WATER ENERGY AGRICULTURE
Nexus iN iNdia
a Case study of Punjab

Centers for International Projects Trust (CIPT)

The Centers for International Projects Trust (CIPT) is a non-profit organization based in New Delhi. CIPT works on developing and piloting new models for effective water and energy management across different regions in India. It works towards performing applied research in the areas of agriculture, water, climate change, energy and related socio-economic perspectives and provide rigorous research-based knowledge as the foundation for various field-based initiatives.

With its strong institutional mechanisms and innovative approach CIPT aims at holistically addressing the issues of water and agriculture in the country through different low-cost precision technologies, nexus modelling and extension methods.

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authors

Preface

The success of green revolution and emergence of Punjab as food bowl of india paved the way for intensive agricultural practices and input use. The positive effects of this phenomenon outweighed the adverse effects till the mid-1980s but started appearing critical in later periods. The recent period has witnessed the crisis of stagnating yields, rising costs, declining productivity and depleting natural resources, especially water.

The water table in Punjab started declining faster since the mid-1990s. With the large scale cultivation of paddy and provision of free electricity being cited as the major reasons for such decline, there are serious concerns on sustainability of groundwater resources in the state.

The present study estimates the gaps between demand and supply of water in Punjab with special focus on agriculture. it outlines various scenarios and makes projections for water and electricity in various sectors of Punjab economy during the period of 2020-2050. The study highlights that the continuation of business as usual scenario in Punjab will worsen the groundwater situation and will require a hugely expanded outlay for power subsidies which may not be sustainable in the long run. serious efforts towards precision technologies and crop diversifications can help in achieving sustainable pathways in agriculture.

We hope that findings of this study will be useful to the researchers, development agents and policy makers engaged in ensuring sustainable water, agriculture and livelihood nexus in the state as well as in the country.

authors

ਮੁੱਖ ਮੰਤਰੀ, ਪੰਜਾਬ

CHIEF MINISTER, PUNJAB

Foreword

I am delighted to release the report on water, energy and food nexus in Punjab, prepared by Center for International Project Trust (CIPT).

This report, while covering aspects central to the concept of resource conservation and management such as water, energy, agriculture and livelihood security also focuses on the scientific models used to estimate the water, energy and food requirement of Punjab in future and project different scenarios for sustainability of water, energy and food in the State.

This report on nexus also make us aware on the current utilization trend of water, energy and food in Punjab and how policy measures and strategies can improve the sustainable availability of these resources for future generations. The report strives to highlight achievements, challenges and opportunities in water, energy and food nexus, alongwith forward looking recommendations.

It is imperative that we draw significant learning from the report on WEALS nexus and disseminate its findings among all stakeholders for appropriate actions at the various levels.

I congratulate CIPT for producing this report with such an empirical rigor and zest and hope that it will be greatly useful for all stakeholders related to water, energy and agriculture sectors in Punjab.

(Amarinder Singh)

USAID
FROM THE AMERICAN PEOPLE

FOREWORD

This water-energy-agriculture nexus study, undertaken as part of USAID's Water-Agriculture-Livelihood Security in India (WEALS) project, addresses the intra-and inter-sectoral linkages between the agriculture, industrial and energy sectors. The WEALS report gives a detailed assessment of demand and supply conditions of critical resources, water and energy, which are essential to better understand the current context prevailing in the State of Punjab.

Agriculture is the mainstay for the people living in Punjab and has traditionally contributed to prosperity and well-being of farmers. However, intensive use of agro-chemicals, cultivation of water intensive crops, ground water irrigation and rapid growth of mechanization has had detrimental impact on the ecological health of the region since the early 1980s. This has led to serious economic and ecological consequences including stagnation in agricultural growth, rising distress in the farm community, high infestation of pest and diseases, water contamination and overuse.

In this study, innovative scenarios are designed to estimate the impact of various innovative technologies on the demand and supply of these resources, with due consideration for increasing threat from changing climate, urbanization and industrialization in the region. The study canvases trends of resource consumption since the 1970s by agriculture, commercial and domestic sectors. These scenarios clearly demonstrate the scope of conservation of natural resources for making agriculture sustainable for Punjab.

I congratulate CIPT for undertaking a comprehensive and holistic approach for this nexus study to ensure water, energy, agriculture and livelihood sustainability for Punjab. I hope that this report will be used and disseminated broadly to influence practitioners and policy makers for making agriculture sustainable.

Michael Satin

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Chandigarh, the

Chief Principal Secretary to Chief Minister, Punjab
ਮੁੱਖ ਪ੍ਰਮੁੱਖ ਸਕੱਤਰ
ਮੁੱਖ ਮੰਤਰੀ, ਪੰਜਾਬ

Message

The water, energy and food nexus is deeply intriguing and highly complex. Rapid economic growth and rising population are aggravating the pressure on these resources, to cater to their ever-increasing demand. Escalating demand for these resources in all the sectors will have cascading effect on the sustainable supplies. These disturbing developments in Punjab demand a thorough assessment about the resource utilization patterns which can facilitate policy makers, scholars and researches in making agriculture sustainable in long run. The changing climate conditions and growing demands will render the nexus more elusive.

An integrated approach needs to be undertaken for simultaneous achievement of water, energy and food security. The present study by CIPT fills the gap that exists in terms of scientific assessment of water, energy and food nexus in Punjab.

The study unveils four broad scenarios and provides future estimation for water and energy needs in Punjab. The results of the study may prove useful in evolving long term policies for water, energy, agriculture and livelihood security.

I congratulate CIPT team for this commendable work.

6.3.2018

(Suresh Kumar)

Columbia Water Center
EARTH INSTITUTE | COLUMBIA UNIVERSITY

Message

I am very pleased to see that CIPT has developed this synthesis of water-energy and agriculture, with examples from Punjab and elsewhere. India faces a multi-pronged challenge of how best to manage its primary resources to meet the nutritional needs of the population. Punjab has been a critical piece of the Green Revolution story that allowed India to progress from chronic food shortages in the first half of the 20th century to surpluses despite tripling its population. However, this has come at the expense of a water and energy resource crisis. A perpetually shifting climate has now aggravated this situation in terms of a declining resource base for water, and increasing evaporation. However, much of the degradation of the resource base is of local human origin, and is manifest through unaccountable canal water use, overpumping of aquifers, and industrial and agricultural pollution of water bodies. The energy required to pump groundwater and treat polluted waters is a significant part of the energy budget, and comes largely from coal, thus exacerbating the climate change issue. The root of many of these problems is not the farmer, who is at the nexus of all 3 issues, but the policies of the governments that relate to the procurement of agricultural products and direct and indirect subsidies for water, fertilizers, pesticides and electricity. These can and need to change to achieve sustainable regional and national development. The CIPT report, by laying out several of these issues, quantitatively, provides the primary input for policy analysis and reform. I know that the CIPT has a number of ideas on how the associated policies at the state and at the national level can be changed in a manner that is politically and economically feasible, and congratulate them on taking the first steps in this direction

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List of Abbreviations

Toe	Tonne of Oil Equivalent
ET	Evapotranspiration
FAO	Food and Agriculture Organization
EJ	Exa-Joule (108)
GIS	Geographic Information System
RIHN	Research institute for humanity and nature
GOI	Government of India
UNEP	United Nations Environment Programme
BCM	Billion Cubic Metre
CGWB	Central Ground Water Board
CPHEEO	Central Public Health and Environmental Engineering organization
MW	Megawatt
PAU	Punjab Agricultural University
LPCD	Litres per capita per day
IEA	International Energy Agency
WWDR	World Water Development Report

Executive Summary

Global water, energy and food demand are expected to grow significantly by 2050, resulting into scarcity and increased intra as well as inter-sectoral competition. The water-energy-agriculture (WEA) nexus evolves through supply-demand relationships and is becoming more complex over time and with increasing climate change threats. The developing countries will be more prone to the adverse impacts arising from unsustainability of the nexus as compared to the developed countries. A better understanding of the WEA nexus will help in identifying more effective and efficient pathways for sustainability.

The adoption green revolution technologies in Punjab during late-1960s was the most viable option to achieve long-term food security in India and paved the way for intensive agricultural practices. The expansion in area under irrigation along with assured procurement at remunerative prices facilitated the adoption high yielding varieties of wheat and rice. Bringing more area under cultivation and multiple cropping in a year resulted into substantial increase in input use as well as food production. While the state has achieved the status of “Food Bowl of India”, its agriculture sector now suffers from stagnation in growth, over-exploitation of groundwater resources, sharp increase in electricity usage and huge burden of power subsidies in agriculture. The rise in demand for water and energy in other sectors are changing the intra and inter-sectoral dynamics and call for a better understanding of the WEA nexus in Punjab. Any threat to the sustainability of the nexus in Punjab may seriously threaten the food security of the nation.

An integrated water, energy, agriculture and livelihood sustainability (WEALS) model was developed and was named as CIPT-WEALS Model. Considering water as the prime resource for long-term sustainability, the model derives the agricultural energy demand from the water use itself. The CIPT-WEALS model is based on the following framework:-

1) Sectoral assessment of demand and supply for water.
2) Resulting over-exploitation of groundwater resources and fall in groundwater table.
3) Future scenarios for agricultural production, water usage and electricity consumption.
4) Projections for future water and energy demand and fall in groundwater table.
5) Long-term policy options for Punjab.

The model uses the data on various parameters from established sources for the period of 1980-2013. The aggregate demand for water in Punjab (all sectors) has increased from 4.55 million ha m to 5.94 million ha m with the agricultural water demand increasing from 3.03 million ha m to 3.85 million ha m during 1980-2013. During this period, total annual water demand in agriculture increased by 27% and demand for rice crop increased by more than 140%, with the share of rice in total water demand increasing from 23.4% to 44.6%. The annual supply of water exceeded the annual demand till 1990 but lagged substantially thereafter, resulting into the depletion of groundwater table. The predictability of groundwater table by CIPT-WEALS model was strong as shown by high correlation between actual and predicted water table. The water demand for industry, drinking and sanitation were estimated by using WATERGAP model and CPHEEO guidelines. The demand for electricity in agriculture was derived from the actual water use estimates obtained from CIPT-WEALS model and demand in other sectors was obtained based on the estimates of past growth and assumptions on future growth. During the period 1987-88 to 2015-16, annual electricity consumption in domestic sector grew by 7.1%, in agriculture sector by 2.6%, in industrial sector by 3.9%, in commercial sector by 9.7% and in other sectors by 2.4%.

Scenarios of Agricultural Production and Water Usage in Agriculture

The CIPT-WEALS model develops four broad scenarios of water, energy and agriculture in Punjab on the basis of assumptions on future changes in the cropping pattern, energy and water consumption and potential of intelligent water saving technologies. These four scenarios are termed as:

1. Business As Usual (BAU) scenario, assuming no change in cropping pattern.
2. Crop Diversification (DIV) scenario, assuming decline in 1.2 million ha area from under rice.
3. Intelligent Water Saving Technologies (TECH) scenario assuming the development and promotion of precision water efficient technologies.
4. Combination of Crop Diversification and Intelligent Water Saving Technologies (DIVTECH) scenario.

A total of 24 scenarios were developed for Punjab for the years 2020, 2030, 2040 and 2050.

The estimates of the CIPT-WEALS model reveal that the overall water demand in Punjab will increase by about 31% from the current levels of 4.55 million ha m annually to 5.94 million ha m in 2050. The crop diversification scenario will bring no reduction in water demand by 2050. There will be a three-fold increase in industrial water demand. Intelligent water saving technologies can bring 45% reduction in agriculture water demand and will check the rise in overall water demand to only 5.5% by 2050. Under the severely declining rainfall, the annual demand-supply gap for water will more than double at 2.8 million ha m by 2050, amounting to almost 90% of the existing water supply. The gap will range between 0.71 to 1.43 million ha m under the technology scenario.

The excessive use of water in all the sectors will lead to a faster depletion in groundwater table in Punjab and it may reach almost 43 m by 2050. It is obvious that the decline will have wide regional variations but the CIPT-WEALS model limits itself to the overall estimates at this point of time.

While crop diversification may not help in checking the groundwater table, innovative water saving technologies may limit it between 23-34 m by 2050.

Total electricity demand in Punjab may increase significantly and may vary between 286-314 billion kWh in 2050 depending on low or high energy-growth scenarios. While the energy demand in agriculture may increase by around 150% under the BAU scenario, it will increase by 27-100% under crop diversification scenario. Technology scenario will bring a significant in electricity use in agriculture, bring the use below half the current levels. Compared to the agriculture sector, the demand for electricity from other sectors of the economy will increase by multiple times. The share of agriculture sector in total power consumption in the state will certainly decline due to relatively much higher increase in consumption in other sectors. The share of agriculture sector will vary between 3-13% under different energy growth scenarios.

The cumulative amount of power subsidies in Punjab will vary between Rs 1.84-2.63 lakh crore in BAU scenario, between Rs 1.66-2.10 lakh crore in crop diversification scenario during the entire period of 2020-2050. The above figures reflect that the crop diversification can help in reducing the cumulative power subsidy burden by Rs 30-40 lakh crore under declining power prices and by Rs 50-60 lakh crore under the constant power prices during the entire period of 2020-2050. The technology scenario has the potential to bring a significant reduction in power subsidy bill of the state with annual savings of approximately Rs 7200-10000 crore.

The results of the study point towards the following major policy options for the Punjab state.

1. Establishment of a multi-disciplinary Water Technology Center in the State.
2. A comprehensive state strategy to promote intelligent water saving technologies.
3. Further research on Water-Energy-Agriculture Nexus using CIPT-WEALS model in Punjab with an aim to integrate more aspects of the economy, larger number of parameters, possibilities of downscaling to sub-regional levels and potential to use the model as a decision tool.
4. The state should undertake capacity building exercise of various stakeholders on Water-Energy-Agriculture Nexus.

There should be a comprehensive strategy to plan energy security in Punjab with greater emphasis on clean energy mechanisms. Solar energy can be the best future option for investing energy security of Punjab.

Chapter 1

Introduction

Water, energy and food are basic to a healthy and prosperous human life. These are key components of an economic system, and being a part of the ecosystem regulate the economic system. In the past, increasing population, rise in income growth, fast-growing urban population and industrialization have fuelled rapid increase in the demand for freshwater, energy and food. These trends are unlikely to subside in the future, implying a faster growth in demand for resources for food production (Hoff, 2011). By 2050, global demand for food is expected to be higher by 50-70% than its current level (FAO, 2011; Vuuren et. Al, 2016; FAO 2012, WWDR4 2012). The growth in demand in the low- and middle-income countries would grow faster, necessitating an increase in food production at least by 77% (FAO 2012). Most of these countries face acute constraint of land, and about 90% of the required growth in food production has to come from increase in cropping intensity and adoption of yield-enhancing technologies and practices. Intensification will result in 10-19% more withdrawal of water per annum (FAO, 2011). Also, there will be a significant increase in demand for water for domestic and industrial purposes, reducing its availability for agriculture by 18% (CA,2007; Strzepek, 2010). Likewise, overall energy demand is projected to increase by 80%, and the agricultural demand by 84% (Pimentel et al.2008; OECD 2012).

