FOOD SECURITY, WATER AND ENERGY NEXUS IN INDIA

EXECUTIVE SUMMARY

India realized a quantum jump to 230.67 million tonnes of food grain in 2007-08 as compared to the mean of 209.03 and a range of 198 to217 million tonnes in the previous four years. The comfortable level of food buffer stock and sound fundamentals of agriculture are able to withstand the global economic recession triggered in 2008-09. Incremental production from the limited and fatigued land resources is also essential to cope with demographic dynamics, changes in the food habits and livelihood styles. The States of Punjab, Haryana and UP contribute about 98% of wheat and 52% of rice to the buffer stock. Punjab procured about 81 % of rice and 57 % of wheat compared to 24% and 21% of rice and wheat procurement at all India level. Further, the Punjab contributed 36 % rice and 56 % wheat to the central pool. About 97.6% of net sown area of Punjab is irrigated with 71% contribution of ground water. About 41 billion m^3 of virtual water goes out of State while contributing to the food buffer stock and 76% of it is ground water.

There is an average annual negative balance of 12 billion m^3 of water leading to sharp decline in the ground water levels and contribution of Punjab to the food security is not sustainable in the long range. In 2007 about 7.5 billion (750 crores) units of electricity (28% of total consumption of the State) was consumed by tube-wells. If the present trend in the decline of water table continues, electricity consumption will double by 2023. Punjab State Electricity Board is losing about Rs.2000 crores (Rs.20 billion) per annum with accumulated losses of Rs.15000 crores (Rs. 150 billion) up to 2007-08 and rice alone accounts for Rs.14400 crores (Rs. 144 billion) of losses. There will be a phenomenal replacement cost of tube-wells to the farmers with further decline in water table. Overall this trend in the excessive consumption of water, energy and investment portfolio is not favourable for

sustainable food security of India. Remedy for this malady lies both within Punjab and elsewhere especially in the Eastern India

The ultimate analysis reveals that anaerobic or puddled rice cultivation is the main culprit. Delay in the transplanting of rice after scorching heat of May-June, diversification into its cultivation practices, alternative but equally remunerative crops or commodities can cut down the water consumption. Technological innovations for enhancing productivity of alternative production of vegetables, fruits, dairying, pulses, oil seeds etc. may be evolved to be economically better than rice cultivation. This would require strengthening and consolidation of R&D infrastructure and restructuring of subsidy into incentives in such a way that farmers switch over to the most efficient practices of irrigation, other inputs and diversifications.

Loss in food grain production especially of rice in Punjab due to contemplated diversification has to be compensated elsewhere to maintain integrity of national food security. Eastern India with 2-3 times more rainfall as compared to Punjab, highest unexploited good quality ground water aquifers in Assam, West Bengal, Bihar and vast resources of social capital have relative advantage for sustainable production of water guzzling crops like rice, banana, sugarcane and aquaculture. Managing 11 million ha of land remaining fallow after paddy harvest, high productivity of winter maize and Boro rice are very attractive opportunities. Special emphasis on correcting soil acidity by liming especially for cultivating oil seeds, pulses, vegetables and fodder crops is essential. In-situ conservation, recharging of ground water and runoff harvesting especially in undulating topographies should be the main driver for improving productivity and cropping intensity. Improvement in the traditional rice-fish production system and alternative aquaculture-horticulture based farming systems of ponds and dykes have tremendous potential in high rainfall, coastal and shallow water table areas. Managing vulnerability and risks due to climatic changes would encourage investment decision with reduced possibilities of distress.

An assured system of delivering improved technologies, inputs, support price, procurement and prompt payment in eastern Indian States will only be able to create healthy competition with Punjab, Haryana, Western Uttar Pradesh, etc. Consolidation of fragmented land holdings, enabled land tenure and leasing systems, rural electrification and infrastructure development are the prerequisite of green revolution in the alternative states and regions. A comprehensive planning and investment decisions to realize win-win development of all states, regions and stakeholders is called upon for this huge but noble cause of national integrity, food security and social harmony.

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1.0 Introduction

The most important lesson of the 2008-09 global economic slowdown is that food security is of supreme national importance for maintaining social harmony, national integrity and sovereignty of India. India's current population of 1.12 billion (112 crores) is likely to grow to 1.35 billion (135 crores) by 2023 and demands 23 % increase in agricultural production. Probabilities of occurrence of droughts, crop failures and livestock damages vary from once in 2.5 to once in 15 years in various agro-ecological regions of India. Historical occurrences of devastating famines in India are well documented in the literature. After the Bengal famine of 1943 India could withstand severe droughts of 1972, 1987 and 2002 due to the Green Revolution leading to food buffer stock in the country. Similarly 40 million ha of land is vulnerable to floods, loss of crops, livestock and livelihoods, devastations, miseries and periodic relocations of people. Water logging and accumulation of salts in the soil surface is a slow degradation process but sizable area is getting afflicted especially in canal commands year after year. This has happened in South Western Punjab, Southern Haryana, Indira Gandhi Canal command of Rajasthan, Sharda Sahayak of Uttar Pradesh and others.

Public investments into hydroelectric power generation, canal networks, rural electrification for energising ground water harnessing, roads, markets, other infra-structure, research and development ushered in the Green Revolution. India's food grain production touched the ever highest record of 230.67 million tonnes in 2007-08 after hovering around 198 to 217 (average 209) million tonnes in the previous 40 years with a very high comfort level of buffer stocks. The net irrigated area of 58.5 million ha in India comprising 40 % of net sown area contributes 60 % to the food-grain production.

About 60 % of the net sown area in India is rain-fed, complex, diverse, under-invested and contributing 40 % to the food-grain production and supporting 40 % population is highly vulnerable. The average food-grain productivity of predominantly irrigated 5 top most States is about three t ha^{-1} compared to about one t ha^{-1} under rain-fed conditions. Productivity of the rain- dependent 80 % area under fruits, 100 % grazing lands and forests is also very low, un-reliable and distress prone. Climate change due to global warming is increasing complexities and vulnerability of food security both in the irrigated and rain-fed agriculture. Frequency of extreme weather events of heat waves, cold waves, cyclones, floods, droughts, outbreaks of pests and diseases have increased especially during the past 20 years. During 1951-2007 the frequency of dry spells (break in monsoon) and the number of dry spell days (break in monsoon days) showed an increasing trend. Particularly, there was a clear increase in the percentage of long breaks compared to the total number of breaks. Rise in surface sea water temperature and levels have been mapped. Climatic changes have a few opportunities and many problems of vulnerability of the futuristic food security. This calls upon short and long-term strategies for moderating, coping, adaptations, mitigation and safety-nets.

