intensively irrigated areas, facing over-exploitation. 2. Improve the efficiency of utilization of green water or the rainwater held in the soil profile (P_e). 3. Reduce the soil water depletion, through reduction in the amount of residual moisture held in soils after harvesting[10]. 4. Reduce the consumptive use of water (ET) through shift to low water consuming crops that are economically more efficient, i.e., crops that give higher net returns per every unit of water consumed (Rs/ET) (Kumar, 2007).

But, under the current pricing regime followed in canal water, and the electricity pricing policy followed by many states for farm sector, the marginal cost of using water and electricity are close to zero, except when the supply of energy and water is extremely limited. Such conditions do not leave any incentive among farmers of these regions to adopt measures to improve the efficiency of water use in irrigation except those which also improve the returns per unit of land. Therefore, what is most important is to introduce reforms in water and energy sector, including volumetric pricing of canal water, and consumption based pricing of electricity used in groundwater (Kumar *et al.*, 2008).

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[10] Micro irrigation systems such as drips and sprinklers are some of the technologies to reduce the non-beneficial soil water depletion from cropped land (Narayanamoorthy, 2004; Kumar et al., 2008). Zero tillage is another technology and can be useful in rice-wheat system. Plastic mulching is another technology useful for a wide range of crops (Kumar et al., 2008).

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