Energy and water are being limited resources, are becoming scarce due to rising demand from several quarters. This would have serious implications for economic development in general and agricultural development in particular. In the past, most of the global food crises were related to climate change, energy, food security, economic recession and financial turbulence, which are interlinked and have an impact on the water resources (FAO, 2012). Globally, 70% of the available water is used for irrigation, 19% for industrial purposes and 11% for municipal sector (FAO 2011; IEA, 2013). But, there are considerable disparities in usage of water across countries. In the high-income countries, industrial activities and agriculture account for almost a similar share of 42-43% in total water usage. On the other hand, in the low- and middle-income countries 70-90% of the water is used in agriculture (FAO, 2011).

Expansion of irrigation has helped increase in food supplies, decline in real food prices and reduction in poverty. But, this supply-driven approach has led to an excessive increase in demand for water (FAO, 2011). By 2030, irrigation water withdrawal is expected to increase by 11% against a 17% increase in harvested irrigated area, and most of it would be in the developing countries (FAO, 2011a). In India, it is projected to increase by 28%. In addition, the urban and industrial use of water is also projected to increase considerably, which will further worsen the demand-supply situation.

Climate change, by adversely affecting the rainfall and surface runoff, will pose a significant threat to water resources, leading to acute scarcity of water. This would pose serious implications for food security. According to comprehensive assessment of water management in agriculture, by 2050 the food production would require a consumptive water-use of 6800 km3, a quarter of which would be met through irrigation. Rising population and higher calorie requirements would require an additional 5600 km3. Despite expansion of irrigation and improvements in its efficiency in irrigated as well as rainfed areas, the supply of water will fall short by 3300 km3.

There has been a significant shift in energy use from traditional to commercial sources especially in the industrialized countries. The global energy production and use grew more than 50 times from 0.2 billion toe in 1850 to 11.4 billion toe in 2007 and further to 13.5 billion toe in 2013 (IEA, 2013) with fossil fuels being the major source. OECD countries accounted for 65% of the global energy consumption in 1965, which gradually declined to 50% in 2007 and 39.2% in 2013. The share of developing countries (non-OECD) in the total energy use more than doubled, from 12.5% in 1973 to 34.5% in 2013. Food production accounts for about 30% of total energy consumption in the world. Intensification of agricultural production systems has led to an increased use of the energy-consuming inputs such as agro-chemicals, fertilizers, electricity and diesel, particularly in developing countries such as India, Bangladesh, China and Vietnam. Currently, the mechanical pumping of ground water in 10% of the world's arable land consumes 0.255 EJ per annum (Exa Joules per annum). However, this resource-intensive path to achieve food security appears to be unsustainable in long-run. The efficient and sustainable use of resources would depend on their level of interactions among themselves and with the production and economic systems in which these are used.

Water-energy-agriculture nexus

Water, energy and agriculture are inter-connected through supply–demand relationships, expressed as energy for water, water for energy, energy for food, water for food and food for water and so on. Water is used for producing nearly all types of energy, and energy is used provisioning of water (access, transport, treatment and use). Similarly, agricultural production requires energy as well as water. The intra- and inter-sectoral interactions have risen due to substantial increase in demand for water, energy and food and are likely to be stronger in future. Due to burgeoning food demand, the demand for irrigation water will increase sharply, and the increased pace of urbanization (especially in developing countries) and rising population will cause a parallel rise in the demand for water in household and industrials sectors. Increased dependence on groundwater for intensive agriculture will cause a sharp increase in demand for electricity amidst its increasing demand from other sectors. The growing competition for water and energy is worrisome and calls for their efficient use as well as more efficient inter-sectoral allocations.

For the first time in 2007, the '2030 World Resource Group' highlighted the need for understanding the nexus among resources focusing on water scarcity as an emerging threat to economic development. The World Economic Forum also served as a platform to promote water security "with the intent to change the political economy of water agenda, from mostly an MDG-related 'access' issue to an issue of 'access' in the context of wider resource security and economic growth in its report 'Water Security- The Water-Food-Energy-Climate Nexus' (WRG 2030 Report, 2012). These issues echoed subsequently in 'the Bonn 2011 Conference' on 'The Water, Energy and Food Security Nexus – Solutions for the Green Economy', and the conference outcomes served as Germany's contribution to the Rio+20 process that led to the United Nations Conference on Sustainable Development. These results were finally discussed in the event – 'The Water Energy Food Security Nexus in Practice – Makes it Happen', within the UNCSD conference theme 'Green Economy' in the context of sustainable development and poverty eradication (Lesse et. al, 2015). Post this, the concept of water, energy and food security nexus was captured in several events such as international conference on 'Water, Energy, Environment & Food Nexus: Solutions & Adaptations under Changing Climate' in Lahore, 2012; 6th World Water Forum held in Marseillies, 2012; conference on 'Sustainability in Water-Energy-Food Nexus and Synergies & Tradeoffs organized by the Global Water System Project (GWSP) in Bonn, 2014. In all these deliberations the emphasis was laid on raising awareness about water-energy-agriculture nexus, challenges related to the nexus and solutions for a healthy nexus.

Approaches to assessment of the nexus

The nexus of water-energy-agriculture can be examined using qualitative as well as quantitative approaches. Qualitative approaches analyse core characteristics of the interactions among water, energy and food systems at a specific unit level such as individual, household and district, and the quantitative approaches assess the nexus at a larger scale covering multiple levels. Qualitative assessment uses questionnaire schedules to gathering unit-level data (Strasser et al., 2014). This approach has been used by the Research Institute for Humanity and Nature (RIHN) to examine water-energy-food nexus in Laguna de Bay in Asian-Pacific region (Endo et al., 2015). Integrated mapping with the help of GIS tools at multiple spatial scales is another important method of qualitative assessment of the nexus. These tools provide information on the quantity and quality of natural resource flows, location of sources of water, land use and land cover maps, land surface temperatures, etc. The integrated maps developed through GIS overlay individual maps for identifying key issues essential to providing solutions for better planning within a specific area.

Integration of qualitative and quantitative tools for better assessment of the nexus at all levels is “need of the hour”. The initial step is to build integrated water, energy and food system modelling that contribute to the sustainability of nexus at higher levels. This requires development of robust analytical tools, conceptual models, appropriate and validated algorithms and robust data sets on use of water, energy and food. For an integrated nexus system, it is necessary to understand the framework of each of the component of the nexus. For this, several tools, approaches and methods have been developed that consider resources as inputs in production function (Bazillion et al, 2011). The single sector modelling exercises have, however, yield limited information. As the interactions between various sectors have shown increased intensity with more visible inter-sectoral impacts in recent periods, it calls for integrated assessment have gained ground. The integrated assessments intend to allocate resources across sectors, based on their intra and inter-sectoral interactions. In addition to this, increased emphasis on development of future scenarios for a comprehensive planning also necessitates the efforts towards integrated assessment. Over time, the single sector accounting tools have been integrated to build scenarios to inform policy makers to anticipate, plan and manage transitions and devise policies and strategies in an uncertain world together.

Chapter 2

The State of Agriculture, Water and Energy in Punjab

After independence, India faced a major challenge of feeding its 361 million people. It produced 51 million tonnes of foodgrains in 1951 that translates into per capita availability of 395 gram/ day (GOI, 2015). To enhance foodgrain production, the Indo-Gangetic plains, encompassing the states of Punjab, Haryana and western Uttar Pradesh were identified as potential regions for introduction of improved technologies and practices. The package of high yielding seeds, assured irrigation and chemical fertilizers helped the country to be food self-sufficient towards the mid-1980s (Sidhu, 2002; Singh, 2009; Chand, 1999; Singh, 1992). The foodgrain production more than doubled by 1970-71 and more than tripled by the late-1980s lifting their per capita from 469 gram/day in 1971 to 510 gram/day in 1991 (GOI, 2015). The path of intensive agriculture followed, however, had significant implications for water and energy resource-use.

Agriculture

Since the introduction of high yielding varieties of wheat during the mid-1960s and of rice during the early-1970s, the cropping pattern in Punjab underwent a significant change. Between 1960-61 and 2015-16, the net sown area increased from 3.7 million ha to 4.14 million ha and the gross cropped area from 4.7 million ha to 7.9 million ha. From 56% of the gross cropped area under irrigation in 1960-61, the state now has almost entire area under irrigation. Cropping intensity increased from 126% in 1965-66 to 191%, and the entire rice and wheat area is cultivated with high yielding varieties. During the same period, fertiliser use increased from 12 kg/ha to 460 kg/ha, and electricity consumption in agriculture is now 4878 kWh/ha of net sown area. The total consumption of electricity in Punjab agriculture has increased more than 35 times, from 340.7 million kWh in 1967-68 to 12029 kWh in 2015-16. The number of tractors witnessed a quantum jump from 22000 in 1970-71 to 4.77 lakh in 2013-14.

The foodgrain production in Punjab has increased from just 3.16 million tonnes in 1960-61 to 28.4 million tonnes in 2015-16, with the production of wheat growing from 1.74 million tonnes to 16.1 million tonnes and that of paddy from 0.35 million tonnes to 17.7 million tonnes over the same period. In 2014-15, Punjab contributed about 42% wheat and 24% rice to the national food pool (GOI, 2015). The contributions were as high as 73% of wheat and 45% of rice during the 1980s (Vatta et. al, 2013).

The success of green revolution paved path for intensive agriculture in Punjab. And, due to higher yields, low production and market risks rice and wheat emerged as the dominant crops leading to their monoculture in the seasons these are grown. Rice and wheat together occupy about 80% of the gross cropped area in Punjab. Nonetheless, technology-led growth had a significant impact on poverty, the head-count poverty fell from 54.9% in 1973-74 to 21.9% in 2011-12 (Planning Commission, 2014).

Irrigation has been an important factor in the success of green revolution. But, expansion of cropped area and increase in cropping intensity have led to a significant increase in the demand for irrigation water. Rising profitability in agriculture facilitated private investments in tube-wells; the number of tube-wells increased from 1.98 lakh in 1970-71 to 13.85 lakh in 2013.14. Three-fourths of the cropped area is now tubewell irrigated (Vatta et.al 2013, Ghuman, 2017), which has resulted in over-exploitation of the groundwater resources. The net groundwater availability which was 0.30 million ha m in 1984 turned into a deficit of 1.48 million ha m in 2011. Of the total of 138 development blocks, in more than 110 the withdrawal of groundwater far exceeds their recharging rate. In addition, rising population, urbanization and industrialization have also caused substantial increase in demand for water.

Water resources

Freshwater sources: Water resources include surface water, groundwater and rainwater. These components are associated with one another through the hydrological cycle. The inter-relationship among these is determined by the rainfall that contributes to groundwater through drainage and to surface water through run off. Likewise, seepage from canal networks, and return flow of water for irrigation contributes to replenishment of groundwater.

The mean normal rainfall in Punjab is 435.6 mm, most of which is received during monsoon season from June to October. The annual rainfall increased from 600 mm in 1971 to 700 mm in 1997, but declined considerably to around 400 mm after 1997 (Figure 1). Such a drastic decline in rainfall had an adverse effect on water resources.

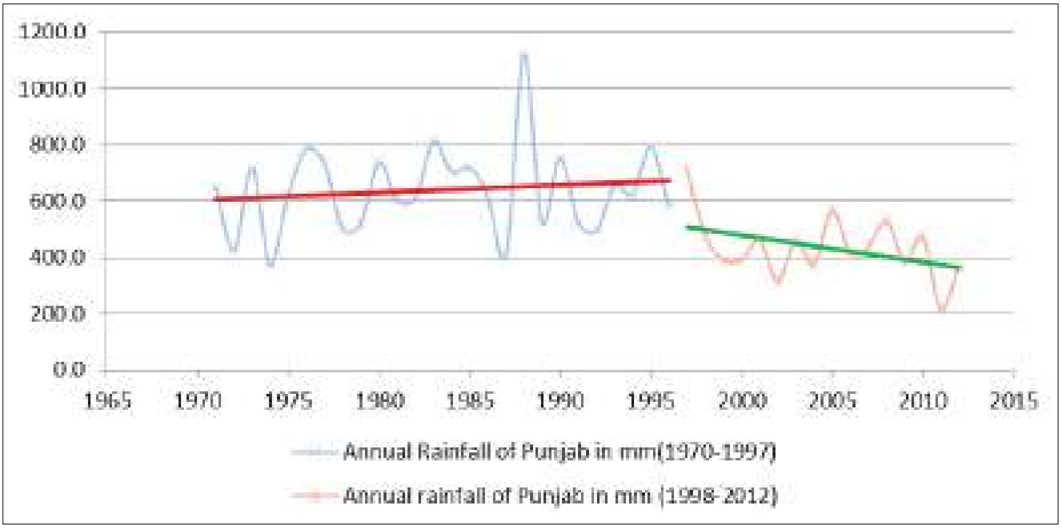

Figure 1: Temporal variation in average annual rainfall in Punjab, 1970-2012

Source: Statistical Abstracts of Punjab, various issues

There is considerable spatial variation in the distribution of rainfall in the state. Based on the quantum of rainfall, the districts in the state can be divided into high, medium and low rainfall districts (Table 1). Gurdaspur, Pathankot, Hoshiarpur and Rupnagar in the foothills of Shivaliks receive high rainfall of 800-950 mm. Shahid Bhagat Singh (SBS) Nagar, Jalandhar, Sahibzada Ajit Singh (SAS) Nagar, Amritsar, Kapurthala, Patiala, Tarn Taran and Fatehgarh Sahib fall in the medium rainfall category with a mean annual rainfall of 500-700 mm. Rainfall is low (250-500mm) in Moga, Muktsar, Ludhiana, Faridkot, Barnala, Sangrur, Bathinda, Ferozpur, Fazilka and Sangrur.