Irrigation is a great moderator of vulnerability especially of the marketable surplus of exports and consolidation of food buffer stocks. Three States of Punjab, Haryana and Uttar Pradesh in the Indo-Gangetic plains collectively contribute 98 % wheat and 52 % rice to the central stock for maintaining food, nutritional, feed and national security.

Punjab leads in irrigation with 97.6 % of its net sown area under irrigation followed by Haryana (85.2 %), Uttar Pradesh (71.6 %) and all remaining states with less than 51 %. There is a conjunctive use of surface and ground water resources with about 20 million ground water extraction structures in the country. Overall, ground water accounts for 60 % of the net irrigated area (58.5 million ha) in India. Ground water contribution to the net irrigated area varies from 65 to 74 % in the States of Bihar, Gujarat, Madhya Pradesh, Maharashtra, Punjab, Rajasthan and Uttar Pradesh. Overall ground water management is very crucial for meeting incremental demands and maintaining sustainability in the long term perspective.

1.1 Scope of Position Paper

The northern State of Punjab in India has played a pivotal role in sustaining the national food security and is referred to as the 'Granary of India'. However, in sustaining the agricultural production, Punjab has already depleted its good quality ground water resources. The State is currently facing the problems of a declining ground water table in the central part, increased energy cost for pumping and deterioration of ground water quality and there are indications that the water availability would emerge soon as a limiting factor even to sustain the present production levels unless remedial measures are undertaken immediately.

In this position paper, a critical evaluation of availability of ground water in Punjab has been made as an illustration. Remedial solutions such as artificial recharge of ground water, utilisation of poor quality water, delaying rice transplanting, crop diversification, restructuring of incentives, improving productivity in the water-rich eastern States, etc. have been presented to rationalise the ground water use for sustaining the agricultural production for maintaining perpetual food security in the country.

2. A Case Study of Punjab

The State of Punjab has a total geographical area of 5.036 million ha (1.5 % of India) out of which 4.184 million ha (83 %) is net sown area of which 3.677 million ha (88 %) was sown more than once during 2006-07. Very high intensive cropping led to multiple nutrient deficiencies, land degradation and extensive use of chemical fertilizers with high cost of production. The marginal, small and medium holdings, up to 4 ha, constitute more than 65 % of the total holdings. It may be seen that since 1970-71, though there was a marginal increase

(3.2 %) in the net sown area from 4.053 to 4.184 million ha yet the area sown more than once rose sharply by 126.3 % from 1.625 to 3.677 million ha (Figure 1). This phenomenal increase in the cropping intensity was possible only because of extensive irrigation based on the utilisation of surface and ground water resources.

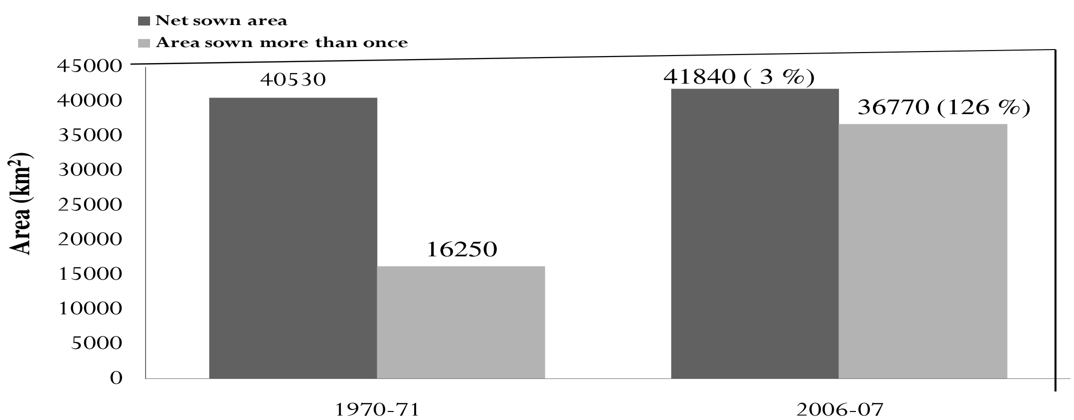

Figure 1. Net sown area and area sown more than once over the years in Punjab

Water utilisation in Punjab leads all the States with 97.6 % of its net sown area under assured irrigation. The State has an extensive network of about 145,000 km canals and about 100,000 km watercourses with the annual rainfall varying from 300 mm in South West to 1100 mm in North-East with a mean of 770 mm. Area irrigated by canals declined by 7.5% from 1.286 million ha in 1970-71 to 1.189 million ha in 2006-07 due to reduced carrying capacity and efficiency of the system and decreased availability of surface water (Figure 2). Thus, presently surface water resources serve directly only 29 % of the irrigated area in the State. On the other hand, net irrigated area through wells and tube-wells increased tremendously from 1.591 to 2.88 million ha (1.8 times) during 1970-71 and 2006-07, respectively; covering 71 % of the total irrigated area in the State. This was made possible due to phenomenal rise (6.4 fold) in the number of tube-wells from 192,000 in 1970-71 to 1,232,000 in 2006-07. This works out to be a private investment of Rs.6162 crores (Rs.61.62 billion) @ Rs.50,000 per tube-well at current rate, mostly by the farmers.

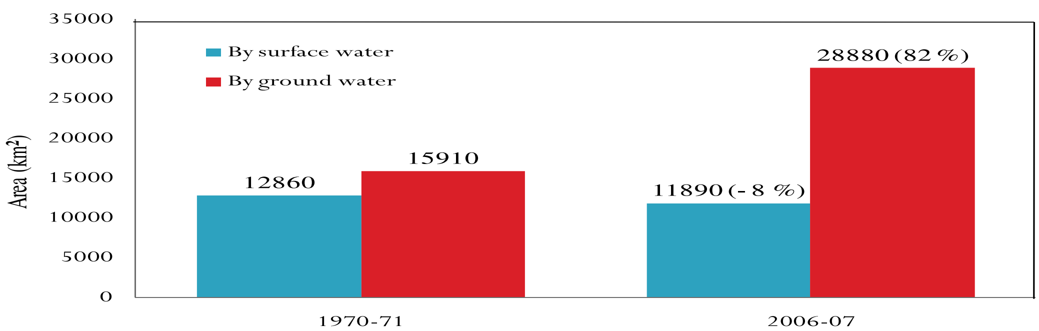

Figure 2. Net irrigated area by source over the years in Punjab

Punjab has been allocated 17.95 billion m^3 of water out of the average annual river flow (surface water) of 42.4 billion m^3 in the Sutlej, Ravi and Beas Rivers. Its replenishable ground water resources are estimated as 21.44 billion m^3 every year. Thus, the total available water resources in the State are 39.39 billion m^3 $year^{-1}$ against an estimated annual demand of 61.73 billion m^3, showing a deficit of 57 % for a major riparian State. About 40% area of South-West Punjab is having poor quality or saline water.