Table 1: Variation in annual rainfall across various districts in Punjab

Districts	**Annual rainfall in mm**						
	1970	1980	1990	2000	2010	2013	Average
			Heavy rainfall region				
Gurdaspur	926	1155	1215	830	446	1499	959
Pathankot	926	1155	1215	830	446	1499	959
Hoshiarpur	999	906	1076	658	636	586	791
Rupnagar	983	759	1092	793	897	958	785
			Medium rainfall region				
SBS Nagar	171	874	1196	699	605	594	672
Jalandhar	171	874	1196	364	560	594	651
SAS Nagar	770	797	878	717	398	398	596

Amritsar	595	870	651	208	679	686	574
Kapurthala	555	683	781	542	555	697	546
Patiala	556	836	663	641	484	504	537
Tarn Taran	595	870	651	208	542	686	508
Fatehgarh Sahib	556	836	663	155	422	422	473
Low rainfall region							
Moga	444	511	568	175	399	797	450
Muktsar	366	511	568	358	351	797	437
Ludhiana	757	38	524	437	604	555	426
Faridkot	366	511	568	257	459	797	424
Barnala	522	521	527	202	412	412	403
Sangrur	522	521	527	202	416	325	364
Bathinda	499	356	342	136	253	593	330
Firozpur	232	956	422	130	203	300	329
Fazilka	232	956	422	130	203	300	329
Mansa	499	356	342	77	121	121	250
Punjab (average)	672	739	755	392	472	695	569

Source: Statistical Abstract of Punjab, various issues

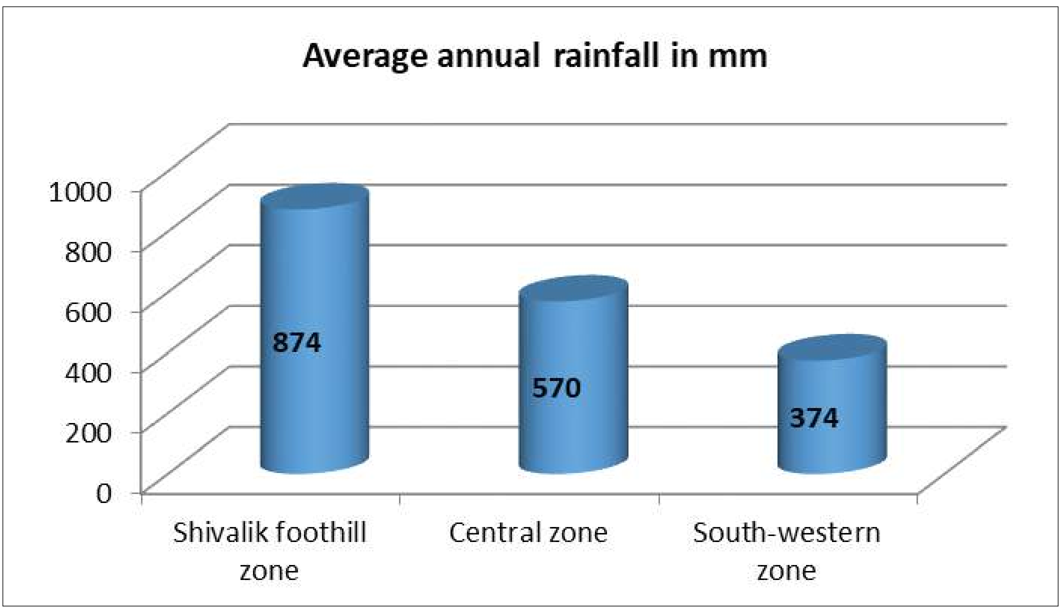

Figure 2: Average annual rainfall across three agro-climatic zones in Punjab, 1970-2002

Source: Statistical Abstracts of Punjab, various issues

Total river water allocated to Punjab is around 17.93 billion cubic meters (BCM), mainly through Sutlej, Beas, Ravi and Ghagger rivers. The river water is distributed to command area through 14,500 km long network of six major canals viz. Upper Bari Doab, Bist Doab, Sirhind, Bhakra Main, Bikaner and Ferozepur Canal). The total command area under these canals is 30.88 lakhs hectares. Besides, the state has 21 wetlands (12 natural and 9 man-made) spread over 155.78 sq. km., and 4,952 ponds.

Over time, groundwater has emerged as dominant source of irrigation in Punjab. The annual replenishable groundwater is 22.53 BCM as against a draft of 34.88 BCM, much more than the permissible limit. The intensive use of groundwater in agriculture along with its growing uses in industrial and household sectors has adversely affected net ground water availability. The net groundwater availability declined from 0.30 million ha m in 1984 to 0.03 million ha m in 1999, and further to (-) 1.48 million ha m in 2011 (Figure 3). The groundwater development (ratio of gross groundwater draft to net ground water availability) in the state is 172%.

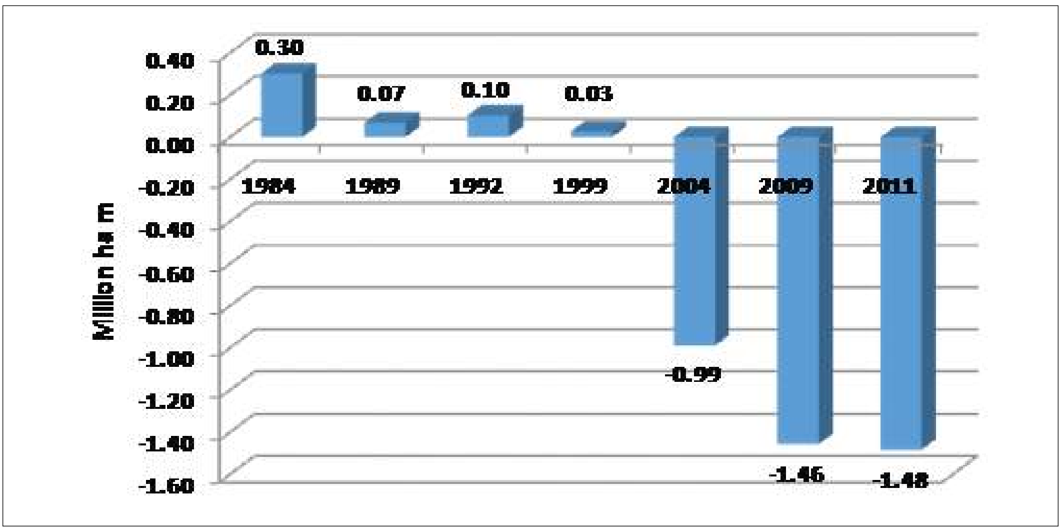

Figure 3: Trends in net groundwater availability in Punjab, 1984-2011

Source: Central Ground Water Board, Punjab

sectoral water scenario

There is no doubt that agriculture is the largest consumer of water, its use in industrial and households sectors has also increased significantly. The demand for water in agriculture increased sharply. During 1980s and 1990s, the annual water demand was 3.36 million ha m against a supply of 3.66 million ha m. However, afterwards the water balance changed. While, the annual water demand kept increasing, its supply contracted. In 2014-15, the annual water demand was 4 million ha m, and the supply was 2.54 million ha m (Figure 4).

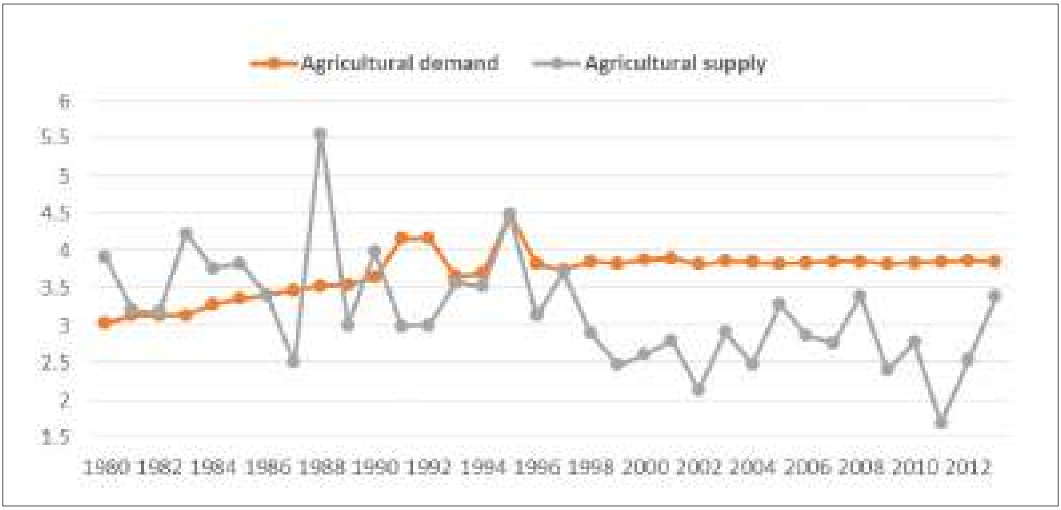

Figure 4: Trends in demand and supply of water in Punjab agriculture

Source: CIPT-WEALS estimates

Changes in cropping pattern accompanied by intensive cultivation has been the most important factor in the incessant increase in demand for water. Rice, a water-intensive crop, has emerged as the dominant crop in kharif season, increasing its share in the total cropped area to 36% in 2013-14 from 17.4% in 1980-81. The cropping intensity has increased from 126% in 1960-61 to more than 191% in 2014-15. Accordingly, the demand for water for rice cropping increased from 0.81 million ha m to 1.70 million ha m. In other words, the share of rice in the total water consumption in agriculture increased from 26% to 44%.

There has been an increase in the number of industrial units, especially of small scale units, from just 24 in 1966 to over 1.6 lakh in 2009 (Department of Industries, 2009). The number of medium and large-scale industries too increased from 122 in 1966 to 306 in 2009. Though, not much information on water use in the industrial sector is available, through application of WATERGAP model we estimate industrial demand for water at 0.83 BCM in 2010-11.

The population of Punjab has increased from 1.35 crore in 1971 to 2.77 crore in 2011, and the share of urban population increased from 23.7% to 37.5%. The drinking water demand as per the norms of CPHEEO stands out at 1.01 BCM (0.44 BCM for rural and 0.57 BCM for urban). By 2025, population of the state is expected to reach 3.06 crore, and accordingly the demand for water to 1.59 BCM. In sum, though agriculture is the main user of water in Punjab, the industrial and household sectors consume 15 per cent of the total water available.

Major challenges

The water-intensive agriculture, rising population accompanied by rapid urbanization and industrialization pose a serious threat to the long-term sustainability of water resources. The demand for water far exceeds its sustainable supply level, and has resulted into over-exploitation of the groundwater resources. The current water supply is barely sufficient to meet three-fourths of the total irrigation water requirements, and it is expected to squeeze further owing to its rising demand in other sectors.

In south-western part of the state, the expansion of canal network and non-exploitation of the native brackish water has resulted in rise in water table causing problems of waterlogging and salinity. On the other hand, due to over-exploitation of good quality water in the central part the water table has declined to critical levels (more than 10m). The deterioration in water quality due to contamination by industrial effluents is another important challenge.

Of 138 development blocks in the state, 110 are over exploited, 4 are critical and 2 are in semi-critical stage (CGWB, 2012). The number of dark or over-exploited blocks that were 60-70 between 1984 and 1992 has increased to 100 after 2004. The number of over-exploited blocks has almost doubled during 1984 to 2011 (Table 2).

Table 2: Trends in groundwater exploitation across various development blocks in Punjab, 1984-2011

Category of blocks/ Year	1984	1986	1989	1992	1999	2004	2009	2011
Dark/Over-exploited	53	55	62	63	73	103	110	110
Dark/Critical	7	9	7	7	11	5	3	4
Grey/Semi-critical	22	18	20	15	16	4	2	2
White/Safe	36	36	29	33	38	25	23	22
Total	118	118	118	118	138	137	138	138

Notes: Over-exploited, critical, semi-critical and safe blocks represent more than 100%, 90-100%, 70-90% and below 70% levels of groundwater development, respectively. Groundwater development reflects the ratio of annual ground water extraction to the net annual ground water availability

Source: Central Ground Water Board, Punjab

Most of the over-exploited blocks are in the central zone, which is dominated by rice-wheat system. In other words, over-exploitation of groundwater resources is severe in the blocks/regions where paddy is the dominant crop and groundwater is fit for irrigation. In other blocks, it is either maize or cotton that dominates the cropping pattern and the groundwater availability is poor due to deep aquifers (e.g. in sub-mountainous zone) or if available it is unfit for irrigation due to its saline nature as in the south-western zone.

The groundwater table in the central Punjab fell annually by 17cm during the 1980s and by 25cm during the 1990s. The decline has been the sharpest in the past about one and a half decade; 91 cm per annum between 2000 and 2005 and 75 cm afterwards. Only 3.7 per cent of the area in central zone had a water table depth of more than 10m in 1973, which increased by 26.7% in 1990 and 91.6% in 2010. The area with water table depth of more than 15m was only 0.6% in 1973, which remained almost same until 1990 but increased to 75.1% in 2010. On the whole, more than 50 per cent of the area in the state has water table depth exceeding 20m (Table 3).

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Table 3: Decline in water table in central Punjab

Year	Per cent area with water table depth of more than		
	10m	15m	20m
1973	3.7	0.6	0.4
1980	5.7	0.6	0.4
1990	26.7	2.9	0.4
2000	53.2	14.1	0.1
2005	85.4	42.1	14.5
2010	91.6	75.1	50.5

Source: Statistical Abstracts of Punjab, Various Issues

Energy use in Punjab

There has been a significant increase in energy consumption in Punjab. The cumulative consumption of electricity in Punjab during 1987-88 to 1995-96 was 129 billion kwh, which increased to 211 billion kwh during 1997-98 to 2006-07 and further to 309 billion kwh during 2007-08 to 2015-16 (Table 4).

During 1987-88 to 1995-96, agriculture with a share of 42% in total electricity consumption was the largest consumer, followed by industrial sector (37%), and the domestic sector (14%). The sectoral shares changed drastically --the industrial sector emerged as the largest consumer of electricity though its share in total consumption declined to 34.4% during 2007-08 to 2015-16. The share of agriculture also declined to 30%. The electricity consumption in the domestic sector more than

Table 4: Trends in electricity consumption in various sectors of Punjab economy (million kwh)

Period	Domestic	Industrial	Agriculture	Commercial	Others	Total
1987-88 to 1995-96	18529 (14.3)	47856 (37.0)	54837 (42.4)	3297 (2.6)	4683 (3.6)	129202 (100.0)
1997-98 to 2006-07	45209 (21.5)	83756 (39.8)	66680 (31.7)	9771 (4.6)	5139 (2.4)	210555 (100.0)
2007-08 to 2015-16	78892 (25.5)	106389 (34.4)	93340 (30.2)	22826 (7,4)	7698 (2.5)	309245 (100.0)
Compound annual growth rate (%)	7.1	3.9	2.6	9.7	2.4	4.2

Source: Punjab State Power Corporation Limited (PSPCL), Patiala

quadrupled and accounted for 25.5% of the total consumption. The share of commercial sector increased from 2.6% to 7.4%.

In terms of annual growth, the total electricity consumption increased at an annual rate of more than 4% in the past three decades, however, with differential rates across sectors. The lowest growth in consumption was experienced by the agriculture sector (2.6% per annum), followed by industrial sector (4% per annum), domestic sector (7.1% per annum) and commercial sector (9.7% per annum).

Rising incomes, growing urbanization and industrialization have been the major reasons for increase in electricity consumption in non-agricultural sectors. These sectors are expected to grow further, implying more demand for electricity in the times to come. The growth in electricity consumption in agriculture is due to its increasing use for pumping groundwater for irrigation. The total number of tubewells in the state has increased from 6 lakh in 1980-81 to 14.06 lakh in 2014-15, and the share of electric tubewells from 46% to 88% (Table 5).

Table 5: Trends in the number of tubewells in Punjab, 1980-81 to 2014-15

Year	Total number of tubewells (lakh)	Electric tubewells as %age of total tubewells
1980-81	6.00	46.7
1990-91	8.00	80.8
2000-01	10.73	73.4
2010-11	13.82	82.6
2014-15 (P)	14.06	87.8

Note: The values for 2014-15 are provisional

Source: Statistical Abstracts of Punjab, 2015

There are about one million operational holdings in Punjab, much less than the number of electric tubewells. That means, there is more than one electric tubewell for every operational holding in the state.

The provision of free electricity to the agriculture has led to vicious cycle of rising electricity consumption in agriculture as well as power subsidies. The power subsidy in agriculture has increased from Rs 693 crore in 1995-96 to Rs 3095 crore in 2010-11 and the per hectare power subsidy rose from Rs 1676 to Rs 7421 during the same period (Singh, 2012). In order to meet the ever-growing demand for electricity, the government of Punjab has enhanced electricity supply by installing more power plants. The installed capacity increased from 680 MW in 1970-71 to 10955MW in 2014-15. Despite this, supply of electricity falls short of its requirement, leading to widening of the gap from 4.2% in 2000-01 to 15% in 2015-16.

Chapter 3

Modelling Water-Energy-Agriculture Nexus

As the demand for water as well as energy use has undergone significant change across sectors, there is a need to examine the intra- and inter-sectoral trade-offs and synergies in their usage so as to ensure their long-term sustainability. In other words, the nexus between resources and sectoral outputs with special emphasis on agriculture, the largest consumer of water and second largest consumer of electricity in the state, needs to be evaluated.

The Centers for International Projects Trust (CIPT) has attempted to develop a model (CIPT-WEALS) for integrated assessment of the nexus among water, energy, agriculture and livelihood sustainability. In formulating the nexus, water has been considered as the prime resource for sustainable agriculture, and energy consumption in agriculture is derived from water use in agriculture. Water and energy scenarios for other sectors are based on their past trends and the assumptions regarding future economic growth and demographic changes. We also build up impact of climate change in the model through changes in rainfall and the adaptation strategies (e.g. crop diversification and innovative technologies and practices. The CIPT-WEALS is based on the following framework

- Sectoral assessment of demand for and supply of water.
- Over-exploitation of groundwater resources and fall in groundwater table.
- Future scenarios of agricultural production, water usage and electricity consumption.
- Projections of future demand for water and energy, and fall in groundwater table.
- Long-term policy options.

Sectoral assessment of the demand and supply of water

Supply of water: The annual supply of water is arrived at combining surface water (canals) and that available through rainfall. Total surface water supply in Punjab is taken as 1.45 million ha m. Availability of water from rainfall is estimated as:

Water supply from rainfall = Average annual rainfall * (1-run-off coefficient)* total geographical area.

The water supply varies depending on the extent of annual rainfall. The run-off coefficient has been estimated following Garde et al. (1983). Details of run-off coefficients for 2000-01 to 2012-13 are given in Appendix 1.

As usual, 15% of the total water supply is allocated for industrial and domestic sectors, and the remaining 85% to agriculture. The CIPT-WEALS has used this pattern of allocation to estimate the demand-supply gap.

Demand for water: The demand for water has been estimated separately for each of the sector viz. agriculture, industry and household. Demand for water in agriculture is estimated taking into consideration water requirements of crops and the area under their cultivation. The water requirements is based on evapotranspiration (ET) value of a crop. The ET values for crops estimated at Punjab Agricultural University (PAU), Ludhiana are given in Table 6.

Table 6: Evapotranspiration (ET) values for different crops in Punjab

Crop/Crop group	ET values (m)
Paddy	0.60
Wheat	0.38
Maize	0.48
Barley	0.30
Bajra	0.25
Pulses	0.45
Oilseeds	0.25
Sugarcane	1.35
Potato	0.30
Cotton	0.60
Others	0.45

Source: Punjab Agricultural University, Ludhiana

Water demand (agriculture) =

Where, A_i is the area under a crop and ET_i is the evapotranspiration value for that crop.

Water demand for industrial sector has been estimated employing WaterGAP model developed at the Institute of Physical Geography, Goethe University, Frankfurt, Germany (for details: https://www.uni-frankfurt.de/45218063/WaterGAP). We estimate industrial demand for water at 0.83 billion cubic meter (BCM) in 2010-11.

Demand for water in domestic sector is estimated taking into consideration the daily water requirements of individuals in rural and urban areas. The daily water demand for each population group has been converted into annual demands, multiplied these with their respective populations and then added up to make the total demand. As per CPHEEO the rural and urban water consumption is 70 liter/capita/day and 170 liter/capita/day, respectively. Thus, we arrive at an estimate of water demand of 1.08 BCM in 2011.

The estimated demand for water in different sectors has been added up to arrive at the total demand for water in Punjab. The estimates of demand for and supply of water for the period 1980 to 2013 are shown in Table 7. The estimates clearly show that although demand for water had been constant until the mid-1990s but it was within limits of sustainable supply. Post mid-1990s the demand for water remains almost constant at 4.5 BCM, but there was a substantial decline in its supply owing to significant reduction in rainfall.

The demand for water in agriculture increased substantially, from 3.03 million ha m in 1985 to 4.48 million ha m in 1995 then dropped and remained constant at around 3.85 million ha m in recent years. Between 1980 and 2013, the annual water demand in agriculture increased by 27%, however, the demand of rice crop increased by 140% due to significant expansion in area under rice (from 1.18 million ha to 2.85 million ha). This led to a rise in the share of rice in the total water consumption in agriculture from 23.4% to 44.6%.The water supply through canals is 1.45 million ha m, which comprises 38% of the total water supply to agriculture, and one-third of the overall supply.

Over-exploitation and fall in groundwater table

Having estimated demand for and supply of groundwater, we look into the variations in the gaps between supply of and demand for groundwater during 1980-2013. Till 1990, supply of water exceeded the demand (Figure 5), however, after 1990 the demand was more than supply, and to the extent of about one million ha m.

Table 7: Total demand and supply for water in Punjab, 1980 to 2013 (million ha m)

Year	Water demand for rice	Total agricultural water demand	Total water demand	Total water supply
1980	0.71			
(23.4)	3.03	3.73	4.61	
1985	1.03			
(30.6)	3.36	4.06	4.53	
1990	1.21			
(33.3)	3.63	4.33	4.68	
1995	1.31			
(29.3)	4.48	5.18	5.18	
2000	1.57			
(40.4)	3.88	4.58	3.30	
2005	1.59			
(41.4)	3.83	4.53	3.98	
2010	1.70			
(44.2)	3.84	4.54	3.47	
2013	1.71			
(44.6)	3.85	4.55	4.09	

Note: Figures in parentheses are %age share of rice water demand in total agricultural water demand

Source: CIPT-WEALS Model

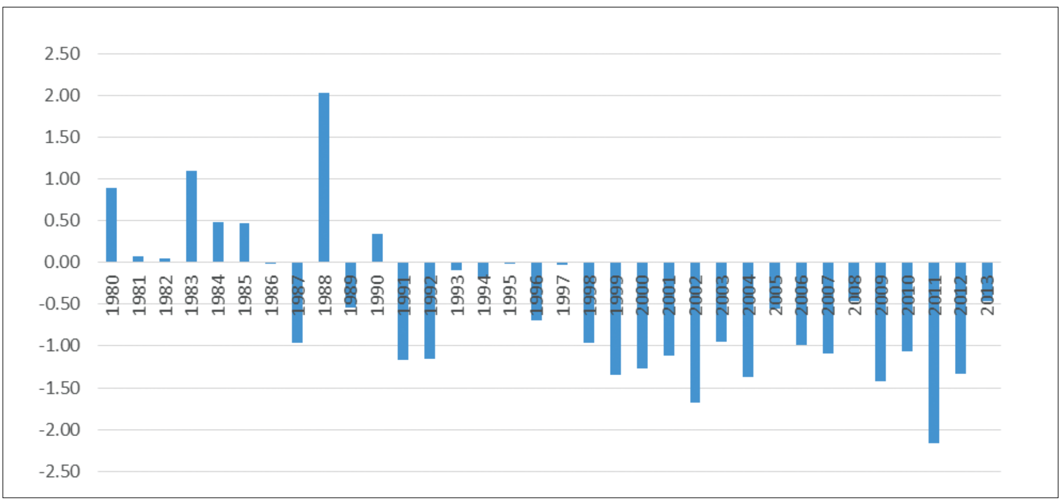

Figure 5: Trends in the gap between total demand and supply for water in Punjab, 1980-2013

Note: Gaps were estimated by using CIPT-WEALS Model

The widening gap between demand and supply has been causing faster depletion of the groundwater resources in the state. We compare estimates of the groundwater table from CIPT-WEALS model to those with actual levels and find these highly consistent. The coefficient of correlation between the two is 0.78 indicating a high degree of accuracy in the model-predicted water table.

Figure 6 compares estimates of predicted groundwater table with the actual one during the period of 1980 to 2013. The fall in groundwater table is well-predicted by ET values and not the actual water use, as is suggested in the literature. In the following section, we will show that while the change in the water table depends on ET values, it is the actual water use by crops that determines electricity supply.

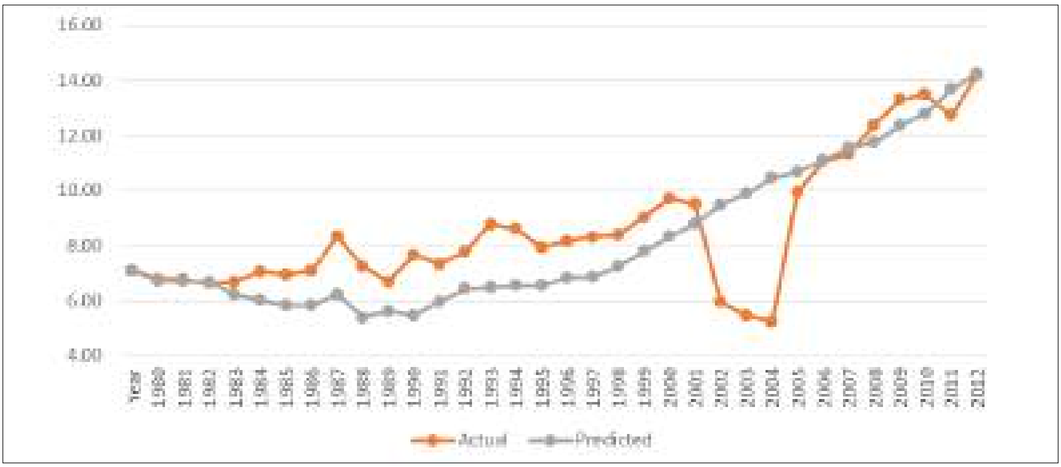

Figure 6: Comparison of actual and predicted groundwater table in Punjab, 1980 to 2013

Note: Predicted levels were determined using CIPT-WEALS Model

Chapter 4

Future scenarios of agricultural production, water use and energy consumption

Having validated CIPT-WEALS model for its predictability, we now attempt to develop scenarios for demand for and supply of water over the period until 2050. These scenarios have been built on several assumptions regarding the agricultural production, climate change, resource-use efficiency, urbanization and industrialization. These assumptions are as follows:

Sectoral demand for water

The demand for water in agriculture is assumed to be determined by ET value as explained earlier, i.e. the sum of water use in individual crops.

The demand for water in industrial sector has been estimated using WATERGAP model for the year 2011. In 2011, industrial water demand was 0.83 BCM and it is expected to increase to 2.45 BCM in 2050. As discussed in the previous section, the future domestic demand for water is estimated assuming daily water needs of 70 liter/capita/day for rural population and 170liter/capita/day for urban population. Using the projected growth in population the domestic demand is expected to reach 2.7 BCM in 2050. The details of water demand in domestic and industrial sectors is given in Table 8. The future water demand in the domestic and industrial sectors is expected to grow at an annual rate of 3%.

Table 8: Expected growth in domestic and industrial water demand in Punjab (billion cubic meter)

Sector	2010	2050
Domestic	1.08	2.70
Industry	0.83	2.45
Total domestic and industry	1.91	5.15
Compound annual growth rate (%)	3	

Source:

Sectoral demand for electricity

The demand for electricity in the agriculture is estimated as:

$$E=\alpha mgh$$

Where, E is the energy demand in joules; m is the mass of groundwater to be lifted (it is total water demand minus surface water availability); g is the acceleration due to gravity and is taken as 9.81 m/s2; h is the depth of groundwater in meters. α is the correction factor used to arrive at the actual demand for energy in the agriculture and it incorporates the motor efficiency as well as the difference in actual water use and evapotranspiration needs of the crops. It is mentioned that the estimates of electricity use in agriculture are prepared using actual water use in rice crop and evapotranspiration value of other crops. This is because the electricity requirements depend on the amount of water to be lifted for irrigation, which is equal to the actual water use (net of canal water). The actual water use in rice cultivation is higher (1500 mm) compared to its evapotranspiration value of 600 mm. The study has assumed no difference in such values for other crops in the CIPT-WEALS model.

Further, electricity demand in agriculture is estimated through the demand for groundwater i.e. agriculture water demand minus canal water supply. Based on the groundwater requirements and considering the average horse power of motors along with the depth of water table, the demand for electricity in agricultural sector has been derived. The demand by industrial and household sectors has been taken from Punjab State Power Corporation Limited (PSPCL, Patiala). The supply of electricity to the agriculture sector is supposed to be equal to the estimated demand. This assumption has been made considering the priority for supply of electricity to agriculture.

The demand estimates are made assuming low and high energy growth scenarios. The future growth in domestic, industrial, commercial and other sectors has been estimated using data from the Punjab State Power Corporation Limited. Low energy demand growth scenario has been developed assuming that the future growth in energy demand in domestic, industrial, commercial and other sectors will follow the same trend as in the past, i.e. during 1987-88 to 2015-16 (Table 9).

Table 9: Trends in energy consumption in different sectors of Punjab economy

Period	Domestic	Industrial	Agriculture	Commercial	Others
Period 1: 1987-88 to 1995-96	18529	47856	54837	3297	4683
Period 2: 1997-98 to 2006-07	45209	83756	66680	9771	5139
Period 3: 2007-08 to 2015-16	78992	106389	93340	22826	7698
Compound annual growth rate (%)	7.1	3.9	2.6	9.7	4.2

Note: The figures represent cumulative consumption of electricity during the given period and are in million kwh.

Source: Punjab State Power Corporation Ltd.

High energy demand growth scenario has been developed because of accelerating growth in energy consumption in recent years, i.e. during 2005-06 to 2015-16. Assuming that these trends will persist in the future as well, we find an annual growth of 8.7% in the domestic sector, 3.4% in the agricultural sector, 3.2 % in the industrial sector, 10.4 % in the commercial sector and 3.9 % in the other economic sectors.

Changes in rainfall pattern

The average annual rainfall in Punjab has undergone a significant change. While the long-term average annual rainfall in the state was 569mm during 1970 to 2013, it declined to 459 mm during 2000 to 2013. Considering only the lowest rainfall years during 2000 to 2013, the average rainfall falls to around 400 mm per annum. Since rainfall is the most important contributor to water supply, we incorporate changes in rainfall in CIPT-WEALS model. Three rainfall scenarios have been assumed, i.e. 569mm, 459mm and 400mm.

Agricultural production and water use

Three broad scenarios of agricultural production and water usage in agriculture have been developed considering different rates of growth in energy and changes in rainfall. These scenarios are developed on the assumptions of future changes in cropping pattern, and the possibilities of adoption of intelligent water saving technologies. These four broad scenarios are termed as:

- Business As Usual (BAU) scenario.
- Crop Diversification (DIV) scenario.
- Intelligent Water Saving Technologies (TECH) scenario.
- Combination of Crop Diversification and Intelligent Water Saving Technologies (DIVTECH) scenario.

The BAU scenario assumes that there will be no change in cropping pattern, i.e. no shift in area away from paddy to other crops, and no further addition to paddy area because paddy area seems to have reached its extensive limit.