The major consumptive use of water in the State is for irrigation with priority allocation for drinking water supply. As per Ground Water Estimation Committee-1997 (GEC-97) Methodology, 10 % of the available water resources in the State are reserved for drinking and irrigation purposes. The poor or unfit quality of underground water for drinking and irrigation purposes, particularly in the Southwest Punjab is also a major concern in the State. Since ground water is not being pumped, there is extensive use of canals, water table is rising at a fast rate and investment into drainage has become another item of expenditure, energy consumption and cost of production,

2.1 Food-grain Production vis-a-vis Water Transfer

Substantial increase in area under crops grown more than once has been primarily due to the availability of assured ground water for irrigation in Punjab. Between 1960-61 and 2006-07, the area under wheat increased from 37 % to 94 % and area under rice increased from 6 % to 71 %, at the expense of other crops such as cotton, maize, gram and pulses. The production of rice in the Punjab State has increased from 0.69 to 10.14 million tonnes with corresponding yield increase from 1765 to 3868 kg ha^{-1} (2.2 fold) between the years 1970-71 and 2006-07, respectively. Similarly production of wheat in the State has also increased from 5.15 to 14.60 million tonnes with corresponding per ha yield improvement from 2238 to 4210 kg (1.9 fold) during 1970-71 and 2006-07, respectively. Productivity gain was much higher in water guzzling rice crop compared to the traditional and agro-ecologically benign wheat crop.

Punjab has played a central role in sustaining India's food security and is referred to as 'Food Basket of India'. In the past decade in spite of being 1.5 % of country's geographical area, the production of rice and wheat in Punjab was 11 % and 21 %, respectively of the total rice and wheat production in the country (Table 1). Out of 9.18 million tonnes production of rice and 14.66 million tonnes production of wheat, the State supplied 7.39 (81%) and 8.39 (57%) million tonnes of rice and wheat, respectively to the central pool; contributing 36 and 56 % of all India central pool stock and consolidated the national food security (Figures 3 and 4).

Table 1. Production and procurement of food-grains in Punjab vis-a-vis India

Food-grain	**State/all India**	**Production* (million tonnes)**	**Procurement* (million tonnes)**
Rice	Punjab	9.18	7.39 (81 %)
	All India	86.53	20.47 (24 %)
Wheat	Punjab	14.66	8.39 (57 %)
	All India	70.82	14.87 (21 %)

*Mean of 1997-98 to 2006-07.

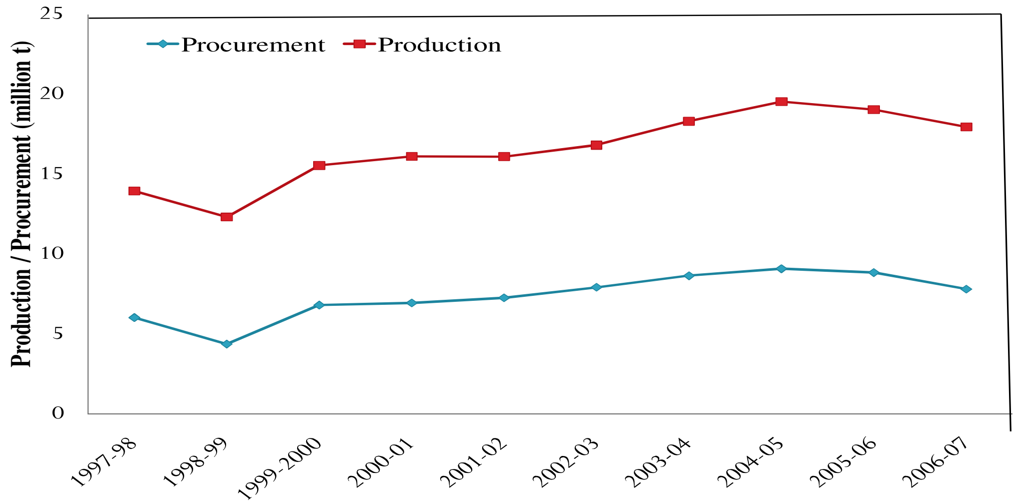

Figure 3. Production and procurement of rice in Punjab

The amount of water required in the production process of an agricultural or industrial product is called the 'virtual water' of the product. The real water content of products is generally negligible if compared to the virtual water content. For example, to produce 1 kg of wheat in India, 1654 litres of water is required, whereas to produce 1 kg of rice 3702 litres of water is required. When goods and services are exchanged, so is the virtual water and this is called as virtual water trade. Virtual water can be seen as an alternative source of water and thus can be an instrument to achieve regional water security. Virtual water transfer through trade is becoming an important component of water management in regions where water is scarce.

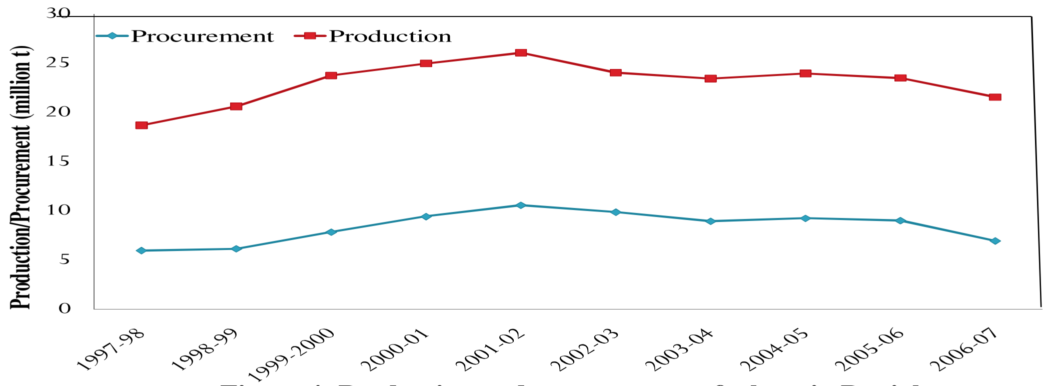

Figure 4: Production and procurement of wheat in Punjab

By contributing 7.39 and 8.39 million tonnes of rice and wheat, respectively to the central pool the Punjab transfers 27.35 and 13.88 billion m^3, respectively (total 41.23 billion m^3) of virtual water used in the food-grain production, out of the State every year. The ground water accounts for major part of the annual draft of 31.16 billion m^3 (76 %) as virtual water transfer out of the State; whereas the surface water meets the rest of the demand of 10.07 billion m^3. Similar estimates are being compiled for other States contributing to the central food stock pool. Quantification of the virtual water content transferred out of the States would not only increase people's water awareness but also lead to other steps in efficient water management. Melting of Himalayan glaciers due to global warming may create problems for maintaining food security in the long run. Considerable saving of water is possible if water-efficient technology is deployed to produce the food-grains in the States. Zero tillage, straw mulching with Happy Seeder, bed sowing/planting and aerobic rice cultivation are important tillage and agronomic opportunities to save water consumption. Delayed transplanting to avoid scorching heat of May-June, diversification with less water consuming rice varieties of Basmati 1121 and PAU 201 have been able to save water without compromising productivity.