The potential of crop diversification has been taken from the Draft Agricultural Policy of the state that envisages to shift 1.2 million hectares away from rice to less water-intensive crops such as maize, cotton, sugarcane, pulses, oilseeds, fruits and vegetables. Table 10 presents existing area and targeted area under different crops. It is assumed that intended crop diversification is achieved by 2020. Any delay in crop diversification will delay accrual of potential benefits in terms of water and energy savings.

Table 10: Proposed alternative crop choices for diversification in Punjab

Crop	Current area (lakh ha)	Potential area (lakh ha)	Change (lakh ha)
Rice	28.00	16.00	-12.00
Maize	1.30	5.50	3.20
Cotton	4.80	7.00	2.20
Sugarcane	0.70	2.60	1.90
Pulses	0.20	1.50	1.30
Oilseeds	-	0.20	0.20
Fruits and Vegetables	0.50	1.00	0.50
Kharif fodder	4.00	5.50	1.50
Others	1.50	3.50	2.00

Source: PSFC, 2013

In the third scenario (TECH), we assume large-scale adoption of intelligent water saving technologies. The adoption of these technologies will lead to a significant reduction in ET values of crops. The development and promotion of these technologies will require a significant amount of resources (financial and others). Hence, it is assumed that the reduction in ET values will be gradual over the period of thirty years after 2020. It may reflect development of new technologies, refinement of the old technologies and increasing technological adoption. Under TECH scenario, it is assumed that a successful strategy will lead to 5% reduction in ET values by 2020, 15% by 2030, 25% by 2040 and 35% by 2050 (Table 11). The stakeholder discussions have revealed that it is possible to achieve such levels of efficiency.

Table 11: Target reduction in ET values under TECH scenario in Punjab, 2020 to 2050

Year	Reduction target in ET values (%)
2020	5
2030	15
2040	25
2050	35

Note: These assumptions were verified in the Stakeholder Conference of CIPT held at Chandigarh in March, 2017

Finally, we combine crop diversification and intelligent water saving technologies and develop a scenario called DIVTECH. The objective is to achieve the best results through improving synergy between crop diversification and technological adoption.

A total of 24 scenarios have been developed. A brief description of these is given in Table 12.

Table 12: Brief description of future scenarios of CIPT-WEALS model

Broader Scenario	Sub-scenario	Scenario Name	Description
A. Business As Usual (BAU)	1. Normal Rainfall and Normal Energy Growth	BAU_NR_NE	No change in cropping pattern; annual rainfall of 569mm; usual growth in energy demand.
	2. Declining Rainfall and Normal Energy Growth	BAU_DR_NE	No change in cropping pattern; annual rainfall of 459mm; usual growth in energy demand.
	3. Severely declining rainfall and normal energy growth	BAU_SDR_NE	No change in cropping pattern; annual rainfall of 400mm; usual growth in energy demand.
	4. Normal Rainfall and High Energy Growth	BAU_NR_HE	No change in cropping pattern; annual rainfall of 569mm; high growth in energy demand.
	5. Declining Rainfall and High Energy Growth	BAU_DR_HE	No change in cropping pattern; annual rainfall of 459mm; high growth in energy demand.
	6. Severely declining rainfall and high energy growth	BAU_SDR_HE	No change in cropping pattern; annual rainfall of 400mm; high growth in energy demand.
B. Crop Diversification (DIV)	1. Normal Rainfall and Normal Energy Growth	DIV_NR_NE	Cropping pattern changes as per Draft Agricultural Policy; annual rainfall of 569mm; usual growth in energy demand.
	2. Declining Rainfall and Normal Energy Growth	DIV_DR_NE	Cropping pattern changes as per Draft Agricultural Policy; annual rainfall of 459mm; usual growth in energy demand.
	3. Severely declining rainfall and normal energy growth	DIV_SDR_NE	Cropping pattern changes as per Draft Agricultural Policy; annual rainfall of 400mm; usual growth in energy demand.
	4. Normal Rainfall and High Energy Growth	DIV_NR_HE	Cropping pattern changes as per Draft Agricultural Policy; annual rainfall of 569mm; high growth in energy demand.
	5. Declining Rainfall and High Energy Growth	DIV_DR_HE	Cropping pattern changes as per Draft Agricultural Policy; annual rainfall of 459mm; high growth in energy demand.
	6. Severely declining rainfall and high energy growth	DIV_SDR_HE	Cropping pattern changes as per Draft Agricultural Policy; annual rainfall of 400mm; high growth in energy demand.

C. Intelligent Water Saving Technologies (TECH)	Normal Rainfall and Normal Energy Growth	TECH_NR_NE	Adoption of technologies result in achieving water saving targets; annual rainfall of 569mm; usual growth in energy demand.
	2. Declining Rainfall and Normal Energy Growth	TECH_DR_NE	Adoption of technologies result in achieving water saving targets; annual rainfall of 459mm; usual growth in energy demand.
	3. Severely declining rainfall and normal energy growth	TECH_SDR_NE	Adoption of technologies result in achieving water saving targets; annual rainfall of 400mm; usual growth in energy demand.
	4. Normal Rainfall and High Energy Growth	TECH_NR_HE	Adoption of technologies result in achieving water saving targets; annual rainfall of 569mm; high growth in energy demand.
	5. Declining Rainfall and High Energy Growth	TECH_DR_HE	Adoption of technologies result in achieving water saving targets; annual rainfall of 459mm; high growth in energy demand.
	6. Severely declining rainfall and high energy growth	TECH_SDR_HE	Adoption of technologies result in achieving water saving targets; annual rainfall of 400mm; high growth in energy demand.
D. DIVTECH (Combination of Crop Diversification and Intelligent water saving technologies)	1. Normal Rainfall and Normal Energy Growth	DIVTECH_NR_NE	Change in cropping pattern along with water saving technologies; annual rainfall of 569mm; usual growth in energy demand.
	2. Declining Rainfall and Normal Energy Growth	DIVTECH_DR_NE	Change in cropping pattern along with water saving technologies; annual rainfall of 459mm; usual growth in energy demand.
	3. Severely declining rainfall and normal energy growth	DIVTECH_SDR_NE	Change in cropping pattern along with water saving technologies; annual rainfall of 400mm; usual growth in energy demand.
	4. Normal Rainfall and High Energy Growth	DIVTECH_NR_HE	Change in cropping pattern along with water saving technologies; annual rainfall of 569mm; high growth in energy demand.
	5. Declining Rainfall and High Energy Growth	DIVTECH_DR_HE	Change in cropping pattern along with water saving technologies; annual rainfall of 459mm; high growth in energy demand.
	6. Severely declining rainfall and high energy growth	DIVTECH_SDR_HE	Change in cropping pattern along with water saving technologies; annual rainfall of 400mm; high growth in energy demand.

Chapter 5

Projected Demand for Water and Energy, and fall in Groundwater Table

Water demand

The projected demand for water in agriculture, domestic and industrial sectors is shown in Table 13. The aggregate demand for water is likely to increase significantly. Under BAU scenario, it will increase by about 31% from the current 4.55 million ha m to 5.94 million ha m in 2050.

Table 13: Estimates of future demand for water in Punjab, 2020 to 2050 (million ha m)

Year	Agricultural demand	Industrial and domestic demand	Total demand
A. Business As Usual (BAU) scenario			
2020	3.85 (81.7)	0.86 (18.3)	4.72 (100.0)
2030	3.85 (76.8)	1.16 (23.2)	5.01 (100.0)
2040	3.85 (71.3)	1.55 (28.7)	5.40 (100.0)
2050	3.85 (64.8)	2.09 (35.2)	5.94 (100.0)
B. Crop Diversification (DIV) Scenario			
2020	3.80 (81.5)	0.86 (18.5)	4.73 (100.0)
2030	3.80 (76.6)	1.16 (23.4)	4.95 (100.0)
2040	3.80 (71.9)	1.55 (28.1)	5.35 (100.0)
2050	3.80 (64.5)	2.09 (35.5)	5.89 (100.0)
C. Innovative Water saving Technologies (TECH) scenario			
2020	3.66 (80.9)	0.86 (19.1)	4.52 (100.0)
2030	3.28 (73.9)	1.16 (26.1)	4.43 (100.0)
2040	2.89 (65.0)	1.55 (35)	4.45 (100.0)

2050	2.51 (54.5)	2.09 (45.5)	4.59 (100.0)
D. Combination of Crop Diversification and Intelligent water saving technologies (DIVTECH) Scenario			
2020	3.61 (80.7)	0.86 (19.3)	4.47 (100.0)
2030	3.23 (73.6)	1.16 (26.4)	4.38 (100.0)
2040	2.85 (64.7)	1.55 (35.3)	4.40 (100.0)
2050	2.47 (54.1)	2.09 (45.9)	4.56 (100.0)

Note: Figures in parentheses are percentages of total demand

Source: CIPT-WEALS Model

Crop diversification will not bring any significant savings in water use in agriculture as demand in this sector will decline by only 0.05 million ha m annually when compared to the BAU scenario. The additional demand for water in the BAU and crop diversification scenarios will arise due to significant increase in demand from domestic and industrial sectors. The annual water demand in agriculture will remain almost unchanged at 3.85 million ha m in BAU scenario and 3.80 million ha m with crop diversification. The demand for water in industrial sector will increase three-fold over the current level, and will reach to 2.09 million ha m by 2050. Marginal decline in demand for water in agriculture, and substantial increase in demand from domestic and industrial sectors would cause a considerable change in sectoral shares of water usage. The share of agriculture will decline to 82% in 2020, 77% in 2030, 71% in 2040 and below 65% in 2050.

The technology scenario provides a different case. It causes a decline in demand for water in agriculture due to adoption of innovative water saving technologies. The total annual water demand will be around 4.5-4.6 million ha ma during 2020 to 2050. Due to increased water-use efficiency in agriculture, the share of agriculture in total water demand will decline to 80% in 2020, 74% in 2030, 67% in 2040 and 57% in 2050. The agriculture, through the adoption of innovative water-efficient technologies and practices, has potential to release more than 8% of its share to domestic and industrial sectors by 2050. On the whole, with this scenario, the total water demand in 2050 will be just 5.5% more above the current level.

Under the DIVTECH scenario, the overall annual water demand will be 4.47 million ha m in 2020 and will finally reach 4.56 million ha m in 2050. The share of agriculture sector in the total water demand will come down to as low as 54% by 2050.

Demand-supply gap

The ever rising demand for water would lead to widening of the gap between its demand and supply, and would result in increased over-exploitation of water resources in future. The average annual demand-supply gap for water that was around 1.3 million ha m in 2011-13 would increase to 2.78 million ha m by 2050 under BAU with severe decline in rainfall situation, though the gap will be 2.06 million ha m under normal rainfall situation (Table 14). The gap will amount to 53-88% of the available water supply in the state during 2050.

Table 14: Estimates of gap between demand and supply of water in Punjab, 2020 to 2050 (million ha m)

Year	Rainfall situation		
	Normal rainfall (569mm)	**Declining rainfall (459 mm)**	**Severely declining rainfall (400 mm)**
A. Business As Usual (BAU) Scenario			
2020	0.83 (21.3)	1.30 (38.1)	1.55 (49.1)
2030	1.13 (28.9)	1.60 (46.8)	1.85 (58.5)
2040	1.52 (39.2)	1.99 (58.5)	2.25 (71.1)
2050	2.06 (52.9)	2.53 (74.2)	2.78 (88.0)
B. Crop Diversification (DIV) Scenario			
2020	0.77 (19.8)	1.24 (36.4)	1.49 (47.3)
2030	1.07 (27.4)	1.54 (45.1)	1.79 (56.7)
2040	1.47 (37.7)	1.94 (56.8)	2.19 (69.3)
2050	2.00 (51.4)	2.47 (72.5)	2.72 (86.2)
C. Innovative Water Saving Technologies (TECH) Scenario			
2020	0.64 (16.4)	1.11 (32.5)	1.36 (43.0)
2030	0.55 (14.1)	1.02 (29.9)	1.27 (40.2)
2040	0.56 (14.4)	1.03 (30.2)	1.28 (40.6)
2050	0.71 (18.2)	1.18 (34.6)	1.43 (45.3)

D. Combination of Crop Diversification and Intelligent water saving technologies (DIVTECH) Scenario			
2020	0.58 (14.9)	1.05 (30.9)	1.30 (41.3)
2030	0.50 (12.8)	0.97 (28.4)	1.22 (38.6)
2040	0.52 (13.3)	0.99 (28.9)	1.24 (39.2)
2050	0.67 (27.3)	1.14 (33.5)	1.39 (44.1)

Note: Figures in parentheses are percentages of the total water availability during the particular year

Source: CIPT-WEALS Model

As there will not be any substantial improvement in the water use under the crop diversification scenario, the demand-supply gap will amount to 2-2.72 million ha m, which will be around 51-86% of the available water supply. The adoption of water saving technologies will reduce demand-supply gap considerably, within the range of 0.71-1.43 million ha m which will amount to 18-45% of the available water supply. The technologies can help reduce the demand-supply gap for water by more than half by 2050. The combination of crop diversification and technologies will marginally improve the gap when compared to the pure technology scenario.

Fall in water table

As a result of the widening demand-supply gap for water, the water table would decline considerably in the BAU scenario. It may fall below 43 m by 2050 under the BAU and crop diversification scenarios (Table 15). The falling water table can be arrested through adoption of intelligent water saving technologies.

Table 15: Estimates of the future groundwater table in Punjab under different scenarios, 2020 to 2050 (metres)

Year	Rainfall situation		
	Normal rainfall (569mm)	**Declining rainfall (459 mm)**	**Severely declining rainfall (400 mm)**
A. Business As Usual (BAU) Scenario			
2020	16.29	17.47	18.10
2030	20.27	23.41	25.09
2040	25.66	30.76	33.49
2050	32.95	40.01	43.80
B. Crop Diversification (DIV) Scenario			
2020	16.29	17.47	18.10
2030	20.02	23.16	24.84

2040	25.17	30.27	33.01
2050	32.22	39.28	43.07
C. Innovative Water Saving Technologies (TECH) Scenario			
2020	16.13	17.30	17.94
2030	18.58	21.72	23.40
2040	20.85	25.94	28.68
2050	23.40	30.46	34.25
D. Combination of Crop Diversification and Intelligent water saving technologies (DIVTECH) Scenario			
2020	16.13	17.30	17.94
2030	18.36	21.50	23.18
2040	20.43	25.53	28.26
2050	22.81	29.87	33.66

Source: CIPT-WEALS Model

With the adoption of innovative water saving technologies or combining technologies with the crop diversification will help in arresting the water table between 22 to 34m under different rainfall situations. Apart from the depletion of water resources, decline in rainfall would have serious implications for the demand for electricity and power subsidy. It is obvious that the decline will have wide regional variations but the CIPT-WEALS model limits itself to the overall estimates at this point of time. It is important to note that the crop diversification scenario does not lead to any improvement in the water table. The water table is projected to reach about 43 m by 2050 under this scenario as well. It points to the need to look for policy options other than crop diversification for long-term sustainability of groundwater resources. Under the TECH scenario even with a severe decline in rainfall, the water table will reach around 34 m by 2050, which is one-fifth less than that in the BAU scenario.