2.2 Ground Water Balance

As a result of extensive rice-wheat cultivation in Punjab and other States, the 'good quality' water resources have been and continue to be over-exploited. The average annual water balance in Punjab shows a deficit of 12 billion m^3, which is currently being met through over-exploitation of ground water resources resulting in continuous decline of water table in Central Punjab representing 79% area of the State having good quality ground water (Table 2).

Table 2. Average annual water balance in Punjab

S.No.	Source	Amount of water (billion m^3)
1.	Canal water	14.5
2.	Rainfall and seepage	16.8
3.	Total availability	31.3
4.	Water demand	43.3
5.	Annual deficit	12.0

The over-exploitation of ground water is resulting in the fall of ground water table in most of the blocks, except the South-western districts of Bhatinda, Ferozpur and Mukatsar where the main ground water body is saline and tube-wells are not feasible. On an average there is about 145 % over-exploitation of ground water in the State with the highest over-utilization of 254 % in the Jalandhar District.

2.3 Impact of Canal Networks on Ground Water

When the first head-works was constructed at Madhopur in 1859, along with the Upper Bari Doab Canal network, the ground water table was very deep in the range of 30.3 m along the foot-hills to 51.5 m towards the south-western relatively dry zone. The canal head-works were further extended at Ropar in 1873 and Haussainewalla (Ferozpur) in 1927. Since the efficiency of canal irrigation was less than 37 %, the ground water table started rising. The water table rose within 1 to 4 m below ground level in many parts and by 1964, about 23 % Punjab was water-logged and soil became saline (unproductive). Canals were lined to check seepage and batteries of heavy duty tube-wells were installed to pump water into the canals for lowering the water table. A network of open drains was also constructed to take away flood water at a faster rate.

Introduction of high yielding varieties of water guzzling rice crop and rural electrification led to an exponential growth in the drilling of tube-wells by the farmers. Subsidized electricity worth Rs. 14.4 billion (Rs. 1440 crores) annually to rice cultivation alone and the availability of fresh ground water at shallow depths as well as the convenience of ground water irrigation led to the redundancy of canal irrigation. Many farmers dismantled field channel network to recover land and canal water was diverted to south-west Punjab where tube-wells were not feasible due to poor quality ground water. This ultimately culminated into excessive fall in ground water table in the Central and water logging in the South-west Punjab. The ground water built over 105 years was consumed in less than 30 years and desertification is imminent if the 'Business as Usual' continues. The excessive supply of canal water to South-west Punjab has led to steep rise in ground water level and created water-logged conditions with the accumulation of excessive salts in the soil surface. Thus, Punjab is now suffering both by declining water table in about 80 % Central area and rising water table with diminished productivity in the remaining 20 % of Southern State.

2.4 Consequences of Ground Water Over-exploitation

With reference to All India average the percentage utilisation of ground and surface water potential is high in Punjab (http://www.mowr.gov.in/micensus/mi3census/index.htm) (Table 3). Further among the States, Punjab and Haryana have the highest percentage of ground water irrigation schemes as a source of supplementary irrigation in the commands of major and medium irrigation projects (34 % in Haryana and 32 % in Punjab). Return flows or seepages of canal system are being recovered by tube-wells.

Table 3. Percentage utilisation of ground and surface water in Punjab

Source	**Potential created (000 ha)**	**Potential utilised (000 ha)**	**Percentage**
Ground water	6287.15	5747.62	91
Surface water	17.99	16.61	92

In sustaining agricultural production and food security, Punjab has already overused and depleted its good quality ground water resources. In most of the State, increasing dependence on ground water resources has led to widespread decline in water table in the Central Punjab, high investment into tube-wells, increased operation and maintenance cost, more power consumption and deterioration of ground water quality. By 2006, the ground water table had sunk to the depth ranging between 15.45 and 27.58 m in the districts of Amritsar (15.45 m), Kapurthala (18.48 m), Fategarh Sahib (19.70 m), Patiala (24.24 m), Moga (24.85 m), Ludhiana (25.15 m), Sangrur (26.97 m) and Jalandhar (27.58 m). The highest depletion of ground water has been observed in the district of Jalandhar known for the cultivation of the highly commercial crop of potato. In the scenario 'Business as Usual' the mean ground water table depth in central Punjab, which was 22.8 m during 2006, would fall to 34.2 m in 2016 and 42.5 m in 2023 leading to unimaginable investment to sustain State's economy.

During a short span of a decade between 1997 and 2007, there has been a four-fold increase in cumulative fall in water table in the central districts of Punjab. During the same period, Punjab farmers' indebtedness also increased four-fold from Rs. 57 billion (Rs. 5700 crores) to Rs. 240 billion (Rs. 24,000 crores). Thus, the main reason for the indebtedness of Punjab farmers' is the rapid fall of ground water table and replacement of shallow (centrifugal) pump with deep (submersible) pumps which is three times more expensive. Regular supply of subsidized/free power to tube-wells during the hot months of April-May is responsible for the fall of ground water table in the State.

The overall ground water situation in Punjab is summarised as under:

1. Annual ground water availability : 21.44 billion m^3
2. Annual ground water extraction : 31.16 billion m^3
3. State of ground water development : 145 %
4. Very high level of ground water is being extracted in Amritsar, Fategarh Sahib, Jalandhar, Kapurthala, Mansa, Ludhiana, Moga, Nawanshahr, Patiala and Sangrur Districts
5. Over-exploited Blocks in 1984 : 64 (47 %)
6. Over-exploited Blocks in 2004 : 103 out of 137 (75 %)
7. Critical Blocks in 2004 : 5
8. Semi-critical Blocks in 2004 : 4
9. Decline in ground water table : 4 to 120 cm $year^{-1}$
10. Area identified by CGWB for ground water recharge :22,750 km^2 (2.275m ha) (45% of geographical area)

The CGWB and others have carried out sample studies in Punjab to determine the impact of over-exploitation of ground water. The outcome of the study is summarised as follows:

- Over-exploitation constrained the farmers to lower down the centrifugal pumps in deepened wells with extra cost. Many accidents of collapsing of wells and casualties occurred during digging or deepening the wells. Accumulation of poisonous gases in the wells led to unconsciousness and even deaths of people while repairing pumps at the bottom of the well.