Energy demand

In projecting demand for energy, it was assumed that falling water table would influence energy consumption in agriculture only, and not in other sectors. The total energy demand in Punjab is likely to grow faster even on the assumption that it may grow at a rate as in the past three decades. The total demand for electricity would increase to 82-92 billion kwh in 2030, 148-166 billion kwh in 2040 and to 286-314 billion kwh in 2050 under the low energy growth scenario (Table 16). Under high energy growth scenario, the total electricity demand would be 91-101 billion kwh in 2030, 172-200 billion kwh in 2040 and then between 379-424 billion kwh in 2050. In any case, by 2050 the electricity consumption in Punjab would be 8-11 times as compared to the current consumption.

Table 16: Estimates of total annual demand for electricity (all sectors) in Punjab, 2020 to 2050 (billion kwh)

Year	Low energy growth scenario	High energy growth scenario		
	Total electricity demand	Increase factor	Total electricity demand	Increase factor
2020	48-53	1.32-1.44	49-54	1.36-1.48
2030	82-92	2.23-2.50	91-101	2.47-2.74
2040	148-166	4.04-4.51	172-200	4.69-5.44
2050	286-314	7.78-8.53	379-424	10.32-11.52

Note: The total electricity demand in Punjab during a particular year varies under different scenarios. Hence range of the estimates has been presented above. Complete details are provided in the appendices at the end. Increase factor represents the ratio of electricity demand during a particular year and the level of electricity use in 2013

Source: CIPT-WEALS Model

Nonetheless, electricity consumption in agriculture will be influenced by crop diversification as well as the adoption of technologies and management practices in agriculture. Though in BAU scenario, electricity consumption in agriculture is projected to increase faster, crop diversification and adoption of innovative water saving technologies can help in arresting the pace increase in electricity consumption in agriculture (Table 17). By 2050, the energy demand might grow by a factor of 2.31-3.86 in the BAU scenario. Such increase factor will be 2.35-3.15 under the DIV scenario and 2.06-3.02 under the TECH scenario. Although, crop diversification helps to reduce the pace of electricity consumption in agriculture, the innovative water saving technologies will reduce it to a higher extent. For example, in BAU scenario the electricity demand for agriculture may increase to as high as 39 billion kwh, but it gets reduced to 31-32 billion kwh under the strategy of crop diversification and adoption of water saving technologies in agriculture. Though DIVTECH scenario did not yield any significant advantage over TECH scenario in terms of water savings in Punjab agriculture, it provides a huge advantage in consumption of electricity as the highest estimate of electricity consumption in agriculture in 2050 appears to be less than half of the BAU estimates at 17 billion kwh.

The consumption of electricity in other economic sectors will grow faster than in agriculture. Even under BAU scenario, electricity consumption in agriculture will rise by 2-4 times in 2050 but at a much faster rate in other sectors (domestic, industry, commercial and others) due rapid urbanization, industrialization and commercialisation. In the domestic sector, by 2050 the electricity demand will increase 12.65 times if current trends in its consumption persist and to 21.90 times if the growth in its consumption accelerates (Table 18). The demand for industry would grow 3-4 times. The commercial sector will experience the highest increase of 30.74 times in low growth scenario and 38.89 times in high growth scenario.

Table 17: Estimates of annual demand for electricity in agriculture sector in Punjab, 2020 to 2050 (billion kwh)

Year	BAU Scenario	DIV Scenario	TECH Scenario	DIVTECH Scenario				
	Demand	Increase factor	Demand	Increase factor	Demand	Increase factor	Demand	Increase factor
2020	11-13	1.14-1.31	9-11	0.93-1.03	12-13	1.17-1.30	9-10	0.87-0.97
2030	14-19	1.42-1.91	12-15	1.22-1.52	14-18	1.41-1.78	10-12	0.94-1.19
2040	18-28	1.80-2.72	17-22	1.66-2.18	17-24	1.69-2.33	10-14	1.02-1.41
2050	24-39	2.31-3.86	24-32	2.35-3.15	21-31	2.06-3.02	12-17	1.15-1.69

Note: As in Table 15. As agriculture demand was estimated using water demand in agriculture and the predicted groundwater table, the estimates remain same under the low as well as high energy growth scenario. However, they vary under different rainfall scenarios

Source: CIPT-WEALS Model

Table 18: Estimates of total annual demand for electricity in different sectors (other than agriculture) in Punjab, 2020 to 2050 (million kwh)

Year/Sector	Domestic	Industry	Commercial	Others
A. Low energy growth scenario				
2020	16719 (1.62)	16140 (1.31)	5623 (1.91)	1093 (1.18)
2030	33198 (3.21)	23663 (1.92)	14193 (4.83)	1385 (1.50)
2040	65919 (6.37)	34691 (2.81)	35821 (12.18)	1756 (1.90)
2050	130890 (12.65)	50860 (4.12)	90406 (30.34)	2226 (2.40)
B. High energy growth scenario				
2020	18548 (1.79)	15394 (1.25)	5879 (2.00)	1210 (1.31)
2030	42717 (4.13)	21094 (1.71)	15814 (5.38)	1773 (1.92)
2040	98377 (9.51)	28903 (2.34)	42532 (14.46)	2600 (2.81)
2050	226562 (21.90)	39605 (3.21)	114396 (38.89)	3812 (4.12)

Note: Figures in parentheses are the increase factor (ratio of electricity demand in a particular year to that in 2013 in a particular sector). Estimates for other sectors are based on their past growth pattern and do not depend on the scenarios as in Table 16

Source: CIPT-WEALS Model

Table 19: Sectoral shares in total electricity use in Punjab, 2020 to 2050 (% share)

Year/Sector	Agriculture	Domestic	Industry	Commercial	Others
A. Low energy growth scenario					
2020	18.4-25.3	31.6-34.5	30.5-33.3	10.6-11.6	2.1-2.3
2030	11.7-21.2	36.1-40.5	25.7-28.8	15.4-17.3	1.5-1.7
2040	7.0-16.8	39.7-44.4	20.9-23.3	21.6-24.1	1.1-1.2
2050	4.1-12.6	41.7-45.7	16.2-17.8	28.8-31.6	0.7-0.8
B. High energy growth scenario					
2020	17.8-24.4	34.1-40.8	21.8-30.8	10.8-12.9	2.2-2.7
2030	10.6-19.3	42.3-50.5	14.4-23.2	15.7-18.7	1.8-2.1
2040	5.7-13.9	49.1-57.1	8.4-15.8	21.2-24.7	0.9-1.5
2050	3.0-9.3	49.1-59.7	4.6-10.0	27.0-30.1	0.9-1.0

Note: The total electricity demand in Punjab during a particular year varies under different scenarios. Hence range of the estimated shares has been presented above. Complete details are provided in the appendices at the end

Source: CIPT-WEALS Model

The highly differential growth trends in electricity consumption across sectors would alter their shares in total demand. At present, agriculture and domestic sectors account for 28% each in the total electricity consumption, and industrial sector consumes 34%. By 2050, the share of domestic sector is likely to increase between 42-46% with low energy growth assumption and between 49-60% with high energy growth assumption (Table 19). The commercial sector would consolidate its share between 27-32%. The share of industrial sector would decline between 16-18% in low growth and 5-10% in high growth situations. The share of agriculture will squeeze considerably (3-13%) depending on the success of crop diversification and adoption of technologies and management practices.

Power subsidies

Currently, government provides free power for agricultural purposes. Assuming that the policy of free power continues, the estimates of power subsidies are derived multiplying the projected electricity consumption in agriculture in a year with its expected price in that year. Although, electricity price has risen significantly in the past, there is a possibility that it may decline in due to increasing investments in alternative cheaper sources such as solar and wind energy. Thus, we estimate power subsidy for agriculture assuming (i) unit price of Rs 5 in 2020, which would remain unchanged until 2050, and (ii) it may decline continuously until 2040 and remains unchanged afterwards. Further, we assume that electricity supply to agriculture will be provided free.

With declining electricity price, the annual power subsidies in agriculture under BAU scenario are estimated in the range of Rs 5846 crore to Rs 6687 crore in 2020, Rs 5526 crore to 8345 crore in 2040 and Rs 7070 crore to Rs 11839 crore in 2050 (Table 20). The cumulative outlay on power subsidies would be in the range of Rs 1.84 lakh crore to Rs 2.63 lakh crore. Crop diversification may reduce subsidy burden by 10-20%, technologies by 4-9% and combination of both crop diversification and technologies by 39-44% during the entire period of 2020-2050.

If electricity prices remains unchanged, the cumulative of power subsidies in BAU scenario would be more, Rs 2.60 lakh crore to Rs 3.78 lakh crore, and with crop diversification these will be between Rs 2.37 lakh crore to Rs 3.03 lakh crore. Under the constant prices situation, there will be a 9-20% reduction in power subsidies achieved by crop diversification, 5-13% reduction by technologies and 26-40% reduction in subsidies by combination of crop diversification and technologies in Punjab during 2020-2050.

Table 20: Estimates of power subsidy in Punjab agriculture, 2020 to 2050 (Rs crore)

Year	BAU scenario	DIV scenario	TECH scenario	DIVTECH scenario
A. Declining power prices				
2020	5846-6687	4762-5290	5960-6628	4448-4946
2030	5820-7808	4996-6198	5784-7284	3851-4862
2040	5526-8345	5106-6695	5194-7145	3129-4329
2050	7097-11839	7217-9646	6326-9258	3524-5199
Cumulative total (2020 to 2050)	184705-263385	166342-210844	177713-232504	113672-148215
B. Constant power prices				
2020	5846-6687	4762-5290	5960-6628	4448-4946
2030	7275-9760	6244-7747	7229-9105	4814-6078
2040	9210-13909	8510-11158	8657-11909	5251-7215
2050	11828-19732	12029-16077	10544-15429	5873-8664
Cumulative total (2020 to 2050)	260565-378481	237285-303428	248810-330092	156669-207349

Note: The range of estimates is given as subsidy estimates differ under different rainfall assumptions

These estimates highlight that although crop diversification does not appear to be very promising in achieving considerable water saving in agriculture, it shows a huge potential to reduce the power subsidy burden in Punjab as it causes substantial reduction in electricity consumption in agriculture by reducing the pumping needs for irrigation. In addition, a combined strategy to promote crop diversification as well adoption of innovative water saving technologies in agriculture will yield even higher dividends by reducing power subsidies within the range of 39-44%. If electricity prices do not decline in future, the subsidy burden will be substantially higher. These findings indicate the need for investments in development and promotion of (i) intelligent water saving technologies in agriculture, ii) promote crop diversification in Punjab and (ii) explore cheaper and renewable sources of energy, for efficient and sustainable use of natural resources and for reducing the subsidy burden on state exchequer.

Chapter 6

Conclusions and Policy Options

The success of green revolution paved the way for intensive agriculture in Punjab. Access to irrigation facilitated adoption of high yielding varieties and increased use of inputs like fertilisers and agro-chemicals. It also led to over-dependence on groundwater sources for irrigation, causing a severe imbalance between demand and supply of water in agriculture. Increase in total cropped area (reflected by the parallel increase in cropping intensity) and dominance of paddy in the cropping pattern are responsible for such an imbalance. As a result, groundwater table in Punjab has fallen at a much faster rate in recent one-and-half decade. Demand for water in agriculture has increased from 3 million ha m during the 1980s to about 3.85 million ha m in recent years, and the overall demand for water has jumped from 3.7 million ha m to 4.55 million ha m during the same period. A significant decline in rainfall during this period also had an adverse effect on water supply, further widening the demand-supply gap. The total water supply has declined from about 4.5 million ha m during the1980s to less than 4 million ha m in recent years.

The future projections through CIPT-WEALS model point towards further widening of the gap between demand and supply owing to a significant increase in demand for water in other sectors of the economy. Even in the absence of any significant increase in demand for water in agriculture, sharp increase in non-agricultural uses of water may cause the overall demand for water to reach around 6 million ha m 2050. The share of agriculture in total water use would decline substantially from around 85% to 65%. Though crop diversification does not appear to benefit in reduction of agricultural water demand, development and promotion of water efficient technologies in agriculture may help to contain the rise in overall water demand at around 4.59 million ha m. On the supply side, decline in rainfall from the normal annual would reduce water availability. The annual supply would further decline from the current level of 3.89 million ha m to 3.16 million ha m if there is a severe reduction in rainfall. A decline in the canal water would also worsen the situation further. The gap between demand and supply may increase to as high as 2.78 million ha m by 2050, amounting to around 88% of the available water. It will trigger a further fall in water table, which may reach as low as 44 m by 2050. However, under water efficient technologies can bring the demand-supply gap for water to around 45% due to which the water table fall may be restricted to around 34m by 2050.

The overall electricity consumption in Punjab may reach as high as 314 billion kwh by 2050, considering the past trend in electricity consumption during 1987-88 to 2015-16. However, faster growth in electricity consumption in domestic, industrial and commercial sectors in Punjab may cause the overall electricity consumption to reach 424 billion kwh. In other words, the overall electricity consumption in Punjab in 2050 may reach 8-11 times of the current consumption. In agriculture, owing to a sharp decline in water table, electricity consumption may more than triple and reach 39 billion kwh by 2050, though its share in overall electricity consumption would fall to around 12%. Despite its limited impact on water savings, crop diversification can bring almost 20% reduction in electricity consumption in agriculture. Emphasis on innovative water efficient technologies will also yield almost equal savings in electricity. However, focusing on both crop diversification and water efficient technologies may bring more than 55% reduction in electricity consumption by 2050, when compared to the BAU scenario.

Under the provision of free power to agriculture, power subsidy to the agriculture sector will more than triple by 2050 and will amount to Rs 19732 crore per annum. Success of crop diversification and water saving technologies can bring reduce subsidies to Rs 8664 crore per annum. Under a declining power prices situation, the annual burden of power subsidies by 2050 will be Rs 11839 crore in BAU scenario and Rs 5199 crore under crop diversification plus technologies scenario. The cumulative amount of power subsidies in agriculture during 2020-2050 may reach as high as Rs 3.78 lakh crore under BAU scenario, though it may be lower at Rs 2.07 lakh crore, if power prices decline in future. Under any situation, crop diversification and water saving technologies will bring substantial reduction in amount spent on power subsidies.

The findings of the study point to the need for investments in research on development and promotion of innovative water saving technologies and practices which can bring significant reduction in water needs of the crops (evapotranspiration needs). There should be a special emphasis on development of low-cost technologies in order to increase the likelihood of their adoption. The state requires a paradigm shift in irrigation by devising a strategy for shift from flood irrigation to micro-irrigation methods and hence the development of related technologies at lower costs. Long-term focus on developing short-duration varieties of major crops will also help in reducing the water demand.

As crop diversification in combination of water saving technologies will yield substantial savings in electricity consumption and reduce power subsidies, a comprehensive crop diversification plan needs to be developed. As past efforts of crop diversification in Punjab have not been very successful, the new strategy should look into innovative mechanisms for reducing production and marketing risks for alternative crops. Strengthening of supply chains for these crops and exploring promising value chains is required. Deficiency price support for crops such as maize and cotton and exploring niche markets for alternative crops through strengthening of market intelligence activities in the state will produce good results. The crop diversification strategy must also explore mechanisms to discourage farmers from cultivating water intensive crops like paddy.