- Initial investments made into centrifugal pumps when water table was shallow became redundant and 3 times more investment was made in replacing with submersible pumps when water table declined. Replacement cost alone of private investment of farmers for about one million tube-wells at the current (2009) rate of Rs. 80,000 each works out to be Rs. 9756 crores (Rs.97.56 billion).
- Electricity consumption was almost doubled.
- Stand-by arrangements for submersible pumps have to be more expensive in the form of diesel generators compared to the cheaper engines with pulley and belt system for the original centrifugal pumps.
- Farmers drilled new tube-wells to greater depths with higher diameter.
- The entire trade of drilling, sale of pumps, repairing and stand-by power arrangements have undergone a sea change with extra cost.

These problems will be further aggravated unless interventions are made without loss of time.

2.5. Subsidized Energy Requirement of Tube-wells.

Although the whole of Punjab is covered by a network of rural electrification, the quantity and quality of the power supply is a crucial factor in extracting ground water. With the separation of rural feeders, the precise estimates of electricity consumption are now available. During 2007, Punjab State Electricity Board (PSEB) supplied 7.5 billion (750 crore) units of electricity to the tube-wells which works out to be 28 % of the total consumption of electricity in the State. If the present trend of decline in the ground water table continues, the requirement of electricity is going to double i.e. 14.5 billion (1450 crore) units annually for pumping ground water by 2023. The PSEB is already under debt and is incurring a loss of Rs. 20 billion (Rs.2000 crores) per annum in subsidizing power supply. The accumulated loss of PSEB by 2007-08 had crossed Rs. 15000 crores (Rs.150 billion). If existing situation continues the accumulated loss of PSEB would be Rs.45,000 crores (Rs.450 billion) by 2023. Out of the current subsidy loss, rice cultivation alone accounts for Rs.1440 crores (Rs.14.4 billion) annually. In addition, most of the farmers also invest their own money for replacing burnt out transformers and other gadgets of utility due to over loading of the system. In Western Uttar Pradesh diesel pumps, with 4 times more expenses as compared to the commercial rates of electricity, are used which indirectly adds to the cost of cultivation.

2.6 Artificial Recharging of Ground Water

Rainfall in Punjab varies from 300 mm in south-west to 1100 mm in Shivalik hills or Kandi region of north-east. About 83% of the total geographical area of the State is net sown consisting of adequate field bunds and land levelling. Accordingly the scope of improving recharging is very limited except in the Kandi belt constituting about 10% area of the State and canal commands in Central Punjab provided water duty is restored.

(a) Watershed Management

It was very effective for re-charging the ground water in one of the World Bank Project in the Kandi area at the foothills of Shivaliks consisting of loose sandstone and more than 20 meter upper sandy layer. The ground water table rose @ 5.9 cm year^{-1};the total rise being 1.12 m in 19 years during 1979-1998. This region produces about 40% runoff which may be recharged in- situ rapidly so as to avoid its losses while flowing down.

(b) Utilizing Outflows from the State

(i) Exact data is not accessible but various estimates show that 0.1 to 1.0 million ha of flood water flows out of the State. On an average this works out to be about 9% of the total water demand of the State. Fortunately there is a network of open drains constructed during 1950s especially in Central Punjab. Water recharging structures can be placed in the bed of these drains which are carriers of the run off.

(ii) Flood water stagnates almost every year in the depressions around Rajpura, Patiala and Fatehgarh Sahib because of inflow of water from Shiwaliks and a thick layer of clay in the upper profile of the soil. This impermeable layer may be punctured with recharging shafts or failed wells and bore-wells can be utilized to push stagnated water below ground quickly before it is lost by evaporation. This will also reduce water congestion period in the field and avoid damages to the standing crops.

(c) Restoring Canal System in Central Punjab

This zone produces two-third of rice and wheat and is highly afflicted with over-exploitation of ground water and other environmental maladies. Subsidized power supply and operational convenience of tube-well irrigation led to dismantling of field channels and other canal water conveyance network. At present only 14% of the area is covered by canals and Central Punjab is not availing recharging of aquifers with the canal water. Moreover canal water duty for south-west Punjab may be curtailed to avoid its water-logging and land degradation. Accordingly there is a strong case to restore field distributaries network or utilize canal water for recharging through shafts in the existing open drainage network.

(d) Recharging of Village Ponds

Ponds have been a traditional system of storing runoff water from roofs, courtyards, streets etc. Their utility for live stocks has gone down due to motorized extraction of ground water by households individually or collectively. Bottom of these ponds was generally sealed with the deposition of silt or clay coming with runoff water and increased longevity of water availability. Now with the improved rural domestic water supply quick percolation of water need to be planned scientifically by avoiding chances of ground water contamination.

(e) Rainwater Harvesting in Urban Areas

Roof rainwater harvesting for ground water recharging is now being ensured in the bye-laws of building constructions. However, runoff appearing from metalled roads, flyovers, paved courtyards, bus stands, railway stations and air strips is more challenging task since it is ridden with the potentials of ground water contamination.

2.7 Drainage and Utilization of Poor Quality Water

In about 20% area of Punjab especially in South-West, ground water is of poor quality which led to non-installation of tube-wells and liberal allocation of canal water. Poor efficiency of canal system covering 70% area in South-West Punjab as compared to 14% in Central Punjab contributed to fast rise in water table in south west with poor productivity. In Haryana about 65% of its geographical area also has a similar fate. Installation of drainage system is constrained due to the disposal problems of poor quality drained water in the land locked region far away from sea. Discharging of poor quality drained water into rivers and canals is prohibited under the environmental laws. Of course some of these waters can be used consecutively with good quality canals, harvested rain or gypsum amended alkali waters. There are also limited choices of cultivating salt/alkali tolerant crops, varieties, fodders, trees and methods of water application and management.

First of all efficiency of the canal water system must be improved in south-west to prevent water logging itself and a vast range of methodologies are available. Horizontal or vertical drainage, dumping of poor quality drained water into an evaporating pond for saline water aquaculture are some of the options to maintain productivity under these challenging situations. Ingress of poor quality shallow water table in south-west into the over-exploited neighbouring blocks with good quality deep water table through reverse flows may also aggravate the problems. A shelf of alternative technologies for raising crops and harnessing of farming system for various contingencies should be thought of.

3. Remedies for Maintaining Food Security

The falling ground water table in the Northwest India especially in Punjab, Haryana, Rajasthan and Uttar Pradesh could be arrested through demand management and applying the following measures of reducing withdrawal and increasing recharging

3.1 Delaying in Rice Transplanting

In the 1970s, rice transplanting in Haryana and Punjab used to start from June 30 after the onset of monsoon rains and high humidity in air reduced evaporative losses. Due to subsidized power the transplanting date was advanced to May and even a second short duration Gobinda rice was also tried before the sowing of main rice crop. The evapo-transpiration (water requirement) of rice transplanted on May 20 is 76 cm, on June 10 is 60 cm (21 % saving) and on June 30 is 52 cm (32 % saving). Also during June 10 to July 10, the ground water table showed an average fall between 3 and 10 m.