For a successful crop diversification strategy and for large scale adoption of innovative water saving technologies, special emphasis should be laid on capacity building of the farmers and other stakeholder in the agriculture sector. Strengthening of the agricultural extension system and integrating ICT tools with the overall agricultural extension strategy is an essential requirement.

There is need to encourage regional crop planning with special emphasis on resource conservation in Punjab. Such planning should examine the availability of resources in a particular region and tend to design the optimal production plans aiming at higher farm incomes and sustainable natural resources in the long run. Regional planning may incorporate development of clusters for certain agricultural commodities, which will be useful in supply/value chain development as well.

Finally, free power for agriculture will generate a vicious cycle of unsustainable water and energy use in agriculture and ever-increasing amount of power subsidies. Continuation of this cycle will make Punjab agriculture highly unsustainable in the long-run. Breaking of this cycle by turning subsidies to productive investments will not only move Punjab agriculture on a sustainable path, but will also sustain the overall state economy by reducing the unproductive expenditure in agriculture. It is necessary to implement gradual withdrawal of power subsidies and increase investments in development of water efficient technologies and practices as well as in a crop diversification strategy for sustainability of water-energy-agriculture nexus in Punjab. In addition to that, the state should also invest heavily in low-cost and clean energy alternatives such as solar energy in light of ever increasing energy demand in the state from all sectors and growing power subsidy burden.

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Appendix

Appendix 1: Low-energy growth scenario - Sector-wise energy consumption in Punjab (million kwh)

Year	Domestic	Industrial	Agriculture	Commerical	Others
1987-88 to 1995-96	18529	47856	54837	3297	4683
1997-98 to 2006-07	45209	83756	66680	9771	5139
2007-08 to 2015-16	78992	106389	93340	22826	7698
CAGR (1987-88 to 2015-16)	5%	3%	2%	7%	2%

Appendix 2: High-energy growth scenario - Sector-wise energy consumption in Punjab (million kwh)

Year	domestic	Agricul-ture	Industrial	Commer-cial	Others	Total
2005-06	5286	7314	9496	1275	687	24058
2006-07	5662	8230	10116	1410	710	26127
2007-08	6349	10022	10865	1591	743	29570
2008-09	6459	9325	10739	1868	752	29144
2009-10	7007	10469	10948	2013	774	31211
2010-11	7915	10117	11031	2361	808	32232
2011-12	8636	10249	11497	2592	832	33806
2012-13	9285	10779	12119	2689	870	35742
2013-14	10344	10224	12348	2941	926	36783
2014-15	11138	10641	13845	3146	985	39755
2015-16	11859	11514	12997	3390	1008	40768
CAGR (2005-06 to 2015-16)	9%	3%	3%	10%	4%	5%

Appendix 3

Groundwater depletion = (Fall in water table)*(Soil porosity)*(area of the region)*correction factor

The porosity of sandy soil loams is 0.16. The estimates of water depth are based on the soil porosity of 0.16. (Experts review)

Appendix 4: Estimates of demand and supply of water in Punjab, 2020 to 2050 (million ha m)

Year	BAU Scenario			DIV Scenario			TECH Scenario			DIVTECH scenario		
	Agri	Non-agri	Total	Agri	Non-agri	Total	Agri	Non-agri	Total	Agri	Non-agri	Total
2020	3.85	0.86	4.72	3.80	0.86	4.66	3.66	0.86	4.52	3.61	0.86	4.47
2021	3.85	0.89	4.74	3.80	0.89	4.68	3.62	0.89	4.51	3.57	0.89	4.45
2022	3.85	0.91	4.77	3.80	0.91	4.71	3.58	0.91	4.50	3.53	0.91	4.44
2023	3.85	0.94	4.80	3.80	0.94	4.74	3.55	0.94	4.49	3.49	0.94	4.43
2024	3.85	0.97	4.82	3.80	0.97	4.76	3.51	0.97	4.48	3.45	0.97	4.42
2025	3.85	1.00	4.85	3.80	1.00	4.79	3.47	1.00	4.47	3.42	1.00	4.41
2026	3.85	1.03	4.88	3.80	1.03	4.82	3.43	1.03	4.46	3.38	1.03	4.41
2027	3.85	1.06	4.91	3.80	1.06	4.85	3.39	1.06	4.45	3.34	1.06	4.40
2028	3.85	1.09	4.94	3.80	1.09	4.89	3.35	1.09	4.44	3.30	1.09	4.39
2029	3.85	1.12	4.98	3.80	1.12	4.92	3.31	1.12	4.44	3.26	1.12	4.39
2030	3.85	1.16	5.01	3.80	1.16	4.95	3.28	1.16	4.43	3.23	1.16	4.38
2031	3.85	1.19	5.05	3.80	1.19	4.99	3.24	1.19	4.43	3.19	1.19	4.38
2032	3.85	1.23	5.08	3.80	1.23	5.02	3.20	1.23	4.43	3.15	1.23	4.38
2033	3.85	1.26	5.12	3.80	1.26	5.06	3.16	1.26	4.42	3.11	1.26	4.38
2034	3.85	1.30	5.16	3.80	1.30	5.10	3.12	1.30	4.42	3.07	1.30	4.38
2035	3.85	1.34	5.20	3.80	1.34	5.14	3.08	1.34	4.42	3.04	1.34	4.38
2036	3.85	1.38	5.24	3.80	1.38	5.18	3.04	1.38	4.43	3.00	1.38	4.38
2037	3.85	1.42	5.28	3.80	1.42	5.22	3.01	1.42	4.43	2.96	1.42	4.38
2038	3.85	1.47	5.32	3.80	1.47	5.26	2.97	1.47	4.43	2.92	1.47	4.39
2039	3.85	1.51	5.36	3.80	1.51	5.31	2.93	1.51	4.44	2.88	1.51	4.39
2040	3.85	1.55	5.41	3.80	1.55	5.35	2.89	1.55	4.45	2.85	1.55	4.40
2041	3.85	1.60	5.46	3.80	1.60	5.40	2.85	1.60	4.45	2.81	1.60	4.41
2042	3.85	1.65	5.50	3.80	1.65	5.45	2.81	1.65	4.46	2.77	1.65	4.42
2043	3.85	1.70	5.55	3.80	1.70	5.49	2.78	1.70	4.47	2.73	1.70	4.43
2044	3.85	1.75	5.60	3.80	1.75	5.55	2.74	1.75	4.49	2.70	1.75	4.45
2045	3.85	1.80	5.66	3.80	1.80	5.60	2.70	1.80	4.50	2.66	1.80	4.46
2046	3.85	1.86	5.71	3.80	1.86	5.65	2.66	1.86	4.52	2.62	1.86	4.48
2047	3.85	1.91	5.77	3.80	1.91	5.71	2.62	1.91	4.53	2.58	1.91	4.49
2048	3.85	1.97	5.82	3.80	1.97	5.77	2.58	1.97	4.55	2.54	1.97	4.51
2049	3.85	2.03	5.88	3.80	2.03	5.82	2.54	2.03	4.57	2.51	2.03	4.53
2050	3.85	2.09	5.94	3.80	2.09	5.89	2.51	2.09	4.59	2.47	2.09	4.56

Note: Agri means agriculture; Non-agri includes domestic and industrial sector

Appendix 5: Estimates of gap between demand and supply of water in Punjab, 2020 to 2050 (million ha m)

Year	BAU Scenario			DIV Scenario			TECH Scenario			DIVTECH scenario		
	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR
2020	0.83	1.30	1.55	0.77	1.24	1.49	0.64	1.11	1.36	0.58	1.05	1.30
2021	0.86	1.33	1.58	0.80	1.27	1.52	0.62	1.10	1.35	0.57	1.04	1.29
2022	0.88	1.35	1.61	0.82	1.29	1.55	0.61	1.08	1.34	0.56	1.03	1.28
2023	0.91	1.38	1.63	0.85	1.32	1.57	0.60	1.07	1.32	0.55	1.02	1.27
2024	0.94	1.41	1.66	0.88	1.35	1.60	0.59	1.06	1.31	0.54	1.01	1.26
2025	0.97	1.44	1.69	0.91	1.38	1.63	0.58	1.05	1.30	0.53	1.00	1.25
2026	1.00	1.47	1.72	0.94	1.41	1.66	0.57	1.04	1.30	0.52	0.99	1.24
2027	1.03	1.50	1.75	0.97	1.44	1.69	0.56	1.04	1.29	0.51	0.98	1.24
2028	1.06	1.53	1.78	1.00	1.47	1.72	0.56	1.03	1.28	0.51	0.98	1.23
2029	1.09	1.56	1.82	1.03	1.50	1.76	0.55	1.02	1.28	0.50	0.97	1.23
2030	1.13	1.60	1.85	1.07	1.54	1.79	0.55	1.02	1.27	0.50	0.97	1.22
2031	1.16	1.63	1.88	1.10	1.57	1.83	0.54	1.01	1.27	0.49	0.97	1.22
2032	1.20	1.67	1.92	1.14	1.61	1.86	0.54	1.01	1.26	0.49	0.96	1.22
2033	1.23	1.70	1.96	1.17	1.65	1.90	0.54	1.01	1.26	0.49	0.96	1.21
2034	1.27	1.74	1.99	1.21	1.68	1.94	0.54	1.01	1.26	0.49	0.96	1.21
2035	1.31	1.78	2.03	1.25	1.72	1.97	0.54	1.01	1.26	0.49	0.96	1.22
2036	1.35	1.82	2.07	1.29	1.76	2.02	0.54	1.01	1.26	0.49	0.97	1.22
2037	1.39	1.86	2.12	1.33	1.80	2.06	0.54	1.01	1.27	0.50	0.97	1.22
2038	1.43	1.91	2.16	1.38	1.85	2.10	0.55	1.02	1.27	0.50	0.97	1.23
2039	1.48	1.95	2.20	1.42	1.89	2.14	0.55	1.02	1.28	0.51	0.98	1.23
2040	1.52	1.99	2.25	1.47	1.94	2.19	0.56	1.03	1.28	0.52	0.99	1.24
2041	1.57	2.04	2.29	1.51	1.98	2.24	0.57	1.04	1.29	0.52	1.00	1.25
2042	1.62	2.09	2.34	1.56	2.03	2.28	0.58	1.05	1.30	0.53	1.01	1.26
2043	1.67	2.14	2.39	1.61	2.08	2.33	0.59	1.06	1.31	0.55	1.02	1.27
2044	1.72	2.19	2.44	1.66	2.13	2.38	0.60	1.07	1.32	0.56	1.03	1.28
2045	1.77	2.24	2.49	1.71	2.18	2.44	0.61	1.09	1.34	0.57	1.04	1.30
2046	1.83	2.30	2.55	1.77	2.24	2.49	0.63	1.10	1.35	0.59	1.06	1.31
2047	1.88	2.35	2.60	1.82	2.29	2.55	0.65	1.12	1.37	0.61	1.08	1.33
2048	1.94	2.41	2.66	1.88	2.35	2.60	0.67	1.14	1.39	0.63	1.10	1.35
2049	2.00	2.47	2.72	1.94	2.41	2.66	0.69	1.16	1.41	0.65	1.12	1.37
2050	2.06	2.53	2.78	2.00	2.47	2.72	0.71	1.18	1.43	0.67	1.14	1.39

Note: NR-normal rainfall; DR-declining rainfall; SDR-severely declining rainfall

Appendix 6: Estimated levels of groundwater table in Punjab under different scenarios, 2020 to 2050 (m)

Year	BAU Scenario			DIV Scenario			TECH Scenario			DIVTECH scenario		
	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR
2020	16.29	17.47	18.10	16.29	17.47	18.10	16.13	17.30	17.94	16.13	17.30	17.94
2021	16.63	18.01	18.74	16.61	17.98	18.72	16.39	17.77	18.50	16.37	17.74	18.48
2022	16.99	18.56	19.40	16.94	18.51	19.35	16.65	18.22	19.06	16.61	18.18	19.02
2023	17.36	19.12	20.07	17.28	19.05	20.00	16.91	18.67	19.62	16.84	18.60	19.55
2024	17.74	19.70	20.75	17.64	19.60	20.65	17.16	19.12	20.17	17.07	19.03	20.08
2025	18.13	20.28	21.44	18.00	20.16	21.32	17.40	19.56	20.72	17.29	19.45	20.60
2026	18.53	20.88	22.14	18.38	20.74	22.00	17.65	20.00	21.26	17.51	19.86	21.13
2027	18.94	21.49	22.86	18.77	21.32	22.69	17.88	20.43	21.80	17.73	20.28	21.64
2028	19.37	22.12	23.59	19.18	21.92	23.39	18.12	20.87	22.34	17.94	20.69	22.16
2029	19.81	22.75	24.33	19.59	22.54	24.11	18.35	21.29	22.87	18.15	21.09	22.67
2030	20.27	23.41	25.09	20.02	23.16	24.84	18.58	21.72	23.40	18.36	21.50	23.18
2031	20.74	24.07	25.86	20.47	23.80	25.59	18.81	22.14	23.93	18.57	21.90	23.69
2032	21.22	24.75	26.64	20.93	24.46	26.35	19.04	22.57	24.46	18.78	22.30	24.20
2033	21.72	25.44	27.44	21.40	25.13	27.12	19.26	22.99	24.99	18.98	22.71	24.70
2034	22.23	26.15	28.26	21.89	25.81	27.92	19.49	23.41	25.51	19.19	23.11	25.21
2035	22.76	26.88	29.09	22.40	26.51	28.72	19.71	23.83	26.04	19.39	23.51	25.72
2036	23.31	27.62	29.93	22.92	27.23	29.54	19.94	24.25	26.56	19.59	23.91	26.22
2037	23.87	28.38	30.80	23.45	27.96	30.38	20.16	24.67	27.09	19.80	24.31	26.73
2038	24.45	29.15	31.68	24.01	28.72	31.24	20.39	25.09	27.62	20.01	24.71	27.24
2039	25.05	29.95	32.58	24.58	29.48	32.11	20.62	25.52	28.15	20.22	25.12	27.75
2040	25.66	30.76	33.49	25.17	30.27	33.01	20.85	25.94	28.68	20.43	25.53	28.26
2041	26.30	31.59	34.43	25.78	31.08	33.92	21.08	26.37	29.21	20.64	25.94	28.78
2042	26.95	32.44	35.38	26.41	31.90	34.85	21.32	26.81	29.75	20.86	26.35	29.30
2043	27.62	33.31	36.36	27.06	32.75	35.80	21.56	27.24	30.29	21.09	26.77	29.82
2044	28.32	34.20	37.35	27.73	33.61	36.77	21.80	27.68	30.84	21.31	27.20	30.35
2045	29.03	35.11	38.37	28.42	34.50	37.76	22.05	28.13	31.39	21.55	27.62	30.88
2046	29.77	36.05	39.41	29.14	35.41	38.78	22.31	28.58	31.95	21.78	28.06	31.42
2047	30.53	37.00	40.47	29.87	36.34	39.81	22.57	29.04	32.51	22.03	28.50	31.97
2048	31.31	37.98	41.56	30.63	37.30	40.87	22.84	29.51	33.08	22.28	28.95	32.53
2049	32.12	38.98	42.66	31.41	38.28	41.96	23.12	29.98	33.66	22.54	29.41	33.09
2050	32.95	40.01	43.80	32.22	39.28	43.07	23.40	30.46	34.25	22.81	29.87	33.66