The Haryana Vidhan Sabha passed the Haryana Preservation of Sub-Soil Water Bill, 2009, prohibiting transplanting of paddy before June 15 of the year or such date as may be notified by the State Government. Similarly, in March 2009 the Punjab Legislative Assembly passed the Punjab Preservation of Sub-Soil Water Act, 2009, to replace the ordinance already issued to restrict paddy transplantation not before 10^{th} June. Punjab State Electricity Board was requested to supply power only after 10^{th} June. Similarly procurement of rice in the market was also deferred to ensure transplanting at desired dates only. It has been observed that delaying the rice transplanting to June 10 arrested 18 cm $year^{-1}$ of the water table fall in the central zone of Punjab without any reduction in rice yield. This timely action of Haryana and Punjab will not only save the ground water in these States but also set an example for other over-exploited States in the country where early sowing of rice is not advisable.

3.2 Diversification in the Past and Future

3.2.1 Crop diversification in Punjab. There was unprecedented crop diversification during the first decade of 1970-80 of ground water development in Punjab. Area under the water guzzling rice crop expanded at the compound rate of 12.4 % whereas area under replaced and less water demanding pearl millet (Bajra) decreased at the compound rate of 9.7 % and maize at 3.5 %. Diverting or consolidating R&D resources and investing into rice-cultivation related development activities improved productivity of rice at the compound rate of 5.5 % compared to the negative growth @ 0.7 % in water savvy Bajra crop. Negative growth in area, productivity and production of less water requiring pulses and oil seeds also led to over-exploitation of ground water resources. Diversification at a very fast rate has led to 80 % of cropped area of Punjab being under rice-wheat system. In central Punjab 85% of Kharif season area is under rice. Total water requirement of Punjab consists of 37% of rice, 32% of wheat, 17.3% of other crops and 13.3% of fodder, vegetables and forests. Mechanization of farming operations also increased overall cropping intensity to 188 % and over-stretched irrigation water consumption. Availability of local and immigrated labours has gone down after the implementation of National Rural Employment Guarantee Scheme which is pushing the agenda of mechanizing the paddy transplanting with implications of cost of production.

Minimum support price, committed procurement, assured payments, expansion in rice mills and exports by private traders also promoted the cultivation of high water requiring rice crop. Currently there is further diversification into the fine and superfine varieties of rice which again is triggered by the opportunities of realising high income through export. Cultivation of Pusa Basmati variety 1121 covered 10-20 % area in 2008 even before its listing for export and was a classical example of bearing risk by the farmers for new technologies. Ultimately the government included this variety into the list of Basmati, permitted its export and on an average relatively high gross return of Rs. 50,000 per acre or Rs.1.25 lakh ha^{-1} was realised during 2008. Fish culture is also being taken up by pumping ground water into ponds with subsidized power and this system consumes much more water as compared to rice. All these developments are taking place in-spite of the fact that ground water table in the 80 % geographical area of the State is depleting and the ground water is even utilized to the tune of 145 % (State average) and as high as 254 % in the Jalandhar district.

The Punjab farmers are fully aware of natural resources degradation, environmental pollution due to burning of rice residue, very high input of energy and risks of a narrow base rice-wheat cropping system. But the convenience of highly developed mechanisation, subsidised electricity and stability or robustness of production is the major drivers of continuing with rice cultivation. Abandoning the cultivation of high water consuming rice for moving into the sustainable strategy can take place only by providing more attractive economic alternatives with massive efforts in R&D, capacity building and large investments. Rice is a staple diet in major parts of India and food security at the country level may be ensured by enhancing its productivity and production in the most befitting agro-ecologies in Eastern India with high rainfall and under-utilized ground water resources.

3.2.2 Vegetables and fruits. Diversifying into sun rising sector of vegetables and fruits with water efficient micro-irrigation has the highest potential (elasticity) of income growth. Ecologically Punjab does not have better competitiveness in the cultivation of fruits with the rest of India except for Kinnow. Therefore cultivation of vegetable is the obvious choice and access to the distant markets is a great challenge for this land locked State situated in the extreme corner on the international border. There are also potentials of accessing the market in the Central Asian countries such as Uzbekistan, Kazakhstan and other neighbouring countries in the region. Direct procurement and retailing of the fresh vegetables and fruits by large companies increased the share of the primary producers (farmers) of retail prices by about 20 % compared to the traditional marketing chains. This was primarily due to reducing wastages during the process of harvesting, packaging, transporting and marketing. Future trends in the growth of restricted marketing potential of fruits and vegetables will be another driver of expanding the basket of diversification options.

Recently Punjab Government has announced setting up of citrus estates, which is a step in the right direction. However cultivation of banana may be taken up with great caution because its water requirement is even more than the rice-wheat system and is also susceptible to frequent cold waves during the month of January.

3.2.3 Livestock and dairying. Like fixed rice-wheat cropping system, livestock sector of Punjab is also highly specialised consisting of predominantly buffaloes and poultry. The initial 20 year period (1970-90) of the ground water development phase witnessed positive compound growth rate of 2 % in the population of buffaloes at the cost of very high negative growth in the population of camels, horses and donkeys. High tech animal husbandry is still another important diversification option because (i) Punjab farmers are tuned to the cultivation of fodders, (ii) network of rural roads enables the collection or aggregation, (iii) processing plants for value addition are available, (iv) corporations like

Nestle and Reliance are providing healthy competitions to the milk cooperatives, (v) it is a 365 days x 24 hours a year activity and generates 6-7 times more employment, and (vi) water requirement of the overall system compared to rice-wheat system seems to be un-quantified.

4. Restructuring of Incentives

Subsidy in power supply may be incentivized in such a manner that it brings in most efficient irrigation technologies. A bonus can be worked out for the most efficient production of marketable rice, wheat or alternative less water requiring crops/commodities such as cotton, maize, milk, vegetables, oil seeds and pulses. This will also lead to maximisation of productivity of the alternative crops requiring less water. The productivity and production of rice has to be enhanced elsewhere like Eastern India where un-utilised ground water (Table 4) and rainfall in the range of 1100 to 2500 mm will be able to sustain production of rice, sugarcane, banana, etc. Availability of ground water per hectare of net sown area is highest in Assam followed by West Bengal, Bihar etc. with sufficient under-utilized potential. This will also require investments into related infra-structure of rural electrification, setting up or relocating of rice and sugar mills in Eastern India.

Bonus system for marketable rice and sugarcane also has to be introduced in Eastern India to ensure ecologically most sustainable land use. This will also call upon more investments into R & D for evolving input efficient package of technologies for the Eastern India. Revamping of the land use across the country will happen only if there is win-win situation for crops, commodities, all stake-holders, situations and States.

5. Improving Productivity in the Eastern India.

Food security is the supreme national priority and loss in cultivation of rice due to over-exploitation of ground water etc. in south western India has to be more than compensated elsewhere and eastern India seems to be the best bet. Eastern India is highly complex, diverse, ecologically fragile, ethnically and socio-culturally unique. It comprises of Assam, Bihar, Chhattisgarh, Jharkhand, Orissa, West Bengal and Eastern Uttar Pradesh and it is necessary to enhance productivity on many counts:

Table 4. Availability of surplus/un-utilized ground water in the Eastern States

State	Net annual ground water availability		Annual ground water draft (billion m^3)	Annual ground water available as surplus/un-utilized	
	(billion m^3)	m^3 ha^{-1} net sown area		(billion m^3)	(%)
Assam	24.89	8973	5.44	19.45	78
Bihar	27.42	4921	10.77	16.65	61
Chhattisgarh	13.68	2872	2.80	10.88	80
Jharkhand	5.25	2968	1.09	4.16	79
Orissa	21.01	3661	3.85	17.16	82
West Bengal	27.46	5186	11.65	15.81	58
Punjab	**21.44**	**5053**	**31.16**	**(-) 9.72**	**(-) 45**

(i) To reduce food security dependence on non-sustainable resources of Northwest India having declining factor productivity and ground water table.

(ii) Eastern India has the highest poverty and high population density requiring investment to enhance income.

(iii) It has many constraints and opportunities.

(iv) Rainfall in the range of 1100–2500 mm can sustain high water requirements of food security systems of rice, sugarcane, banana, fish, etc.

(v) The region has overall very high ecological potential of high productivity.

(vi) The Eastern India representing 37.6 % of total country's area under rice and contributing nearly 55 % of rice production would be an ideal priority of investments.

(vii) New Technologies adoption rate is very low.

(viii) Seasonal outmigration of the social capital will be checked to enhance the socio-economic status.

***5.1 Cropping pattern for Eastern India*.** There are about 12 complex and diverse typologies with locally differentiated cropping systems and resources in the Eastern India. On an average 70% of the net cropped area is under rice crop which, of course, ranges from 47 % in Samastipur (Bihar) to 98 % in Raipur (Chhattisgarh). Rest of the area is occupied by maize, wheat, oil seeds, pulses, jute, sugarcane, vegetables and fruits. However, the rice crop being staple food, major issue of virtual waters and energy consumption in the Northwest India will be given high development priority.

Rice is grown during three seasons of pre-Kharif, Kharif and Rabi (Boro) in uplands, midlands and low lands. Except some districts in West Bengal and Assam, it is cultivated under rain-fed conditions with high risks of floods, droughts and cyclones.

***5.2 Irrigated Boro rice, winter maize and vegetables*.** These are post-rainy and winter season crops without any risk of floods and are essentially irrigated. Very low load of pests and diseases coupled with intensive inputs at negligible risks has led to an average productivity of 6-7 t ha^{-1} of paddy in selected districts. There are vast surplus/un-exploited ground water potential available to bring in all suitable typologies under this strategic system. Rural electrification under RGGVY scheme should become handy to energise tube-wells through incentivizing custom hiring services by selected enterprising farmers to overcome the difficulty of fragmented holdings. Winter maize also has potential of 5-6 t ha^{-1} productivity under assured irrigation and seeds of highbred are being supplied by the seed companies. The area under these crops has gone up in the past and needs further acceleration. Improved varieties are available especially in the private sector and still seed replacement rate is inadequate especially in rice. District level household surveys have revealed highly variable rate in the use of important inputs. Boro, winter and post-flood seasonal crops should be given the highest priority of planning and investing because of negligible risks. Innovative institutionalisation of sharing public utilities, hiring services, collection, procurement and aggregation of purchase of inputs and sales of outputs of small holders would be required.

5.3 Rain-fed area. The percentage of rain-fed rice varies from 99 % in Kalahandi Orissa), to 91 % in Mayurbhanj to less than 1 % in Dinajpur and 24 Parganas of West Bengal . Except some pockets of Eastern Uttar Pradesh, West Bengal and Assam rain-fed agriculture dominates in upland, midlands, low land and deep water rice. Direct seeding of rice in rain-fed condition and transplanting in irrigated areas is generally practised. Availability of improved crop varieties and their replacement rate is very low and farmers still prefer traditional low yielding varieties which can resist droughts, diseases and adapt to risks. Other agronomic practices, in-situ conservation of rainwater, water harvesting upstream of check dams and dug-wells down-stream can provide irrigation at critical stage or during intermittent long breaks in monsoon and ensure sustained productivity. Overall watershed development programmes can realize tremendous benefits by improving productivity and income.

5.4 Rice fallows. Keeping land fallow after the harvest of rice is a major concern as well as opportunity to enhance productivity and production. Remote sensing and analysis of satellite imageries have revealed that about 11 million ha of land is mono cropped with rice, remain fallow and is grazed after the harvesting of rice. Except few selected district of West Bengal, East Uttar Pradesh and Bihar the percentage of fallow land ranges from 64 to 97 %. A second crop of oilseeds, pulses, vegetables and fodder can be raised through appropriate technologies and rainwater conservation. In-situ conservation of rainfall, trenching, contour bunding, dug wells and rainwater harvesting in the fringe forests can ensure raising the second crop. The average investment of an optimally designed system in the upper and midland will be around Rs.25,000 ha^{-1} whereas watershed norms during 11^{th} Plan is up to Rs.15,000 ha^{-1}. The remaining gap of resources can be met from the NREGS because of high employment demand due to poverty and seasonal out-migration of work force in the past. Linking up with RKVY, BRGF and other untied funds could also be considered. Second crop in the fallow lands should be managed in large clusters so as to tackle the problem of traditional and unrestricted grazing.

5.5 Liming. Most of the soils of Chhotanagpur, other uplands and hills of Eastern India are acidic in nature. Soil acidity does not create any problem for the growth and productivity of rice due to water stagnation during growth and nature of he crop. Since rice is being cultivated predominantly as mono crop, neutralization of acidity by liming was not a priority in the past. However, advocacy of growing vegetables, oil seeds and pulses into rice fallow land would certainly require management of acidity to raise productivity and profitability. A network of experiments by ICAR has proved wide spread utility of adding lime to other than rice crops in the Eastern India. Fish ponds in this area would also require periodic liming to create congenial aquatic environment for the high fish productivity. Fortunately liming material is available as a by-product of steel industry, paper mills, sugar mills and can be mined also. For all practical purposes it should be treated as a fertilizer for its distribution subsidy and sale by the dealers of agriculture inputs.