Note: NR-normal rainfall; DR-declining rainfall; SDR-severely declining rainfall

Appendix 7: Estimates for annual demand for electricity in Punjab agriculture, 2020 to 2050 (million kwh)

Year	BAU Scenario			DIV Scenario			TECH Scenario			DIVTECH scenario		
	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR
2020	11693	12908	13374	9523	10211	10580	11920	12789	13255	8895	9544	9892
2021	11941	13369	13916	9767	10575	11007	12171	13190	13737	8976	9729	10132
2022	12196	13844	14472	10022	10950	11448	12423	13593	14221	9054	9909	10368
2023	12460	14334	15043	10287	11338	11901	12674	13997	14706	9130	10087	10600
2024	12732	14838	15630	10564	11738	12368	12925	14403	15195	9204	10262	10829
2025	13012	15357	16233	10852	12152	12849	13177	14810	15686	9277	10434	11054
2026	13301	15893	16853	11153	12580	13346	13430	15221	16182	9348	10604	11278
2027	13599	16445	17492	11466	13023	13858	13685	15635	16681	9418	10772	11499
2028	13906	17015	18148	11793	13481	14386	13941	16052	17185	9488	10940	11718
2029	14223	17604	18824	12133	13955	14931	14198	16474	17694	9558	11106	11937
2030	14549	18211	19521	12489	14445	15495	14459	16900	18209	9628	11273	12155
2031	14886	18839	20238	12860	14954	16077	14722	17331	18731	9699	11440	12373
2032	15233	19487	20977	13247	15480	16679	14989	17768	19259	9770	11607	12592
2033	15590	20157	21740	13650	16026	17301	15260	18212	19795	9843	11775	12812
2034	15959	20850	22527	14072	16592	17945	15536	18662	20339	9918	11946	13033
2035	16339	21567	23339	14512	17180	18611	15816	19120	20892	9996	12118	13257
2036	16730	22308	24177	14971	17789	19300	16102	19586	21454	10075	12293	13483
2037	17134	23076	25042	15450	18421	20014	16394	20061	22028	10158	12472	13713
2038	17550	23870	25937	15951	19077	20754	16693	20545	22612	10245	12654	13947
2039	17979	24693	26861	16474	19759	21521	16999	21041	23209	10335	12841	14185
2040	18420	25546	27817	17021	20468	22316	17313	21547	23818	10430	13033	14429
2041	18876	26430	28806	17592	21204	23141	17636	22066	24442	10530	13231	14679
2042	19345	27347	29829	18188	21969	23997	17969	22598	25080	10636	13434	14936
2043	19829	28298	30889	18812	22765	24885	18313	23143	25734	10747	13645	15200
2044	20328	29284	31985	19464	23593	25807	18667	23704	26406	10865	13864	15472
2045	20841	30308	33122	20146	24455	26765	19034	24281	27095	10990	14091	15754
2046	21371	31370	34299	20860	25351	27761	19414	24875	27804	11123	14327	16045
2047	21916	32474	35520	21606	26285	28795	19809	25487	28533	11265	14573	16347
2048	22479	33621	36786	22386	27258	29871	20218	26119	29285	11415	14830	16661
2049	23058	34813	38100	23203	28272	30990	20644	26772	30059	11575	15098	16988
2050	23655	36052	39463	24058	29328	32155	21087	27447	30858	11746	15379	17329

Note: NR-normal rainfall; DR-declining rainfall; SDR-severely declining rainfall

Appendix 8: Sectoral demand for electricity in Punjab under low energy growth scenario during 2020 to 2050 (million kwh)

Year	Domestic	Industry	Commercial	Others
2020	16719	16140	5623	1093
2021	17906	16769	6168	1119
2022	19177	17423	6767	1146
2023	20539	18103	7423	1174
2024	21997	18809	8143	1202
2025	23559	19543	8933	1231
2026	25232	20305	9800	1260
2027	27023	21097	10750	1290
2028	28942	21919	11793	1321
2029	30997	22774	12937	1353
2030	33197	23662	14192	1386
2031	35554	24585	15568	1419
2032	38079	25544	17078	1453
2033	40782	26540	18735	1488
2034	43678	27575	20552	1523
2035	46779	28651	22546	1560
2036	50100	29768	24733	1597
2037	53658	30929	27132	1636
2038	57467	32135	29764	1675
2039	61547	33389	32651	1715
2040	65917	34691	35818	1756
2041	70597	36044	39292	1799
2042	75610	37449	43104	1842
2043	80978	38910	47285	1886
2044	86728	40427	51871	1931
2045	92885	42004	56903	1978
2046	99480	43642	62422	2025
2047	106543	45344	68477	2074
2048	114108	47113	75120	2123
2049	122209	48950	82406	2174
2050	130886	50859	90400	2226

Note: Others do not include agriculture as agriculture demand has been provided in earlier appendices

Appendix 9: Sectoral demand for electricity in Punjab under high energy growth scenario during 2020 to 2050 (million kwh)

Year	Domestic	Industry	Commercial	Others
2020	18548	15394	5879	1210
2021	20162	15887	6490	1257
2022	21916	16395	7165	1306
2023	23822	16920	7911	1357
2024	25895	17461	8733	1410
2025	28148	18020	9642	1465
2026	30597	18596	10644	1522
2027	33259	19192	11751	1582
2028	36152	19806	12973	1643
2029	39297	20439	14323	1707
2030	42716	21093	15812	1774
2031	46433	21768	17457	1843
2032	50472	22465	19272	1915
2033	54863	23184	21277	1990
2034	59636	23926	23489	2067
2035	64825	24691	25932	2148
2036	70464	25482	28629	2232
2037	76595	26297	31607	2319
2038	83259	27139	34894	2409
2039	90502	28007	38523	2503
2040	98376	28903	42529	2601
2041	106934	29828	46952	2702
2042	116238	30783	51835	2808
2043	126350	31768	57226	2917
2044	137343	32784	63177	3031
2045	149292	33833	69748	3149
2046	162280	34916	77002	3272
2047	176398	36033	85010	3399
2048	191745	37186	93851	3532
2049	208427	38376	103611	3670
2050	226560	39604	114387	3813

Note: Others do not include agriculture as agriculture demand has been provided in earlier appendices

Appendix 10: Estimates of power subsidies in Punjab agriculture under declining price assumption, 2020 to 2050 (Rs crore)

Year	BAU Scenario			DIV Scenario			TECH Scenario			DIVTECH scenario		
	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR
2020	5846	6454	6687	4762	5105	5290	5960	6395	6628	4448	4772	4946
2021	5851	6551	6819	4786	5182	5394	5964	6463	6731	4398	4767	4965
2022	5854	6645	6947	4811	5256	5495	5963	6525	6826	4346	4757	4977
2023	5856	6737	7070	4835	5329	5593	5957	6578	6912	4291	4741	4982
2024	5857	6825	7190	4859	5400	5689	5946	6625	6990	4234	4720	4981
2025	5855	6911	7305	4883	5468	5782	5930	6665	7059	4174	4695	4974
2026	5853	6993	7416	4907	5535	5872	5909	6697	7120	4113	4666	4962
2027	5848	7072	7521	4930	5600	5959	5884	6723	7173	4050	4632	4944
2028	5841	7147	7622	4953	5662	6042	5855	6742	7218	3985	4595	4922
2029	5831	7218	7718	4975	5721	6122	5821	6754	7255	3919	4554	4894
2030	5820	7285	7808	4996	5778	6198	5784	6760	7284	3851	4509	4862
2031	5805	7347	7893	5015	5832	6270	5742	6759	7305	3782	4461	4826
2032	5788	7405	7971	5034	5883	6338	5696	6752	7318	3713	4411	4785
2033	5768	7458	8044	5051	5930	6401	5646	6738	7324	3642	4357	4740
2034	5745	7506	8110	5066	5973	6460	5593	6718	7322	3571	4300	4692
2035	5719	7548	8168	5079	6013	6514	5536	6692	7312	3498	4241	4640
2036	5688	7585	8220	5090	6048	6562	5475	6659	7295	3426	4180	4584
2037	5654	7615	8264	5099	6079	6605	5410	6620	7269	3352	4116	4525
2038	5616	7638	8300	5104	6105	6641	5342	6575	7236	3278	4049	4463
2039	5573	7655	8327	5107	6125	6672	5270	6523	7195	3204	3981	4397
2040	5526	7664	8345	5106	6140	6695	5194	6464	7145	3129	3910	4329
2041	5663	7929	8642	5278	6361	6942	5291	6620	7333	3159	3969	4404
2042	5804	8204	8949	5457	6591	7199	5391	6779	7524	3191	4030	4481
2043	5949	8489	9267	5644	6829	7466	5494	6943	7720	3224	4094	4560
2044	6098	8785	9596	5839	7078	7742	5600	7111	7922	3260	4159	4642
2045	6252	9092	9937	6044	7336	8030	5710	7284	8129	3297	4227	4726
2046	6411	9411	10290	6258	7605	8328	5824	7463	8341	3337	4298	4814
2047	6575	9742	10656	6482	7886	8639	5943	7646	8560	3379	4372	4904
2048	6744	10086	11036	6716	8177	8961	6065	7836	8785	3424	4449	4998
2049	6917	10444	11430	6961	8482	9297	6193	8032	9018	3472	4530	5096
2050	7097	10816	11839	7217	8798	9646	6326	8234	9258	3524	4614	5199
Cumulative total 2020-2050	184705	244257	263385	166342	195308	210844	177713	213376	232504	113672	136156	148215

Note: NR-normal rainfall; DR-declining rainfall; SDR-severely declining rainfall

Appendix 11: Estimates of power subsidies in Punjab agriculture under constant price assumption, 2020 to 2050 (Rs crore)

Year	BAU Scenario			DIV Scenario			TECH Scenario			DIVTECH scenario		
	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR	NR	DR	SDR
2020	5846	6454	6687	4762	5105	5290	5960	6395	6628	4448	4772	4946
2021	5970	6685	6958	4884	5287	5504	6086	6595	6869	4488	4864	5066
2022	6098	6922	7236	5011	5475	5724	6211	6796	7110	4527	4955	5184
2023	6230	7167	7522	5144	5669	5950	6337	6998	7353	4565	5043	5300
2024	6366	7419	7815	5282	5869	6184	6463	7201	7597	4602	5131	5414
2025	6506	7679	8117	5426	6076	6425	6589	7405	7843	4638	5217	5527
2026	6651	7946	8427	5576	6290	6673	6715	7611	8091	4674	5302	5639
2027	6800	8223	8746	5733	6511	6929	6842	7817	8341	4709	5386	5749
2028	6953	8508	9074	5896	6740	7193	6970	8026	8593	4744	5470	5859
2029	7111	8802	9412	6067	6977	7466	7099	8237	8847	4779	5553	5969
2030	7275	9106	9760	6244	7223	7747	7229	8450	9105	4814	5636	6078
2031	7443	9419	10119	6430	7477	8038	7361	8666	9365	4849	5720	6187
2032	7616	9743	10489	6623	7740	8339	7495	8884	9629	4885	5803	6296
2033	7795	10079	10870	6825	8013	8650	7630	9106	9897	4922	5888	6406
2034	7979	10425	11263	7036	8296	8972	7768	9331	10169	4959	5973	6517
2035	8169	10783	11669	7256	8590	9305	7908	9560	10446	4998	6059	6628
2036	8365	11154	12088	7485	8894	9650	8051	9793	10727	5038	6147	6742
2037	8567	11538	12521	7725	9210	10007	8197	10030	11014	5079	6236	6856
2038	8775	11935	12968	7976	9539	10377	8346	10273	11306	5122	6327	6973
2039	8989	12347	13431	8237	9880	10761	8499	10520	11604	5168	6421	7093
2040	9210	12773	13909	8510	10234	11158	8657	10774	11909	5215	6517	7215
2041	9438	13215	14403	8796	10602	11571	8818	11033	12221	5265	6615	7339
2042	9673	13673	14915	9094	10985	11998	8985	11299	12540	5318	6717	7468
2043	9915	14149	15444	9406	11382	12443	9156	11572	12867	5374	6823	7600
2044	10164	14642	15993	9732	11796	12904	9334	11852	13203	5433	6932	7736
2045	10421	15154	16561	10073	12227	13383	9517	12141	13548	5495	7045	7877
2046	10685	15685	17150	10430	12676	13880	9707	12438	13902	5562	7163	8023
2047	10958	16237	17760	10803	13143	14398	9904	12744	14267	5632	7286	8174
2048	11239	16811	18393	11193	13629	14936	10109	13060	14642	5707	7415	8331
2049	11529	17406	19050	11601	14136	15495	10322	13386	15030	5787	7549	8494
2050	11828	18026	19732	12029	14664	16077	10544	13724	15429	5873	7690	8664
Cumulative total 2020-2050	260565	350104	378481	237285	280337	303428	248810	301715	330092	156669	189656	207349

Note: NR-normal rainfall; DR-declining rainfall; SDR-severely declining rainfall

Water-Agriculture-Livelihood Security (WEALS) program in India

Overview

Chronic water shortage and groundwater depletion have emerged as the leading challenge for food security in India. Agriculture consumes over 90% of water in India, and given the high climate variability, irrigation is the key to adequate crop yields, reliable production and farmer income. A variety of government subsidy and food procurement programs has led to the adoption of sub-optimal cropping patterns and has caused a dramatic increase in groundwater pumping. Increased pumping is fast depleting the groundwater resources. It also translates into increased power consumption, leading to unsustainable high levels of budgetary deficits as well as high carbon emissions.

Recognizing the diversity in climate, soils, agricultural practices and socio-economic factors across India, the USAID supported WEALS program seeks to address the water-agriculture-livelihood connect for states of Gujarat, Punjab and Jharkhand. The program includes, on-field engagement with farmers to test and scaleupadoption of appropriate water saving technologies and practices while maintaining yield and income; providing them with access toreliable markets and technologies through corporate engagement in farming; and enabling on-farm best practices to manage chronic risk induced by groundwater depletion and climate risk, through the use of ICT system that helps customize guidance to farmers.

Objectives

- Develop and implement a public-private partnership to provide modern extension services to farmers in Punjab, Gujarat and Jharkhand for climate informed crop choice and irrigation improvements to improve water productivity, income and climate risk management.
- Considering both chronic risk from groundwater depletion and weather extremes, develop and apply farmer targeted risk prediction and management tools, including pilots of policy initiatives.

Tasks

Task 1: Integrated assessment of the hydro-climatology, crops, water and energy systems.

Task 2: Economic analysis of short and long-term farmer and state level outcomes relative to climate, water and energy scenarios.

Task 3: Farm-level field implementation for assessing and promoting specific water and energy saving methods.

Task 4: Climate and market informed agricultural supply chain development integrating farmers and corporate aggregators.

Task 5: Synthesis, results dissemination and policy change stimulation.

Task 6: Scale-up and future replication.

Notes