6. Ground Water Quality in the Eastern India

Ground water in shallow aquifers is generally suitable for use for different purposes. The water quality in deeper aquifers varies from place to place and in some cases, the ground water has been found unsuitable for specific uses due to various geogenic contaminants.

Inland salinity in ground water is prevalent to a lesser extent in Bihar and Uttar Pradesh. In the proximity of Orissa Coast an 8-10 km wide belt of the Subarnrekha, Salandi and Brahamani River outfalls, the upper aquifers contain saline horizons which are decreasing landwards. High concentration of fluoride in ground water above the permissible limit of 1.5 mg litre^{-1} has been recorded in 5 districts (14 %) in Bihar, 2 districts (13 %) in

Chattishgarh, 4 districts (17 %) in Jharkhand, 18 districts (60 %) in Orissa and 7 districts each in Uttar Pradesh (10 %) and West Bengal (37 %) threatening the rural population, using ground water for drinking and domestic purposes, with health hazards of Fluorosis. The occurrence of arsenic in ground water in the intermediate aquifer in the depth range of 20-100 m was first reported in 1980 in West Bengal. The deeper aquifers are free from arsenic contamination. Apart from West Bengal (8 districts; 42 %) arsenic in ground water above the permissible limit of 0.01 mg l^{-1} has been reported in 12 districts (32 %) in Bihar, 5 districts (7 %) in Uttar Pradesh and one district each in Chattishgarh and Assam. Although iron is an essential element for plant growth, detrimental high concentration of iron in ground water has been observed in Assam, West Bengal, Orissa, Chattishgarh and in localised pockets in Bihar, Uttar Pradesh, Jharkhand and North Eastern States. Similarly, high concentration of nitrate (more than 45 mg l^{-1}) has been found in many districts of Bihar, Orissa, Uttar Pradesh and West Bengal.

In general, the quality of ground water has undergone a sea change in the Eastern India to an extent that the use of such water could be harmful to the human health. A few key remedial options are:

1) Encouraging skimming well technology to harness fresh water floating on saline water in the coastal-salinity affected areas.
2) Rainwater harvesting and dilution of ground water with abundantly available surface water resources in the region.
3) Encouraging deeper tube-wells (more than 100 m) in the arsenic affected areas.

7. Diversification in the Eastern India.

There are several opportunities of alternative practices, crops, varieties, commodities and farming systems of strengthening food security reducing dependence elsewhere and some of those are mentioned below:

(i) High soil moisture content at the time of rice harvesting in low lands and plains may delay the sowing of wheat and other Rabi crop. At present the traditional *Utera* system of broadcasting seed in standing rice crop is being followed to manage high soil moisture content especially in heavy soils. This practice can now be replaced with most scientific method of sowing with zero till drills which are now commonly available in the market or on custom hiring basis.

(ii) In other situations nursery of rice can be raised under protected conditions so as to coincide rice transplanting immediately with the onset of monsoon. This gives higher yield of the main rice crop, ensures and timely sowing and better productivity of the second crop.

(iii) Traditional rice-fish culture yields about 200-300 kg ha^{-1} of fish because of wide fluctuations in the depth of surface water in the rice fields. Providing refuge of pits or trenches in 10 % area can provide a desired depth of water constantly. The fish can move to the refuge or trenches when water depth in the rice field goes down. The fish will come out of refuge and graze in the entire rice field again when sufficient depth of water becomes available in the main field. This leads to very high overall productivity of the system.

(iv) Capital intensive and highly diverse fish-based farming system is still a better option in plains and valleys in the high rainfall eastern region or in waterlogged area along the canals. Digging of 1.25 m deep fish pond in 65 % area and raising embankment on remaining 35 % area around the ponds optimizes overall returns. Vegetables, fruits, coconuts, bananas, etc. can be sown or planted on the raised embankment which otherwise is not possible. In this way farmers have option of cultivating 6-7 crops and commodities as compared to rice alone otherwise. On-farm analysis near Bhubaneswar in 2008 revealed that rice cultivation alone returned Rs.42,000 ha^{-1}, banana alone Rs. 64,000 ha^{-1} and the system of fish in the pond and horticulture on embankment returned Rs. 1,98,000 ha^{-1}.

(v) Another on farm fish production-based model for over 15 years provided an average net return of Rs.69,275 ha^{-1} as per 2002 prices under the supervision of WTCER, Bhubaneswar. The most popular integrated farming system for waterlogged soils or high rainfall region consists of locally suitable permutations and combinations of pond, dyke, fish, prawn, ducks, cows, pigs, vegetables and fruits. These are capital intensive diversifications and should be undertaken after proper training of the farmers or producers and under the supervision of an experienced service provider with proper market linkages and inbuilt insurance.

(vi) There are some undulating uplands giving very low and unreliable productivity of rice and millet crops. Rice can be replaced with hardy and highly paying fruit trees like cashew nut, mangoes, etc.

(vii) There are some special attribute niche crops of ginger, turmeric, makhana, etc. in the high rainfall Eastern region provided value is added and shared by primary producers.

8. Sugarcane.

This is another crop with very high water requirements and needs its replacement and relocation outside the ground water declining regions of Western Uttar Pradesh, Haryana, Punjab, etc. Eastern India is highly suitable for growing sugarcane due to (i) its high rainfall and under-utilized replenishable ground water, (ii) there is temporary flooding in certain areas and sugarcane is able to withstand water stagnation, and (iii) germplasm for high rainfall situations is available. This however would require (i) revamping and committed investments into R & D, (ii) Reviving and expanding sugar mills, (iii) rural infrastructure of roads and electrification, and (iv) organizing, sugarcane cultivators into latest model organisations and institutionalization of Primary Producers' Company Ltd.

9. Concluding Remarks

Technological interventions, enabling policies, public investments into canal irrigation development, rural electrification, communication, infrastructure, private investments into ground water development and support prices ensured food security of India. However this led to 2^{nd} generation problems of land degradation, high cost of production and over utilization of ground water due to subsidized power supply. Diversification into water saving land uses in Punjab, other similar areas and compensatory production in Eastern India is called upon. The sustainability of groundwater utilities is one of the core issues which require attention for meeting irrigation and drinking water requirements and ensuring food security. Holistic planning of groundwater development in the east and northeast and adequate recharge measures in the northwest and south are essential so that imbalances of the past are remedied. In other areas too, judicious planning of groundwater development and artificial recharge could result in maximum productivity without raising environmental concerns.

10. Citation

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